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ISSUE 366
JULY-AUGUST 2020

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Cover: *Silhouette of workers on scaffolding at a construction site igorstevanovic/Shutterstock.com*

1.1

Agricultural demand

Slowing growth for fertilizer nitrogen use.

1.5

Construction site safety

In pursuit of zero accidents.

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REGULARS

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Burning ammonia

At the end of last year, in our November/December 2019 issue, I remarked upon the fresh impetus that the International Maritime Organisation's (IMO) target of reducing carbon emissions from shipping by 50% in 2050 (compared to a 2008 baseline) had given to the idea of using ammonia as a shipping fuel. This year, in spite of You Know What, things seem to have, if anything, accelerated.

As we reported in March/April (*Nitrogen+Syngas 364*, p9), maritime engine manufacturer Wärtsilä initiated combustion trials using ammonia to test its properties as a fuel, and the company also announced plans to install ammonia fuel cells in its platform supply vessel *Viking Energy* in 2023.

Just this month, Japanese trading house Itochu signed a memorandum of understanding with Dutch oil storage and terminal operator Vopak for a feasibility study concerning the development of ammonia supply infrastructure for use as a marine fuel for vessels in Singapore. Itochu already operates an ammonia storage and handling facility at Singapore's Banyan terminal, and is now looking at the possibility of building offshore facilities such as a floating storage tank and an ammonia fuel supply vessel. Itochu is also already involved in a project in Japan to develop ammonia supply infrastructure and launch ammonia-fuelled commercial vessels.

In the first week of June, Norwegian oil company Equinor, which charters around 175 vessels at any given moment, unveiled its own programme for decarbonising shipping, including halving 2008-level emissions by 2050 via the use of zero-emission fuels. While it is working towards low carbon, hybrid systems in the short term, in the longer term it too says that it sees ammonia and hydrogen, either with carbon capture and storage or produced via electrolysis, as the most sustainable solution. Equinor is also part of the *Viking Energy* project, above. And just last week, shipping leviathan Maersk launched the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping with an initial donation of $60 million to develop new fuel types and technologies to decarbonise the maritime sector. Maersk has already said (in a report last year) that it sees ammonia, along with biogas and alcohol, as one of its three main "commercially viable" candidate fuels for low carbon shipping.

> **"I have long been a sceptic about ammonia's use as a fuel..."**

I have long been a sceptic about ammonia's use as a fuel. Its toxicity presents significant handling hazards and restrictions on storage and transport which at one stage even led US producers to consider building small scale ammonia plants near centres of agricultural demand to avoid having to ship it by rail, road or barge across the United States. Combustion must also be carefully controlled if creation of nitrous oxides are to be avoided (although cleaning NOx emissions using selective catalytic reduction has become a fairly standard feature of many vehicles these days). It can be corrosive. However, I have to concede that as low carbon fuels go, it does also have its advantages, especially compared to hydrogen. While costs of electrolysis are coming down rapidly, hydrogen is a very difficult fuel to handle, with low energy densities even when refrigerated at -253°C or pressurised to 700 bar, before we even get to issues like hydrogen attack of metals. Converting hydrogen into ammonia removes most of these issues and makes it more easily transportable. And of course, a large scale ammonia storage, handling and shipping industry already exists, especially centred around major ports.

There are apparently issues specific to shipping – engine loads are constantly changing and ammonia needs a pilot fuel to begin combustion, although its use in a fuel cell, as it will be in the *Viking Energy* test bed, would overcome that, as might the use of some kind of hybrid ammonia-electric engine. Still, when companies such as Wärtsilä, Equinor, Itochu, Vopak and Maersk are starting to invest significant sums of money into ammonia as a shipping fuel then it has definitely become an area to watch. ■

Richard Hands, Editor

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Price trends

MARKET INSIGHT

Alistair Wallace, Head of Fertilizer Research, Argus Media, assesses price trends and the market outlook for nitrogen.

NITROGEN

The ammonia market remains oversupplied, and prices are forecast to remain bearish into the third quarter. In Europe, low gas prices are further exacerbating the existing supply length in the region, and the arrival of more Ukrainian exports through the port of Pivdenny (Yuzhnyy) have pulled f.o.b. prices in the region to lows not seen since late 2016.

Spot prices for ammonia loading from Pivdenny fell into the $180s/t f.o.b. in late May, as supply options continue to accumulate for trading companies and buyers in markets west of Suez. Production has been taken offline in Trinidad, Egypt and Indonesia in May and June because of poor demand. Other producers are redirecting ammonia to urea or nitrates production where possible, or operating at lower rates. Industrial demand, which has been the key driver behind the falling price trend, is beginning to improve east of Suez but is still absent in the west, while most economies struggle to recover from the Covid-19 pandemic.

F.o.b. prices have fallen by $40-80/t across key supply regions seen since the Covid-19 outbreak, and while theoretically there is further room to fall, any losses in the month ahead are not likely to be as steep as those seen in recent months. The weak demand outlook for July was confirmed by the settlement of next month's Tampa price at $13/t lower on the month, at $205/t c.fr.

Urea prices bottomed out in mid-May following the purchase of over 600,000 tonnes of urea in an Indian tender. India bought the spot urea available from Ukraine, Egypt and the Middle East at $227-231/t c.fr. Chinese suppliers were unwilling to sell at that level.

These purchases tightened the market and, after a stand-off, prices began to firm in early June when traders had to cover short sales made for June and first half July shipment. The second week of June was particularly active, with more than 500,000 tonnes of granular urea trading and prices jumping by $20/t in some areas. But the recovery in prices has brought Chinese urea back into play. F.o.b. levels rose to $230-240/t in the Middle East and Egypt. Coinciding with falling prices inside China as summer season demand waned and production remained high, this means that Chinese urea is competitive at current offer prices close to $230/t f.o.b.

Another Indian tender is taking place at the time of writing and Chinese urea is expected to figure prominently in the origins for offers supplying India from July onwards. The ability of Chinese suppliers to provide 400-500,000t/month for export in the second half of the year is expected to cap prices in the short term. ■

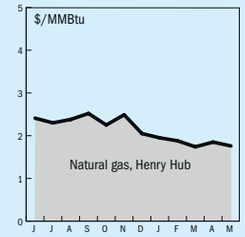
Table 1: **Price indications**

Cash equivalent	mid-Jun	mid-Apr	mid-Feb	mid-Dec
Ammonia ($/t)				
f.o.b. Black Sea	180-200	210-225	220-223	210-225
f.o.b. Caribbean	175-190	200-215	215	200-215
f.o.b. Arab Gulf	180-200	200-220	215-250	220-235
c.fr N.W. Europe	220-245	250-281	250-285	250-281
Urea ($/t)				
f.o.b. bulk Black Sea	195-215	215-228	212-215	203-220
f.o.b. bulk Arab Gulf*	219-245	226-245	222-235	238-250
f.o.b. NOLA barge (metric tonnes)	213-218	263	269	225-240
f.o.b. bagged China	242-263	250-283	240-245	252-270
DAP ($/t)				
f.o.b. bulk US Gulf	293-304	297-323	300	268-294
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	163-165	172	146-148	199

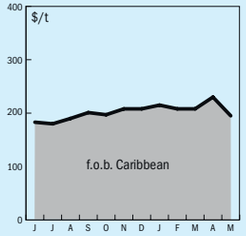
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

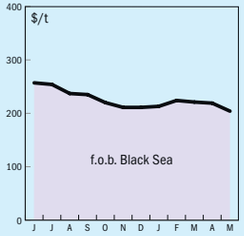
natural gas



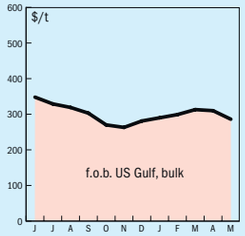
ammonia



urea



diammonium phosphate



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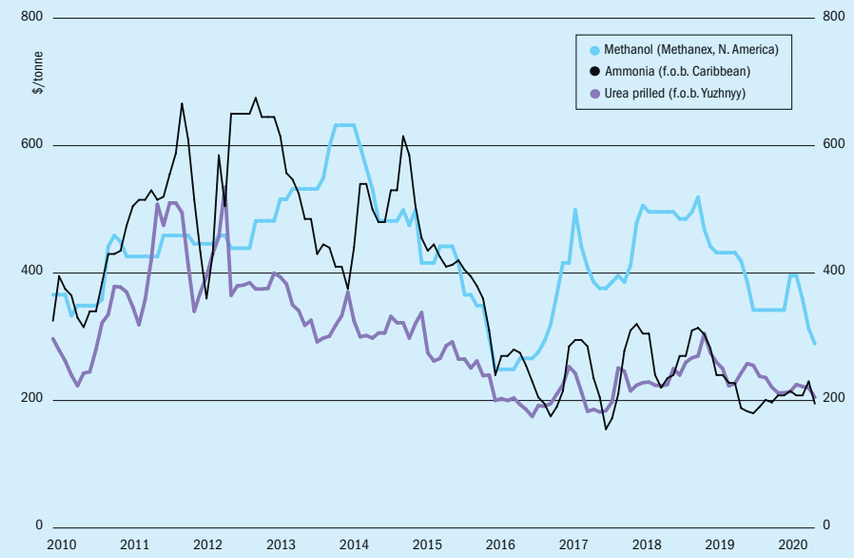
Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Prices remain at low levels, in part because of oversupply due to new plant start-ups. However, there has also been a contraction in demand, especially for technical ammonia – industrial markets for ammonia in China and East Asia have been badly affected.
- Natural gas prices and freight rates remained at historical lows. This means that producer margins remain reasonable and so many plants are still producing. Lockdowns have also affected plant maintenance and many turnarounds have been postponed. There are some market related shutdowns, such as Nutrien in Trinidad, but they have not affected the market significantly.
- Major DAP producers continue to buy ammonia and US agricultural demand remains brisk, with some localised shortages reported during May.

UREA

- Urea prices staged a rally in mid-May, driven by new tenders from India, which led to offers in the $240s/t c.fr, met mainly from the Middle East and FSU. Nevertheless, urea prices are down roughly $50-60/t on the same time last year.
- There was an absence of Chinese offers – Chinese exports have slowed down considerably from mid-March as producers fulfilled domestic demand – which has also helped to reduce oversupply in the market. Chinese exports for May and June looked to be less than 300,000 tonnes.
- Higher demand from Latin America, especially Brazil, Argentina and Mexico have also improved sentiment, and there has been additional demand from Egypt and other parts of Africa.
- However, with the Chinese buying season ending, more urea may be offered onto the international market, with a concomitant effect on urea prices.

METHANOL

- Methanol prices have been falling rapidly in all major markets, with significant oversupply in the market and storage tight. Demand for methanol into fuel blending and ether production is down significantly as major consuming nations travel less due to Covid lockdowns.
- Chinese coastal storage reached 780,000 tonnes at the end of May, and with tanks being turned over to crude oil storage there were fears there might be nowhere for methanol to go. Only MTO production remained a bright spot, with low methanol prices encouraging olefins producers to operate polypropylene capacity. New plants with a capacity of 1.8 million t/a of methanol equivalent are due to start up in 2020.
- European spot prices hit an 11-year low in May, falling below €140/tonne, although this triggered a moderate price rally as traders sought to capitalise on bargains.
- Forecasts for 3Q 2020 are continued weakness in the market. ICIS predicts that global demand will be down 5% in 2020, with recovery taking up to two years. Around 2 million t/a of capacity has so far been idled this year, particularly in Trinidad, as well as Chile, and some start-ups have been postponed, but more is likely to follow. ■

Nitrogen Industry News

EGYPT

Ammonia contract finalised

Maire Tecnimont subsidiary Tecnimont SpA has finalised its $350 million EPC contract with Egypt Hydrocarbon Corp. (EHC) for the construction of a new ammonia plant at Ain Sokhna. The preliminary contract was announced in September last year. The contract for the plant, which will produce 1,320 t/d of ammonia, also includes extensive utilities and offsite facilities. Project completion is scheduled for 36 months from the effective contract date, which will be triggered by financial closure of the project. Project finance is being arranged by the Italian export credit agency SACE and the US EXIM Bank. The ammonia will be used to feed an ammonium nitrate plant, already existing and in operation in the same industrial facility, also owned by EHC.

Basil El-Baz, EHC chairman, said: "This contract is another outstanding opportunity to work with Maire Tecnimont, a company we trust with best in class expertise and experience. The EHC expansion project is a vote of confidence in the Egyptian economy and the reforms that have been undertaken to date. The project will serve as a catalyst for the mining sector, attracting foreign investment and increasing employment opportunities and providing the raw materials needed for the sectors activities."

Pierroberto Folgiero, Maire Tecnimont Group CEO, added: "With this achievement we are proving once again the great resilience of our core business in a particularly challenging period for the whole market. We are also really proud to play a strategic role in the development of the fertilizer industry in Egypt with an entrepreneurial client such as EHC." ■

Stamicarbon completes stripper for urea melt plant

Stamicarbon says that the first piece of high pressure equipment for NCIC's new urea melt plant in Egypt has been completed on time. The stripper was fabricated at Schoeller-Bleckmann Nitec GmbH (SBN) in Austria, and is now awaiting shipment. The new urea melt plant is being built at Ain Sukhna by thyssenkrupp Industrial Solutions (tkIS) as part of a consortium with Egyptian company Petrojet, for Egyptian chemical and fertilizer manufacturer El Nasr Company for Intermediate Chemicals (NCIC). The plant will have a capacity of 1,050 t/d and forms part of a new fertilizer complex which will include 440,000 t/a of ammonia, 380,000 t/a of urea and 300,000 t/a of calcium ammonium nitrate (CAN) every year. Completion is set for 2022.

Stamicarbon's Erfan Afrasiabi highlighted the "teamwork and determination" to deliver on the client's expectations. "I'm really happy because we can now literally touch the results and all the effort put

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in by the team," he said, referring to the completed stripper. "We did a lot of expediting to be sure that all materials would be delivered right on time. Even with high shop load and the impact of Covid-19, and remote expediting and inspections, the stripper was ready exactly on time."

AFRICA

LNG projects likely to be deferred

Sub-Saharan Africa is likely to see a slowdown in upstream activity for ongoing projects and final investment decisions (FIDs) in 2020, according to data and analytics company GlobalData. Conor Ward, Oil & Gas analyst at GlobalData commented: "With global crude oil prices currently hovering around the $30/bbl mark and cases of Covid-19 on the rise daily, companies have been forced to rethink project timelines for 2020 and operators are beginning to scale back spending in the short-term as they struggle to source adequate capital."

Major capital intensive projects in the region such as the liquefied natural gas (LNG) mega projects in Mozambique, as well as the projects in Uganda and Kenya look likely to continue to face further delays considering the current economic climate. The most capital-intensive project in the region is the Mamba complex in Mozambique, and with ExxonMobil expected to reduce capex by approximately 20% it is likely that this project will be unable to secure an FID in 2020, according to Ward. Only efficient and robust projects that can survive in a low-oil-price environment, or can be sheltered from external market factors, are likely to go ahead this year.

Ward continued: "Projects that are already under construction with investment finalised will contractually have to go ahead, but will likely face disruption to their timescales. This will be particularly pertinent for landlocked countries that require external supply chains often deriving from shipyards or supply bases in China or Asia-Pacific where the outbreak of Covid-19 began."

CROATIA

Petrokemija resumes ammonia production

On May 14th Croatian fertilizer producer Petrokemija said that it had resumed operations at its 450,000 t/a Kutina ammonia plant following a week-long shutdown due to a technical failure. The ammonia plant halted operations on the evening of May 7th, but Petrokemija said that its downstream fertilizer plants continued to operate as planned.

NIGERIA

Commissioning ongoing at Dangote

Dangote Industries says that it has achieved mechanical completion at its new fertilizer complex at Lekki near Lagos in Nigeria. In a statement to the Nigerian Investment Promotion Commission, Dangote Group Executive Director for Strategy, Portfolio Development and Capital Projects Devakumar Edwin, said that all sections were completed and were in pre-testing. He also said that the plant started receiving gas from the Nigerian Gas Company and Chevron Nigeria Ltd in February, and was expecting turbine start-up in late June and the beginning of commissioning. He said the Covid-19 pandemic and some technical challenges delayed the inauguration of the plant, which was initially scheduled to take place in May.

The facility consists of two 1.3 million t/a ammonia-urea trains, the first of which is now beginning trial operations, and which is likely to begin producing stable product by September this year. Exports are expected to begin in the first half of 2021. Edwin noted that 25% of production will be reserved for domestic production and the remainder exported.

INDIA

RFCL to begin production in late June

Ramagundam Fertilizers and Chemicals Ltd (RFCL) says that, following the completion of pre-commissioning works and a trial run of the company's newly completed plant at Ramagundam, it expects to begin commercial production in late June. Production had been planned to start at the end of March, but was delayed by India's Covid-19 lockdown. However, the government exempted the company from the lockdown from April because of the importance of fertilizers for India's agricultural industry. The new plant will produce 1.27 million t/a of urea. RFCL is a joint venture between National Fertilizers Ltd (NFL), Engineers India Ltd (EIL), both with a 26% stake, the Fertilizer Corporation of India (FCI) and the Telangana government (11% each), the Gas Authority of India limited (14.3%) and the HTAS consortium (11.7%).

Fertilizer re-starts boost gas demand

India's gas demand rose by around 50% during April as the government eased restrictions on businesses following a two month lockdown due to the Covid-19 pandemic. Although the lockdown officially ended on May 31st, as noted above the government allowed chemical plants, factories and downstream industries to restart ahead of this. State-run distributor GAIL said that sales of gas had increased from 50 million m^3/d at the start of April to around 75 million m^3/d by the end of the month, with fertilizer companies among the biggest buyers, as the onset of harvesting spurred demand for urea. Total Indian gas consumption in March was 139 million m^3/d according to GAIL, with fertilizer plants accounting for 30% of this.

RUSSIA

Casale says that Metafrax AUM project continues to make progress

In a recent public statement, Casale said that, despite the serious hurdles caused by the Covid-19 pandemic and the necessity to insure and preserve the health and safety of all parties involved in the project, particularly the company's own site team, construction of the large ammonia-urea-melamine (AUM) complex at Metafrax is making steady progress.

Casale said: "At the onset of the pandemic, appropriate measures and strategies were quickly put in place in view of soften, to the maximum extent possible, the negative impact due to the situation, especially as far as the schedule is concerned. First and foremost, all our site team members have been tested for the virus. We are happy to say that none has resulted positive. We have strictly complied with all norms and procedures enacted by Russian authorities with the purpose to thwart the pandemic. All this has given us the confidence not only to go ahead but to actually increase the strength of our site team, with more people being deputed there. Meanwhile, for all vendors, specific procedures have been arranged enabling to work remotely, with minimal disruption of the workflow and hence reduced impact on schedule.

"All equipment of all units was already delivered to site before the pandemic struck, while it has been possible to anticipate the critical activity of testing and qualifying the welders since all relevant materials and procedure were made available well in advance than scheduled. Owing to this, the piping prefabrication and installation could be started and it is underway. All the above strengthen our confidence that the ammonia unit will be put on stream within the end of this year."

In a separate statement, the company has also said that a surge test of the turbo-set of the 1,500 t/d nitric acid plant at Navoyazot in Uzbekistan has also been successfully completed, and the acid plant was expected to start up as scheduled at the end of May.

DENMARK

Haldor Topsoe joins UN Global Compact

Haldor Topsoe has joined the United Nations Global Compact, the world's largest sustainability initiative. Joining the compact commits members to aligning policies and action with the UN Global Compact's Ten Principles. These are aimed to provide companies with clear guidelines on responsible business practices within areas such as human rights, labour, the environment, and anti-corruption.

"We are pleased to be a part of this global initiative. Joining the UN Global Compact reaffirms our existing commitment to building our business around responsible and transparent practices. It aligns well with our continuous strive to create sustainable solutions that make a difference in the world of today – and tomorrow. We look forward to engaging with peers to collaboratively learn and promote sustainable development globally," says Christian Stender, Compliance & Sustainability Director.

Topsoe says that it is currently making an assessment of how the company's product offerings impact the world's global challenges according to the UN Sustainable Development Goals (SDGs) framework. The assessment is expected to be finalised later this year.

UNITED STATES

Koch launches digital solutions business

Koch Engineered Solutions, a division of Koch Industries, Inc., has launched *OnPoint*, a digital solutions business which aims to leverage the company's engineering capabilities and expertise in combination with digital technology to deliver greater value for customers. The platform seeks to deliver real-time insights and enhanced system performance across a variety of industrial processes, harnessing knowledge and experience from Koch's equipment businesses to provide actionable insights that help operators identify root causes, analyse performance, and optimise equipment and operations. It is based around John Zink Hamworthy Combustion's *Smart Combustion*™, with the addition of virtual combustion assistant *EMBER*™ as well as *ZoloSCAN*. Koch-Glitsch's *TowerView* solution applies expertise in mass transfer and is another emerging solution in the *OnPoint* portfolio, along with established analytics platform *CORTEX*™ and business intelligence solution *Energy Manager*.

"Historically, industrial operations have not taken full advantage of the data they routinely capture, the knowledge of equipment designers, or advanced data analytics to enable actionable insights," said Chip Hilarides, president of *OnPoint*. "OnPoint was created to bring the deep expertise of John Zink, Koch-Glitsch, and other Koch businesses to industrial operations and usher in the next generation of efficient, profitable operations. The OnPoint team works directly with customers to deliver solutions that help them operate safer, cleaner, more efficiently, and with higher throughput."

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UNITED STATES

Air Products and Haldor Topsoe sign global collaboration agreement

Air Products and Haldor Topsoe have signed a global alliance agreement. Under the terms of the agreement the two companies will use their combined market network for developing potential projects and the combination of their expertise on large-scale ammonia, methanol and/or dimethyl ether (DME) plants to be developed and built globally. It gives Air Products access to Topsoe's technology licenses and the supply of engineering design, equipment, high-performance catalysts and technical services for ammonia, methanol and DME plants that are built, owned and operated by Air Products. It also allows for the integration of Topsoe's technology into many Air Products' technologies including gasification of various feedstocks, and synthesis gas processes.

As an example, Topsoe's technology will be incorporated into Air Products' recently announced world-scale coal-to-methanol production facility in Bengalon, East Kalimantan, Indonesia (see below). In addition, Topsoe technology will also be part of the previously announced world-scale Gulf Coast Ammonia production plant in Texas. Air Products will supply hydrogen and nitrogen for the ammonia production in part from its largest-ever steam methane reformer.

"The global agreement with Haldor Topsoe is very important to Air Products as we continue to expand our scope of supply to customers in developing large-scale projects around the world. We have built a reputation for successfully executing megaprojects. Having this Alliance and access to Haldor Topsoe's technology-leading capabilities will serve to strengthen both our offerings and customer confidence in the reliability and quality of project development and performance," said Dr. Samir J. Serhan, executive vice president at Air Products.

"We are extremely satisfied to enter this Alliance. Air Products is an industry leader, and we share their commitment to providing customers around the world with excellent, innovative, and more sustainable solutions. This alliance forms the foundation for integrated large-scale projects that will benefit from the close collaboration and combined strengths of our two companies," said Amy Hebert, Deputy CEO and Executive Vice President at Haldor Topsoe. ■

MOL to provide ships for NWIW project

Japan's Mitsui O.S.K. Lines (MOL) says that it will invest in the Chinese-backed Northwest Innovation Works (NWIW) methanol project in Washington State, and will provide and operate purpose-built next-generation ships to serve the planned methanol facility at the port of Kalama. The new partnership puts NWIW in the company of one of the world's largest shipping companies, with a fleet of 740 vessels totalling 55 million dwt. NWIW is currently still bogged down in environmental permit applications for its 5,000 t/d methanol plant, which aims to convert abundant shale gas into methanol for shipping to methanol to olefins (MTO) plants in China. NWIW says that in so doing it will displace more carbon intensive Chinese coal-based methanol, bringing environmental benefits. It will also offset 100% of its greenhouse gas emissions from Kalama and use the cleanest available technologies.

Construction on hold at South Louisiana Methanol

Construction work was suspended "for an indefinite period" in April at the South Louisiana Methanol LP site in St. James Parish, Louisiana. The company said that work was halted on the $2.2 billion, 1.8 million t/a methanol plant because of the economic downturn from the coronavirus pandemic. Also said that, although it remains committed to finishing the project, it is seeking new project partners and a new debt finance package. South Louisiana Methanol is a joint venture between New Zealand-based Todd Corp. and Sabic US Methanol, the Houston-based subsidiary of Saudi Arabia's Sabic.

AUSTRALIA

Leigh Creek Energy looking to hydrogen market

Underground coal gasification (UCG) company Leigh Creek Energy says that it is looking at commercialising hydrogen production from its in situ gasification project in South Australia, claiming that it could be the lowest cost producer in Australia, at less than A$1.00/kg H_2. The company is already looking at using syngas generated from UCG to make ammonia and downstream urea, and says that its pilot plant has demonstrated that the project can produce 200,000 t/a of hydrogen at less than $1/kg, which is "much lower than current production costs" and "cheaper than potential competitors". The company has been monitoring the hydrogen market and governmental desire to encourage this development and said while the market has seemed "too immature" in Australia, "things are changing rapidly and the business for hydrogen now warrants further analysis".

Leigh Creek Energy says that it validated its in-situ gasification (ISG) technology in early 2019 following the successful production of commercial syngas from its demonstration plant and announced a commercialisation plan to produce ammonia for up to 2 million t/a of urea manufacture, but added that, "If the market exists in Australia or an export market exists for hydrogen, we can divert excess hydrogen for sale as a standalone product."

In April, Leigh Creek Energy signed an agreement with its major shareholder China New Energy (CNE) for a proposed joint venture for ISG operations in China. The company says it is also in talks with CNE's parent company, Shaanxi Meijin about bringing its hydrogen vehicles, fuel cells and charging stations technologies to Australia.

Renewables projects looking at hydrogen storage

Infinite Blue Energy, developers of the massive $3.5 billion Project NEO renewable power project in New South Wales, says that it is aiming to use hydrogen to store excess power and turn renewable power production into 1 GW of 'baseload' continuous power supply by 2027. Infinite Blue Energy, which is being led by a team of executives with a range of experience previously from the oil and gas sector, said in a statement: "A traditional weakness with solar and wind energy is the variability associated with a reliance on natural seasonal changes and conditions. By converting the solar and wind energy into green hydrogen, it is possible to provide electricity when there is no wind, a cloudy day or limited to zero sun exposure at night via fuel cell technology."

Infinite Blue Energy estimates that the project would require around 235 wind turbines, and 1,250 hectares of land for solar generation, but the company said that it would look to use high-value sites for solar and wind production, in combination with a "distributed generation model" to diversify the project's supplies of renewable power. It says that it will begin a feasibility study and commence design work over the next 18 months and has started negotiations with potential off-takers for both electricity and hydrogen supplies.

It is only one of a number of large scale renewables to hydrogen projects under discussion in Australia. BP has also said it is considering a 1.5 GW wind and solar project in Western Australia to create renewable hydrogen, Siemens has proposed a bigger 5 GW renewable hydrogen project in the same region, and further north the Asia Renewable Energy Hub is contemplating a 15 GW wind and solar project. In Queensland, renewable energy company Austrom Hydrogen has secured land near the Port of Gladstone for a 3.6 GW solar-powered hydrogen facility.

INDONESIA

Coal-based methanol plant planned for Bengalon

Air Products has signed an agreement with PT Bakrie Capital Indonesia and PT Ithaca Resources to build a $2 billion coal-based methanol plant in Bengalon, East Kalimantan. Under the long-term on-site contract, PT Ithaca Resources will supply the coal feedstock and have committed to offtake the methanol production for sale within Indonesia. Air Products will build, own and operate the air separation, gasification, syngas clean-up, utilities and methanol production assets to produce methanol for Bakrie and Ithaca. The facility, based around Air Products' proprietary Syngas Solutions dry-feed gasifier, will produce nearly 2 million t/a of methanol when it comes onstream in 2024.

Seifi Ghasemi, Air Products' chairman, president and chief executive officer, said that, as Southeast Asia's largest economy, Indonesia is committed to reduce its energy imports and efficiently convert abundant coal resources into high-value products. "We are proud to have been awarded another world-scale gasification project, where we will deploy our capital, technology and operational expertise to help Indonesia meet these important goals. This is another example of our long-term strategy to deploy capital into high-return strategic industrial gas projects," he said.

GERMANY

Expanding electrolysis plants to a gigawatt scale

As demand continues to rise for industrial electrolysis plants which can produce 'green' hydrogen cost-efficiently, thyssenkrupp says that it has significantly expanded its manufacturing capacities for such electrolysis plants and can now annually produce electrolysis cells with a total power consumption of up to one gigawatt, in partnership with its strategic supplier De Nora. This production capacity is expected to be expanded in the future.

"Water electrolysis is increasingly emerging as a key technology for building a sustainable, flexible energy system and carbon-free industry. This opens up new markets for us," said Sami Pelkonen, CEO of thyssenkrupp's Chemical & Process Technologies business unit. Christoph Noeres, head of Energy Storage & Hydrogen added: "Especially in energy- and resource-intensive industries such as fuel, chemical or steel production, only green hydrogen opens the way to climate neutrality. For this, we need water electrolysis on a gigawatt scale. We can deliver, and as the number and size of hydrogen projects increases we will further expand our production capacities. But one thing is also clear: it won't work without changed regulatory conditions and fair market opportunities for green hydrogen. In addition to the further expansion of renewable energies, the focus is on adjusting tax systems and crediting the CO_2-reducing effect of green hydrogen in the target markets."

PHOTO: TKIS

Electrolyser installation by Thyssenkrupp Steel.

To simplify the construction of new hydrogen plants and keep costs down, thyssenkrupp offers its electrolysers as prefabricated skid-mounted modules. One module produces 4,000 m³/h of hydrogen. The units are can be combined to realize projects of several hundred megawatts or gigawatts. The patented design of the electrolysis cells, equipped with proprietary anodic and cathodic coatings developed by De Nora, allows high system efficiencies of up to 80%, according to tkIS. So far, more than 600 projects and electrochemical plants worldwide with a total rating of

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over 10 GW have been installed by the company.

Hydrogen for steel production

An agreement has been signed between Rhine-Westphalia power company RWE and Thyssenkrupp Steel Europe to develop a 100MW electrolyser plant project to produce green hydrogen to supply the latter's Duisburg steel mill. The green hydrogen will be used for pig iron production. The companies have agreed that only electricity from renewable energy sources will be used to supply the electrolyser facility.

A 100MW electrolyser, which will be built in 2022, will produce 1.7 t/h of hydrogen gas, meeting 70% of the requirements of the blast furnace at the Duisburg steel plant, leading to the annual production of 50,000 tonnes of climate-neutral steel.

RWE and Thyssenkrupp Steel Europe will establish network connections with gas network operators and relevant authorities based on their understanding that hydrogen transport via pipelines will be possible due to adaptation of natural gas transportation regulations as part of Germany's National Hydrogen Strategy. Thyssenkrupp Steel's aim is to be climate-neutral by 2050, which will require 750,000 t/a of hydrogen, equivalent to the annual output of over 3000 wind turbines.

FRANCE

Integrated power to hydrogen to power project

A consortium made up of Engie Solutions, Siemens Gas and Power, Centrax, Arttic, German Aerospace Center (DLR) and four European universities have contracted to develop the HYFLEXPOWER project – a way of using hydrogen to store and recover renewable power. The project, funded by the European Commission under the Horizon 2020 Framework Program for Research and Innovation, will be the first industrial-scale 'power-to-X-to-power' demonstrator. Incorporating an advanced hydrogen turbine, it will be built at Smurfit Kappa PRF's site - a company specialising in manufacturing recycled paper - in Saillat-sur-Vienne, France. The purpose of the project is to prove that hydrogen can be produced and stored from renewable electricity and then combined with natural gas in ratios up to 100% to generate electricity in combined heat and power plants. For this an existing Siemens SGT-400 industrial gas turbine will be upgraded to convert stored hydrogen into electricity and thermal energy.

The port of Antwerp, Belgium.

Storing fluctuating renewable energy is one of the major challenges of the transition to renewable fuels. In this context, the stakeholders involved in the HYFLEXPOWER project are developing new technologies which can be used across the whole power-to-X-to-power cycle. The installed demonstrator will be used to store excess renewable electricity in the form of green hydrogen. During periods of high demand this stored green hydrogen will then be used to generate electrical energy to be fed into the grid.

The hydrogen production storage and supply facility will be installed at the site in 2021 and the modified gas turbine in 2022. Pilot demonstrations with up to 100% hydrogen for carbon-free energy production from stored excess renewable energy are scheduled to begin in 2023.

EQUATORIAL GUNIEA

Nexant to produce feasibility study for methanol derivatives project

The Ministry of Mines and Hydrocarbons (MMH) of Equatorial Guinea, in collaboration with the Atlantic Methanol Production Company (AMPCO), has awarded Nexant the feasibility study for the construction of a new formaldehyde production plant at Punta Europa. The plant forms part of Equatorial Guinea's Year of Investment 2020 initiative, aiming at investments across the country's midstream and downstream industries and promoting infrastructure that adds value to the hydrocarbons industry. Key projects include a modular refinery for domestic supply, storage tanks for refined products, methanol derivatives manufacturing, an industrial mining area with a gold refinery, and a urea plant project. The feasibility study for the project is expected to be ready by mid-June 2020.

IRAN

Start-up for Bushehr

The Middle East Kimia Pars Petrochemical Company said that it began operations at its new methanol plant at Bushehr in the Pars Special Economic Energy Zone at Assaluyeh, Bushehr Province, on June 8th. The gas-based methanol plant has been constructed in 8 ha of land at the site at an estimated cost of $460 million, and will consume 1.5 billion cubic metres of natural gas per year from the South Pars gas field to produce 1.65 million t/a of methanol at capacity. Haldor Topsoe provided the technology license for the plant, catalysts and some equipment.

BELGIUM

Sustainable methanol project

INEOS subsidiary INOVYN is looking to explore options for the sustainable production of methanol for its vinyls and other downstream production at Lillo near Antwerp in Belgium. As part of a consortium including Engie, Oiltanking, Indaver, Fluxys, the Flemish Environmental Holding Company (Vlaamse Milieu Holding) and the Port of Antwerp, INOVYN is participating in a feasibility study for the use of captured carbon dioxide and sustainably generated hydrogen to produce 8,000 t/a of sustainable methanol. INEOS says that the project forms part of the company's exploration of the potential of alternative energy and sustainable, lower carbon production of chemicals.

The new facility would generate produce methanol to be used by chemical companies in the Port of Antwerp Cluster while future development would lead to increased volumes of sustainable methanol produced for wider industry use, including as a sustainable fuel for marine and road transport.

Geir Tuft, CEO of INOVYN said: "This is a very exciting project and an excellent fit with our sustainability strategy, which includes pursuing options for alternative energy and the sustainable, lower carbon production of chemicals. Specifically, INOVYN will contribute its expertise in hydrogen production and electrolysis to the project, and has identified a suitable location for the proposed demonstration plant at our Lillo Site."

NORWAY

Renewable aviation fuel project

Norsk e-Fuel, a consortium including Sunfire GmbH, Zurich-based carbon capture company Climeworks AG, engineering, procurement and construction (EPC) company Paul Wurth SA and green investor Valinor, which owns Norway's largest private wind power developer Norsk Vind, has announced plans to build a commercial plant for the manufacture of renewable aviation fuel. The facility will use Sunfire and Climeworks' technologies to convert renewable electricity into hydrogen and combine it with CO_2 captured from ambient air and unavoidable CO_2 sources to produce syngas, which will then be processed into renewable fuels. The plant will be built at the Heroya Industry Park in Porsgrunn, with commissioning planned for 2023. It will have the capacity to produce 8,500 t/a of renewable fuel, but there are plans to expand this to 85,000 t/a by 2026.

"To put this in perspective, only one industrial scale plant will already provide enough blended renewable fuel for the top five domestic aviation routes in Norway combined. This would effectively cut the current flight emissions between these cities by about 50%." said Lars Helge Helvig, founder of Valinor and Chairman of Norsk Vind.

CHINA

Clariant reports on catalyst performance at hydrogen plant

Since its restart in July 2019, Zhejiang Baling Hengyi Caprolactam Co Ltd (BHCC)'s hydrogen plant at Hangzhou, Zhejiang province, has seen improved performance following a joint revamp project between Clariant and Shanghai Huaxi. Specialty chemicals company BHCC is a joint venture between SINOPEC Group and Zhejiang Hengyi Group, and runs the largest single train caprolactam plant in the world, with a capacity of 500,000 t/a. The plant's hydrogen unit was revamped with a combination of Shanghai Huaxi's hydrogen technology and Clariant's stabilised copper-zinc *ShiftMax 300* medium temperature shift catalyst.

Since the restart, BHCC's hydrogen production rate has increased by 2.5% per unit of feed to 25,000 Nm^3/h. However, it is also reporting 32% lower electricity consumption and 44.4% higher steam production, with reduced capital investment, as no mechanical structures are required for the waste heat boiler. Furthermore, using *ShiftMax 300* it is possible to recycle all condensate water and steam generated in the stripper as boiler feed water to reduce energy consumption. BHCC says that it expects to accrue total annual savings of around $1 million.

Clariant says that ShiftMax 300 operates at a low steam-to-dry-gas ratio of 0.31 mol/mol, with high activity at low temperatures (185°C), allowing sustained operation at high space velocities, close to equilibrium. Stefan Heuser, Senior Vice President & General Manager at Clariant Catalysts, commented, "We are extremely pleased with the results of our partnership with Shanghai Huaxi at the BHCC hydrogen unit. Our two companies' perfectly complementary products and processes have demonstrated that they can successfully maximise our customer's total hydrogen production, while drastically reducing costs."

TRINIDAD & TOBAGO

Methanol plants idled, delayed

Proman says that the M3 methanol plant at Point Lisas, Trinidad has been idled since mid-April due to falling methanol prices. Proman is one of the partners in Methanol Holdings Trinidad Ltd (MHTL), which operates the M3 plant. This was followed in May by the M2 methanol plant at the same site. They are two of several shutdowns on the island. Canada's Methanex, the world's largest producer of methanol, idled its 850,000 t/a Titan plant on the same industrial estate on April 1st for an "indefinite" period.

Meanwhile, across the island at La Brea, the new methanol and dimethyl ether (DME) project under construction by Caribbean Gas Chemical Ltd (CGCL), a 70% owned subsidiary of Mitsubishi, remains behind schedule as a result of regulatory delays, industrial action, heavy rains in 2017 and 2018, and issues with some contractors, as well as the Covid-19 outbreak. The $1 billion plant, originally scheduled to be completed in December 2018, has a capacity of 1.0 million t/a of methanol and 20,000 t/a of DME. It was close to mechanical completion in March when Trinidad went into Covid lockdown, and is now expected to start-up in the second half of 2020. As well as the Mitsubishi consortium (Mitsubishi Gas Chemical, Mitsubishi Corporation and Mitsubishi Heavy Industry), CGCL's shareholders include the National Gas Company (NGC), with a 20% stake; and Massy Holdings (10%).

SYNGAS NEWS

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People

IFA has announced the appointment of its Senior Director of Agriculture, **Patrick Heffer**, as the organisation's Interim Director General as of May 1st. A formal search process for the next Director General has already been launched. Previous IFA Director General **Charlotte Hebebrand** stepped down at the end of April to assume a new role as Executive Vice-President and Chief Sustainability Officer at Nutrien, and says that she looks forward to continuing engagement with IFA.

During her nearly eight years' tenure at IFA, Hebebrand, working closely with the IFA board and secretariat, introduced a number of new areas of focus and initiatives, including a reshaping and expansion of IFA's market intelligence, a strong emphasis on product and nutrient stewardship, enhanced policy and research capabilities and an expansion of multi-lateral engagements and international cooperation.

"Charlotte has made significant and lasting contributions to IFA and to our industry" said IFA Chairman and CEO of OCP, Mostafa Terrab, who recognised in particular her commitment to dialogue and her far-sighted approach to long-term development and growth, such as the distillation of the plausible future scenarios as part of the IFA 2030 strategic exercise, as well as the creation of a Scientific Panel on Responsible Plant Nutrition. "The Board would like to thank her for her extraordinary service and leadership".

Patrick Heffer is a very experienced, long-standing executive team member who joined IFA in 2002 and for the past 18 years has coordinated the association's global agronomic, market and policy activities in relation to fertilizer use. Before joining IFA, he spent 15 years with the seed industry, including five years with the International Seed Federation, and two years with the FAO's Seed and Plant Genetic Resources Service.

Patrick Heffer (above left), and Roeland Baan (above right).

Heffer, whose appointment coincides with the new global challenges caused by the Covid Pandemic, remarked: "I am grateful for this opportunity, and in cooperation with IFA's team of directors as well as IFA's experienced and devoted staff, I will make sure that the Association continues to deliver on its goals and objectives. In these trying times, we, at IFA, are even more committed to delivering the support, in terms of information, benchmarks, data, market insights, partnerships, policy analysis and reputation management tools, that our members and external stakeholders expect from us."

Gambarotta Gschwendt gas announce the appointment of **Davide Gambarotta** as its new Chief Executive Officer and sole owner designate. He replaces the former CEO with immediate effect, and will keep on his position as CEO and sole director of MDG Handling Solutions. Gambarotta Gschwendt and MDG will operate jointly under the Gambarotta Group, with Gambarotta Gschwendt responsible for the design and production of equipment for bulk material handling and MDG Handling Solutions offering complete EP/EPC packages.

In May **Roeland Baan** joined Haldor Topsoe as the company's new CEO, following the announcement of his appointment back in February. Baan was previously CEO of Finnish steel giant Outokumpu. On his first day in the office, Baan said: "This is a special day for me. Topsoe is an exceptional company that has made a huge difference for the refining and chemical industries for decades. I have no doubt that Topsoe has the potential to expand this strong market position and lead the way into a more sustainable and energy-efficient future. I have been looking forward to begin this journey together with the board and the leadership team as well as Topsoe's customers and dedicated employees."

Jeppe Christiansen, Chairman of the Board of Directors of Haldor Topsoe A/S, commented: "Roeland Baan has remarkable global experience and a proven track record of driving growth, developing businesses and building cohesive organizations. I am convinced he will contribute to the continued strong performance of Haldor Topsoe. Topsoe is a profitable company with a solid core business. With Roeland's direction, we will continue to focus on being global leader in the markets in which we operate."

Gene Mueller has been appointed President, North America for Clariant as of April 1st, 2020. In his role, he will oversee the strategic objectives of the regional business units in pursuit of a company-wide growth agenda. He is also responsible for ensuring the necessary infrastructure is in place to support the businessess effectively. The company currently employs over 1,900 people in approximately 50 sites across the US and Canada, including manufacturing sites, laboratories and sales facilities. Mueller has worked for Clariant in various roles for 30 years, including stints in New Jersey, Charlotte, and Switzerland, where he held the position of Head of Commercial Excellence. In 2013, he moved to Louisville, KY working for the Catalysts business unit where he was responsible for the Fuel Upgrading Market Segment and most recently Business Segment Petrochemicals.

Ahmed El-Hoshy will become the new CEO of OCI NV, effective from August 1st. His predecessor and current CEO, **Nassef Sawiris**, will assume the position of Executive Chairman of OCI's board, with continued responsibility for directing OCI's strategy. El Hoshy is currently chief operating officer of OCI, prior to which he led OCI's expansion in North America from zero in 2011 to its current 5.5 million t/a of fertilizer capacity today. He has also held various other senior leadership roles, including CEO of OCI Partners and CEO of OCI Americas.

Nassef Sawiris commented: "In my new role, I can fully focus on OCI's strategic direction, and I look forward to working with the team to create long-term value for our shareholders, as we can see a wide array of exciting opportunities ahead that benefit the company, the market and our stakeholders. I also believe this is an opportune moment for the management change: this year marks an important inflection point for the company as we expect to achieve run-rate production across the platform, allowing us to benefit disproportionately from a recovery in the economic cycle."

Ahmed El-Hoshy commented: "I am excited to take on this new role and look forward to continue working alongside Nassef, Hassan and the whole team. We have already built an industry-leading and highly efficient global platform that delivers crucial products to the world. We will continue our focus on operational and commercial excellence and recently bolstered this effort with the appointment of **Bart Voet** as VP Manufacturing to lead our global production platform. Our world-class asset base, led by exceptional employees, is well-positioned to drive value and growth within a framework of ever-increasing focus on safety and sustainability."

Fauji Fertilizer Bin Qasim Ltd has approved **Sarfaraz Ahmed Rehman** as director/CEO with effect from June 10th, following the expiry of the contract of **Lt General Javed Iqbal** as Chief Executive Officer and Managing Director of the company. A chartered accountant by qualification, Rehman has 30 years of work experience, beginning with Unilever in 1983 and subsequently in companies such as Smithkline Beecham and Jardine Matheson/Olayan. He also launched Engro Foods Ltd in 2005 and was its CEO for over six years. ■

Calendar 2020

! 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.

AUGUST

30 AUG – 3 SEP

65th AIChE Annual Safety in Ammonia Plants and Related Facilities Symposium, MUNICH, Germany
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363/+1 203 702 7660
Email: iliak@aiche.org

SEPTEMBER

23-24

Gasification Summit 2020, LYON, France
Contact: Avani Mehta, ACI
Tel: +91 9665011195
Email: avani@acieu.net
Web: www.wplgroup.com/aci/event/gasification/

27 SEP – 2 OCT **POSTPONED TO 2021**

Ammonium Nitrate/Nitric Acid Conference, HOUSTON, Texas, USA
Contact: Hans Reuvers, BASF
Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com
karl.hohenwarter@borealisgroup.com
annaconferencehelp@gmail.com
Web: an-na.org

OCTOBER

7-8

Syngas Nitrogen Russia and CIS, MOSCOW, Russia
Contact: Milana Stavnaya,
Programme producer, Vostock Capital
Tel: +7 499 505 1 505
Email: MStavnaya@vostockcapital.com

FEBRUARY 2021

16-18

Nitrogen+Syngas USA, TULSA, Oklahoma, USA
Contact: CRU Events, Chancery House, 53-64 Chancery Lane, London WC2A 1QS.
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

MARCH

1-3

Nitrogen+Syngas 2021, ROME, Italy
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Fax: +44 (0) 20 7903 2172
Email: conferences@crugroup.com

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Plant Manager+

Incident No. 1 Leak in nozzle in urea reactor bottom

High pressure urea equipment often has lined nozzles. A lined nozzle is a full strength carbon steel nozzle that is protected against carbamate corrosion by a 5 or 6 mm thick stainless steel liner plate, which is welded to the carbon steel nozzle on either end. This design is however very vulnerable to fatigue cracking due to the difference in thermal expansion between the austenite liner and the carbon steel nozzle. History shows that such a design will lead to cracking in the long term. The following case study reports on a serious incident in a urea plant where a leak in a urea reactor nozzle caused a plant shutdown but could have resulted in rupture of the high pressure vessel.

Event description
Operators noted an excessive leak in the bottom forged head of the urea reactor in a CO_2 stripping technology 700 t/d urea plant from 1971. The leak detection holes did not indicate any leak. A crack of 50.8 mm was found adjacent to a 203.2 mm nozzle. Extensive thickness gauging was carried out on the head from outside and revealed corrosion on an area about 800 mm in diameter. Thickness loss was intensive in the vicinity of the split where the measured thickness was only a few millimetres. The bottom dished liner section (1,000 mm in diameter) on the lower head was found to be buckled and a corroded groove was noted in the weld between this liner section and the collar around the inner lining sleeve of the 203.2 mm bottom nozzle. This groove was located on the opposite side to the zone of maximum thickness loss and the open split in the lower head. The bottom dished liner section was cut and removed. A thick layer of corrosion products was found covering the carbon steel head. This layer was washed out and the terrifying topography of corroded surfaces was exposed. The removed dished liner section was found corroded on the backside at many locations. Leak detection holes in the lower head as well as in the attached nozzles were found plugged with corrosion products. A corroded hole 30 mm X 70 mm was noted in the lining sleeve inside the 203.2 mm bottom nozzle.

Immediate response action
The plant was shut down when the leakage was identified. The reactor bottom was repaired.

Causes
The locations of the corroded groove in collar weld, the opening in the lining sleeve and the area of most corrosion action and the open split in the carbon steel head all assumed that the whole problem started by a local damage, most probably cracking on the lap weld joint between the bottom liner section and the sealing collar around the lining sleeve inside the 203.2 mm bottom nozzle. This was followed by a seepage of the corrosive solution to the lower carbon steel head. Leak detection holes in the area were blocked with corrosion products and detection of the occurred leak was thus prohibited. Corrosion action continued for a prolonged time with a pronounced rate on the area around the developed crack in liner weld until the head was split open in that area.

Primary consequence:
Near miss of rupture of high pressure vessel.

Secondary consequence:
Unplanned shutdown for a signiifcant number of days costing >US$1 million.

Urea reactor design
The urea reactor is designed to operate at 160 kg/cm² and 200°C and was operating at 140 kg/cm² and 183°C. The reactor has a diameter of 1.68 m and length of 37.5 m. The bottom forging is 50 mm thick. The bottom cup has four nozzles, three of them fitted vertically to the bottom and the fourth one fitted horizontally on the side of the lower cup. The whole shell of the reactor and nozzles are lined with 5 mm 316L stainless steel material. The reactor liner is made up of nine stainless steel segments or compartments, backed with two 10 mm weepholes for each compartment. The weepholes are drilled through the carbon steel shell. The top and bottom cups are also protected with weepholes.

Risk level:
There was a high risk of a major incident.

Prevention safeguards:
- Perform corrosion inspections during turnarounds;
- Apply a solid stainless steel/duplex design of nozzle to avoid thermal cracking risks;
- Assure a proper leak detection system (active vacuum based system with an accurate and reliable ammonia detector).

Mitigation safeguards:
In case of a leak, confirm and locate the leak, shut down the plant and drain the synthesis section as soon as possible.

Additional causes to consider:
- Fatigue cracking at nozzle (bad design);
- No proper leak detection system;
- Nozzle design of HP urea equipment.

UreaKnowHow.com prefers a solid stainless steel/duplex nozzle design for high pressure urea equipment.

This case study report is one of many serious incident reports on UreaKnowHow.com's Fertilizer Industry Operational Risks Database, FIORDA, which has been created for collecting and sharing process safety and reliability information among participating companies in the fertilizer industry.

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Agricultural demand for nitrogen

PHOTO: VALENTIN VALKOV/SHUTTERSTOCK.COM

Agricultural markets represent 75% of nitrogen demand worldwide. Rising populations, changing crop types, moves towards sustainability and the spread of speciality fertilizers and new technologies are all changing the market for nitrogen fertilizers, but the Covid pandemic may affect markets in a variety of different ways.

Nitrogen remains the key nutrient for plant development. It is the fourth most abundant element present in plant tissues, after carbon, hydrogen and oxygen, but unlike them, cannot be sourced from air and water, as atmospheric nitrogen is too tightly bound to itself in an N_2 molecule. Outside of legume crops, which have root bacteria that can convert N_2 into soil nitrate, most crops can only take up nitrogen in the form of NH_4^+ and NO_3^-, mainly the latter. Due to the limited amount of nitrogen available in soils, it usually remains the key determinant of plant growth throughout the plant's life cycle. This is especially true of cereal crops, which are the staple of the world's food supply, which tend to require higher than average applications of nitrogen.

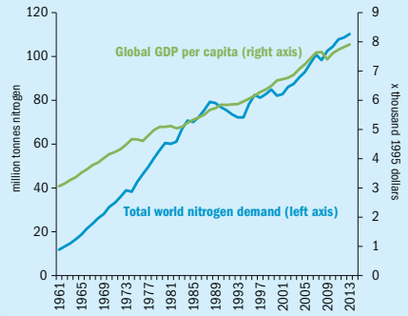
While there is extensive use of manures and there has been some research into allowing non-legume plants to use nitrifying root bacteria in the same way, for the moment artificial nitrogen fertilizer produced via the Haber-Bosch ammonia process and downstream processing into urea, ammonium nitrate and NPK blends remains the main source of agricultural nitrogen worldwide.

Unlike potassium and phosphorus, the other two major plant nutrient requirements apart from nitrogen, nitrogen must be applied annually for plants to receive its benefit. Yara calculates that after one year without nitrogen application, soil fertilizer and productivity declines by 45%, and after two years the fall is 80%. This means that agricultural demand for nitrogen tends to remains relatively predictable and steady. Last year, about 75% of all ammonia produced around the world was consumed either in downstream fertilizer production, or directly as an agricultural nutrient (US farmers in particular use ammonia solutions sprayed directly onto fields as a fertilizer).

Factors affecting demand

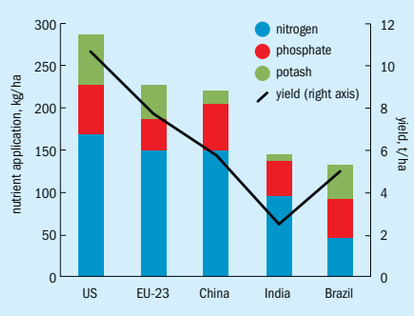
On a long-term basis, two major factors have underpinned the growth in nitrogen demand – global population increase and increasing global incomes. Undoubtedly the most influential aspect over the past 50 years has been the rapid rise in population. The world's population stood at about 3 billion in 1960, 4 billion in 1975, 5 billion in 1987, 6 billion in 1999 and 7 billion in 2011 – in theory, doubling the number of people should double demand for food. This is not the factor it once was; as incomes have risen so fertility rates have fallen, assisted in China by the 'one child' policy which began in 1980. The annual increase in the world's population reached a maximum in 1987, and since then has fallen, albeit slowly, and is projected to begin falling faster over the next few decades – it is currently increasing at an average of 1% per year, but in some regions, especially Europe, Japan and Russia, total population levels are falling. Asia's population is expected to peak in the next couple of decades, and only Africa is still seeing considerable population growth.

Fig. 1: **Nitrogen demand vs incomes, 1961-2014**



Source: IFA, UN

Fig. 2: **Nutrient use vs cropyield, 2014**



Source: Agrium

The other major driver of fertilizer demand growth over the past few decades has been rising incomes in the developing world. As farmers' incomes increase they are able to afford more fertilizer, and as the overall population's income increases people begin to include more meat in their diet, which in turn requires more land given over to raising crops to feed animals, and hence more fertilizer. Figure 1 shows global nitrogen fertilizer demand growth (in blue) on the left hand axis, and global GDP/capita (in inflation-adjusted dollars) on the right. Using GDP per capita strips out the effect of rising population, and shows that while fertilizer demand growth outpaced growth in global incomes during the 1960s and 70s (when the increase in fertilizer use was dominated by rapidly increasing population), from about 1980 onwards demand growth has been led by rising global incomes.

This means that food demand is projected to continue over and above the rate of increase of population, and with it demand for fertilizer – other ways of increasing food production, such as increasing area under cultivation appear not to have had an effect in practice. The amount of arable land under cultivation increased from just under 1.4 billion hectares in the 1960s to about 1.5 billion hectares in 1990, but has stayed relatively constant at that level ever since, as EU measures to take lands out of cultivation and increasing urban sprawl in Asia have been equalled by new regions being cultivated, eg in Brazil.

Negative factors

In tandem with long-term positive factors for agricultural demand, there are factors affecting demand in a negative way. The main one is increasing nutrient use efficiency. Nitrogen fertilizer application per hectare varies from around 110-180 kgN/ha for most of the world to as low as 20 kgN/ha for Africa. Where fertilizer is over-applied or applied at the wrong season, in excess it can leach into watercourses and cause algal blooms and anoxia in water. This became such an issue in Europe during the 1980s that a conscious effort was made to apply less nitrogen and phosphorus and to better target fertilizer application to minimise run-off. The success of this policy has led to Europe's steady lowering of nitrogen consumption, and other countries are gradually following suit. Imbalanced fertilizer application can also be an issue, as occurs in India. Figure 2 shows fertilizer application and yield in a variety of countries. Although India applies as much nitrogen as other countries which achieve better yields, its fertilizer subsidy policy has pushed urea at the expense of other fertilizers, and the lack of P and K means that nitrogen uptake is inefficient.

Government policy is the key determinant for this demand factor, and moves to apply fertilizer more efficiently are likely to see overall demand fall over the longer term. China, which applies over 300 kg nutrient per hectare, has tried to cap demand for fertilizer at 2020 levels, and thereafter decrease it by instead applying fertilizer in a more targeted manner. As China represents 35% of global fertilizer consumption, this is a significant straw in the wind. Overall, IFA reports that nutrient use efficiency has been rising for three decades following a fall to the end of the 1980s, reaching 59% in 2017 across all regions and nutrients. This averages across 72% for the USA, 80% for Brazil, 62% in Europe, but only 47% in China and 40% in India. Increasing nutrient use efficiency (NUE) in India and China are likely to lead to a relative fall in nitrogen fertilizer demand, or possibly in India's case a less rapid rise than might otherwise have been expected.

Short term factors

In the short term, agricultural demand for nitrogen is dependent upon crop prices, especially nitrogen-hungry cereal crops, as these are a key determinant of how profitable it will be to grow a given crop this year, and how affordable fertilizer will be for the farmer. Crop prices in turn are a function of relatively constant demand and known stocks of grain set against variable annual yields determined very much by weather patterns. Here the increasing number and severity of extreme weather events that characterise climate change can have a major impact in increasing agricultural market volatility. This year of course, both fertilizer supply and demand (in the sense of whether farmers would be able to import fertilizer) – and hence pricing – have also had the additional complicating factor of the Covid-19 pandemic and

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associated lockdowns. However, as farms are generally in sparsely populated rural areas where people work outdoors and it is hence easier to maintain a 2m distance from people, and because most governments have designated agriculture as a key national industry, the actual impact of the pandemic has been more muted upon farming activity, and has mainly been on fertilizer supply due to factory and port shutdowns.

The UN Food and Agriculture Organisation (FAO) attempts to provide a regular measure of these important metrics. In its most recent report, published in June 2020, it noted that in spite of uncertainties posed by the pandemic, forecasts for the 2020/21 season indicated a fairly comfortable situation for cereal supply and demand. Relatively mild weather (as compared to, eg the floods that affected North America last year and India's delayed 2019 monsoon) meant that projections for global cereal production this year are up on 2019's already record yield by another 2.6%, at 2.78 billion tonnes, 70 million t/a higher than in 2019. Maize accounts for most of the predicted increase, with an expected expansion of 64.5 million t/a to 1.2 billion t/a due to record harvests in the US, Canada and Ukraine, and near-record harvests in Brazil and Argentina. Rice production is forecast to reach 509 million t/a in 2020, up 1.6%. Only global production of wheat is forecast to decline this year, because of downturns in the EU, Ukraine and the US.

Cereal demand is expected to be up 1.6% in 2020-21 to 2.73 billion t/a, with more feed required for animal rearing. This would indicate that inventories would reach a new record of 927 million tonnes, of up 4.5% at the end of the 2020-21 season, a rise in the cereal stock-to-use ratio to 32.9%, far higher than the low of 21.2% in 2007-08. This will generally indicate falling crop prices.

In spite of these projections, worries about supply of grain did lead to some price increases during March and April, taking prices 7% higher than for the comparable period in 2019.

Regional variation

Nutrien have also said that they expected North American nitrogen demand to remain strong through the planting season, and inland nitrogen prices have remained stable. US corn and soybean cash prices have seen a downturn due to demand challenges created by Covid-19 and anticipation of increased supply this year. There is decreased corn use for fuel ethanol production as people stay at home and drive less. However, US government farm support programs are also expected to increase prices by $0.36/bu for corn and $0.45/bu for soybeans. The US Department of Agriculture forecast 97 million acres of corn planting, up 15 million on 2019, and 84 million acres of soybeans, and although Nutrien put these figures closer to 95 million acres and 86 million acres respectively they still represent a 1-3% increase in total crop expenditures.

In Brazil, the soybean harvest is already complete and will produce 121 million tonnes, 4 million t/a higher than for the previous year. Soybean and corn prices are near historical highs in Brazil, which should support a higher soybean acreage in the 2020 planting season.

Australian soil moisture levels have improved significantly after several years of droughts, which also supports the outlook for increase crop input demand in 2020. Strong fertilizer demand is also expected from India.

Fertilizer supply

Fertilizer price and affordability to farmers are also a key determinant of short term demand for nitrogen fertilizer. Although the Covid19 pandemic has had an impact on fertilizer production, with urea plants shut across India and China during March and April 2020, urea prices actually fell during 1Q 2020, by an average of 15%, indicating that there was no issue with supply – the industry has been in a state of oversupply for five years as the present round of new investment in production comes on-stream and outpaces the average 1% per annum demand growth. Shutdowns of industrial consumers of nitrogen have meant that a higher proportion of overall production is available for agricultural use. Margins for producers have also been helped by falling natural gas prices, to record low levels in Europe and the US. Overall, fertilizers remain relatively affordable for farmers in the short to medium term, although lack of new production coming on-stream over the next couple of years should see prices start to increase again. The difficulty has mainly been in transportation and logistics, with additional Covid-related checks and port shutdowns causing bottlenecks, but, e.g., although urea exports from China to April, at 786,000 tonnes, were down on 2019's figure of 1.3 million tonnes for 1Q 2019, they were up on 2018's low figure of 294,000 tonnes. In their most recent results presentation, Nutrien said that because of limited new export supplies in other markets and reduced Chinese production, they foresaw relatively stable Chinese exports of between 4-5 million t/a in 2020, only slightly below last year's figure of 4.9 million t/a.

Still, some regions, especially India, South America, Western Europe and Australia, remain more dependent on imported nitrogen fertilizer and hence more vulnerable to disruptions in global trade.

Overall forecast

The impact of the Covid-19 crisis on global agriculture remains a difficult one to assess. Containment and mitigation measures taken by governments to limit the spread of the disease have already led to logistical disruptions while immigration restrictions may affect the availability of seasonal agricultural workers in e.g. Europe and North America. Outside of the immediate impact on this year's plantings, however, there are longer term worries about the severe economic crisis that several months of lockdown may impose upon global economies. While demand for staple crops tends to be more resilient, it could lead to reduced demand for higher value crops, as well as biofuels such as corn ethanol in North America and sugar ethanol in Brazil, and soybean-derived biodiesel elsewhere. A recession that significantly reduced farm incomes would affect their ability to purchase fertilizers in coming years. In a recent webinar, IFA noted that during the last global recession, caused by the 2008-09 financial crisis, global nitrogen consumption fell by 3% in the immediate aftermath, although it had returned to its pre-crisis figure within two years. Nitrogen in this respect is more resilient than potash and phosphate. Nevertheless, the potential for a similar reduction in 2020 is there. Fertilizers for spring planting seasons in North America and Europe were largely already purchased by March 2020, and Brazil's fertilizer requirements for soybean planting will not be until September, but the bulk of Asian buying is during the summer months.

Longer term, the impact on nitrogen demand will depend upon global income growth, and that in turn on how severe any economic downtown is. ■

The market for ammonia

A newly constructed refrigerated ammonia barge on the Columbia River, Washington State, USA.

PHOTO: VIGOR INDUSTRIAL LLC

Merchant ammonia capacity, only a relatively small 10% of overall ammonia demand, has been expanding in recent years and was already in surplus even before the current Covid crisis, but longer term a shortage of new projects may tighten the market again.

Global production of ammonia continues to rise. As Table 1 shows, in 2018 this reached 178 million t/a in 2018, and IFA estimates are that it rose by another 2.5% in 2019 to 182 million t/a. However, most ammonia is consumed at the point of production, in captive downstream urea, ammonium nitrate, nitric acid and ammonium phosphate production. The merchant market for ammonia totalled 20 million t/a in 2018, about 11% of global production.

While most (75%) ammonia goes towards fertilizer production, particularly urea, this figure is proportionately lower for merchant ammonia production, which is often used by industrial chemical producers for the production of, e.g., caprolactam (for fibre production), acrylonitrile, adipic acid, isocyanates (for polyurethane production), and low density (explosive grade) ammonium nitrate. Of the merchant ammonia that is used for fertilizer production, most goes to ammonium phosphate manufacture, which is centred on regions of phosphate mining like Florida, Morocco, Jordan etc, and which transports more easily portable ammonia for MAP/DAP production. A small amount is imported by urea and ammonium nitrate producers in regions with relatively high domestic gas cost which makes local ammonia production less economic, such as southern Africa.

Merchant ammonia production, conversely, tends to be in low gas cost regions with easy access to ports and overseas shipping. On a regional basis, as shown in Table 1, it can be seen that the major net importing regions continue to be North America (mainly to feed DAP production in Florida), Western Europe (for a variety of uses, often industrial/technical), South Asia (mostly to feed Indian DAP and some urea production) and East Asia (Japan, South Korea, Thailand and Taiwan are all net importers, again often for industrial/technical uses). By nation, the largest importers are India (2.7 million t/a in 2019), the US (2.5 million t/a), Morocco (1.5 million t/a), Korea (1.3 million t/a) and Turkey (1.0 million t/a). On the export side, the major volumes come from Russia (4.6 million t/a in 2019) and Trinidad (4.5 million t/a). The Arabian Gulf states (including Iran) add another 3.0 million t/a to that, and North African countries (mainly Algeria and Egypt) another 1.9 million t/a.

Changing patterns of supply and demand

The largest importers, historically, as they continue to be, are the United States and India. India is building new ammonia capacity, but this is mostly associated with downstream urea capacity, and the impact on imports for Indian DAP production is expected to be fairly small.

However, US imports of ammonia have been on a steady downward trend over the past decade as more domestic capacity is built or re-started. This has been a consequence of the shale gas boom which has dramatically reduced US gas feedstock costs, and as a consequence reversed the previous trend for US ammonia capacity to drift overseas to countries such as Trinidad. In 2012, at the peak of its import demand, the US bought 7.8 million t/a of ammonia from overseas. By 2019 this had fallen to 2.5 million t/a with the start-up

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Table 1: **World ammonia production, consumption and trade, 2018, million t/a product**

Region	Production	Export	Import	Consumption	Net imports
Western Europe	11.2	1.2	4.1	14.2	2.9
Eastern Europe	5.2	0.3	0.5	5.4	0.2
FSU	23.1	4.3	0.8	19.7	-3.5
North America	20.5	1.6	3.0	21.9	1.4
S/Central America	7.7	4.6	1.8	4.9	-2.8
Africa	9.6	2.2	2.0	9.4	-0.2
Middle East	18.4	3.7	0.9	15.6	-2.8
South Asia	18.4	0	2.9	21.2	2.9
East Asia	61.9	1.7	3.7	63.9	2.0
Oceania	1.8	0.3	0	1.7	-0.3
Total	**178.0**	**20.0**	**20.0**	**178.0**	

Source: IFA

of the 850,000 t/a Yara/BASF ammonia plant at Freeport, Texas. While most of the domestic ammonia capacity that was part of the current construction cycle has now been completed built, there are still plans for more plants further down the line. In particular, Gulf Coast Ammonia has achieved financial closure on a 1.3 million t/a standalone ammonia plant for Texas City which is due to be completed in 2023-24, and which will presumably reduce US ammonia imports still further.

Trinidad

Trinidad, conversely, is facing increasing pressure on its ammonia exports as US demand contracts. Although Trinidad remains the world's second largest exporter of ammonia, its position on the top spot has been taken by Russia in recent years, while domestic gas supply issues have hit production, reducing operating rates to below 75%. Trinidad's exports of ammonia were 4.3 million t/a in 2019, but this is down from 5.3 million t/a a few years earlier.

Gas costs have also become a major issue for Trinidadian producers. The Natural Gas Company of Trinidad and Tobago (NGC) buys gas from local gas producing companies and sells it on to downstream producers, and it has faced difficulties in price negotiations in both directions. Currently downstream producers pay around $2.00-2.50/MMBtu for natural gas, comparable with US prices. However, NGC wants this to rise to $4.00/MMBtu or more to pass more money to upstream producers and incentivise them to exploit more of the island's reserves. Coupled with the impact of the Covid-19 crisis this has led to a number of shutdowns of ammonia and methanol capacity on Trinidad recently, including two of Nutrien's four 600,000 t/a plants.

North Africa

Major changes are occurring in North Africa. In Morocco, OCP, the world's largest phosphate company, is continuing to massively increase its downstream processed phosphate production to gain a greater slice of this market. Production of extra mono- and diammonium phosphate necessitates increased imports of ammonia. Morocco imported 1.5 million t/a of ammonia in 2019. This has risen dramatically from just 270,000 tonnes in 2008, and it is set to increase by another 1.2 million t/a when the next batch of planned MAP/DAP plants come on-stream over the next few years.

Further east, Algeria and Egypt have both been building new capacity, mainly with downstream urea capacity, but some additional surplus ammonia should also be available, including 300,000 t/a from Fertial in Algeria.

China

China is in the midst of a major shakeup of its domestic fertilizer production and use as the government tries to tackle over-application of urea and consequent nitrate leaching into water courses, and air pollution caused by coal-based production of chemicals. There is also a considerable amount of structural overcapacity in most Chinese chemical sectors. Stringent new environmental legislation has closed a large tranche of Chinese ammonia capacity. Around 8 million t/a of ammonia capacity (mostly integrated into urea production) has closed since 2015, and IFA estimates that another net 7 million t/a may close over the next few years.

The Chinese government has also attempted to move to zero growth in fertilizer demand from 2020 to encourage more balanced and efficient use of nutrients. This impacts both upon ammonia demand for urea, but also for ammonium phosphate production. Ammonia demand for industrial production continues to rise, but the slowdown in the Chinese economy has also affected how fast industrial demand is rising. Overall, China has become a net importer of ammonia (about 560,000 tonnes in 2018), but this figure may rise as domestic closures mount.

Russia

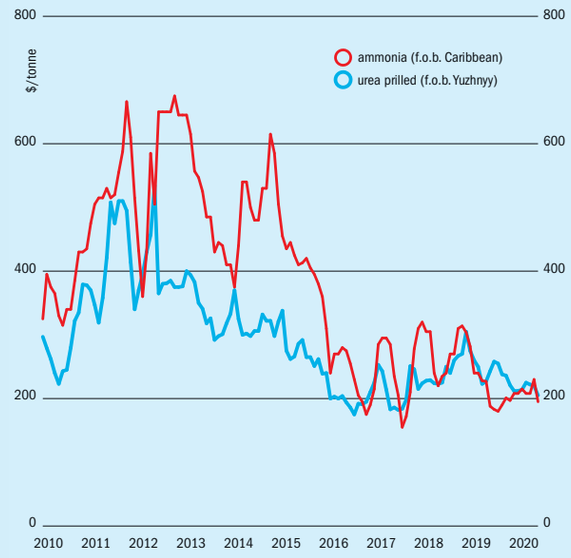
Russia has dramatically increased its exports of ammonia with the start-up of 890,000 t/a of new export-oriented capacity in the past two years at Eurochem's Kingisepp site in northwest Russia. Cheap gas and rising domestic demand for fertilizer is leading to something of a boom for Russian nitrogen production, with several major new plants under construction at Gubakha, Togliatti, Kingisepp, Novgorod and Nevynnomyssk. However, several of these are downstream urea or nitric acid plants with no associated ammonia production, and will in fact absorb some of Russia's ammonia surplus, leading to lower availability once the plants come on-stream in 2021-22.

Meanwhile, to the south Ukraine was also once a major exporter of ammonia, but the conflict in the east of the country and high gas prices have shut down much of the country's production. The export-oriented Odessa Port Plant (OPZ) has been operating only intermittently because of unpaid gas debts.

Iran

Iran exported around 850,000 t/a of ammonia in 2018, making it one of the largest exporters in the Gulf, mainly to India. However, the pull out of the US from the Iran nuclear deal and subsequent resumption of US sanctions on the country has complicated matters. China has become the main buyer of Iranian ammonia, although it is believed much of this is then re-exported. Ammonia exports from Iran are believed to have actually been slightly up in 2019, but the impact of Covid-19 on both Iran and China remains unclear at present.

Fig. 1: **Ammonia and urea prices, 2010-2020** $/tonne



Source: BCInsight

Other new capacity

Recent standalone capacity includes the 660,000 t/a Panca Amara Utama (PAU) ammonia plant in Indonesia, which began operation in 2018 and which has displaced some imports into southeast Asia. Other projected new merchant ammonia capacity over the next few years includes the new Salalah Methanol plant in Oman, which will add 330,000 t/a of capacity by 2021, and potentially some surplus from a third ammonia plant for Ma'aden at Wa'ad Al Shamal, although most of the ammonia will go to ammonium phosphate production. Furthermore, beyond these there is actually not a lot of new merchant ammonia capacity on the horizon. Morocco's OCP is in discussions with Nigeria over the potential construction of a 750,000 t/a ammonia plant in Nigeria by 2023, though there are also reportedly plans for downstream ammonium phosphate production at the site, using phosphoric acid supplied from Morocco, so the net addition to ammonia production may once again be limited.

Oversupply

The start-up during 2018-19 of three major new merchant ammonia plants added 2.4 million t/a of new ammonia to the market, equivalent to more than 20% of the usual merchant ammonia market, and has led to a period of oversupply. Lower than expected direct ammonia applications in the US last year due to bad weather and slack demand in the phosphate sector have at the same time also affected demand, and magnified the effect. Consequently, prices have fallen to historically low levels. A factor in supply of ammonia is the relative price differential between ammonia and urea prices. When ammonia prices are significantly above those for urea, producers who are capable of doing so are encouraged to shut down the urea section of their plant and sell ammonia instead. As Figure 1 shows, ammonia prices were significantly ahead of urea prices for much of the period 2010-2015, and this encouraged the construction of the standalone ammonia capacity that came onstream during 2018-19. Now however, ammonia prices are relatively low and so the incentive to produce ammonia alone is greatly diminished. This should mean that there is a market correction over the next few years as demand increases without a significant increase in supply (and, in the case of Russia and Trinidad, the potential net removal of capacity – in the former case to feed urea production, in the latter for gas price/supply reasons).

This year

The Covid-19 outbreak has naturally had an impact on the ammonia market. In particular, lockdowns in China and elsewhere have adversely affected industrial demand for ammonia in particular. At the same time, very low natural gas prices, especially in Europe, have allowed ammonia producers to kee p operating, albeit at low margins. The result is continuing weakness in the ammonia market, in spite of intermittent operating problems at Yara's 850,000 t/a ammonia plant at Pilbara in Western Australia which have taken some ammonia off the market, and the idling of some of the ammonia plants on Trinidad, as well as in Egypt and Indonesia.

As industrial production recovers in Asia, and with a better ammonia fertilizer application season in the US, the oversupply will ease, but there is still a lot of ammonia in storage that will weigh down upon pricing. Looking towards the medium-term future, and depending upon what course the Covid-19 crisis takes, more demand growth is expected for Indian and Moroccan phosphate production, industrial production in Europe as well as some Turkish nitrate and NPK production, and potentially in China to balance capacity closures. This plus the additional requirement for ammonia in Russia for urea and nitrate production will gradually absorb the ammonia surplus, but it could take a couple more lean years for the merchant ammonia market. ■

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Shchekinoazot's methanol plant, Tula Region, Russia.

PHOTO: HALDOR TOPSOE

Syngas project listing 2020

A round-up of current and proposed projects involving non-nitrogen synthesis gas derivatives, including methanol, hydrogen, synthetic/substitute natural gas (SNG) and gas- and coal to liquids (GTL/CTL) plants.

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
AUSTRALIA							
n.a.	n.a.	Coogee Chemicals	Darwin, NT	Methanol	1,000	FS	2024
BOTSWANA							
n.a.	n.a.	Botswana Oil Ltd	Dumela	CTL	2,700	P	2025
CANADA							
n.a.	Greyrock Energy	Rocky Mountain GTL	Carseland, AB	GTL	70	UC	2022
CHINA							
n.a.	Casale	Anhui Tanxin Tech Co	Hubei, Anhui	Methanol	1,500	UC	2022
n.a.	JM (DAVY™)	Ningxia Baofeng	Yinchuan, Ningxia	Methanol/MTO	6,600	C	2020
n.a.	JM (DAVY™)	Shenhua Yulin Energy	Yulin, Shaanxi	Methanol	6,120	UC	2022
n.a.	Eastman/JM (DAVY™)	Jiutai	Togtoh, Mongolia	Methanol/MEG	3,000	UC	2022
ESTONIA							
n.a.	n.a.	Larkwater	Paldiski	Methanol	5,000	FS	2023
INDIA							
Engineers India Ltd	Haldor Topose	Assam Petrochemicals	Namrup	Methanol	525	C	2020
n.a.	TechnipFMC	HPCL	Vishakhpatnam	Hydrogen	2 x 340	UC	2020
INDONESIA							
n.a.	Air Liquide	Pertamina	Balikpapan	Hydrogen	260	UC	2021
Samsung	Air Liquide	Petronas	Bintulu, Sarawak	Methanol	5,000	DE	2023
n.a.	Haldor Topsoe	Bengalon Coal to Methanol	Bengalon	Methanol	6,000	CA	2024
	Air Liquide						
IRAN							
n.a.	Haldor Topose	ME Kimia Pars	Bushehr	Methanol	5,000	C	2020
Namvaran	Haldor Topsoe	Badr-e-Shargh Pet Co	Chabahar	Methanol	5,000	UC	n.a.
PIDEC	Casale	Apadana Methanol	Assaluyeh	Methanol	5,000	UC	On hold
n.a.	Casale	Bushehr Pet Co	Assaluyeh	Methanol	5,000	UC	On hold
n.a.	Casale	Fateh Sanat Kimia	Dayyer	Methanol	5,000	UC	On hold

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
NETHERLANDS							
n.a.	Air Liquide	W2C Rotterdam	Botlek	Methanol	665	P	n.a.
MALAYSIA							
Samsung	Air Liquide	Sarawak Petchem	Sanjung Kidurong	Methanol	5,000	DE	2023
NIGERIA							
n.a.	Haldor Topsoe	Brass Fert & Petchem	Brass Island	Methanol	5,000	DE	n.a.
ROMANIA							
n.a.	n.a.	Romgaz	n.a.	Methanol	1,500	FS	n.a.
RUSSIA							
n.a.	Haldor Topsoe	Shchekinoazot	Shchekino	Methanol	1,350	C	2019
China Chengda	Haldor Topsoe	Nakhodka Fertilizer	Nakhodka	Methanol	5,400	DE	2023
MHI	Haldor Topsoe	Baltic Gas Chemical	Ust-Luga	Methanol	5,000	CA	2023
Hyundai/NIIK	Haldor Topsoe	Gaz Sintez	Vysotsk	Methanol	4,850	CA	2023
TAIF	Haldor Topsoe	Nizhnekamskneftekhim	Nizhnekamsk	Methanol	1,500	CA	n.a.
MHI	Haldor Topsoe	GTM One	Khimprom	Methanol	3,000	DE	2023
n.a.	JM (DAVY™)	JSC Technoleasing	Skovorodino	Methanol	3,000	P	2023
SAUDI ARABIA							
n.a.	Air Products	Air Products Qudra	Jubail	Hydrogen	415	UC	2023
SWEDEN							
n.a.	Haldor Topsoe	Liquid Wind	Stenungsund	Methanol	135	DE	2023
TRINIDAD AND TOBAGO							
MHI	MGC	Caribbean Gas Chemical	La Brea	Methanol	3,000	UC	2021
MHI	MGC	Caribbean Gas Chemical	La Brea	DME	300	UC	2021
n.a.	Sasol	NiQuan Energy	Pointe à Pierre	GTL	250	UC	2021
TURKMENISTAN							
Rönesans, KHI	Haldor Topsoe	Turkmengaz	Ovadan-Depe	Methanol/MTG	5,225	C	2020
Sojitz, KHI	Haldor Topsoe	Turkmengaz	Ovadan-Depe	Methanol/MTG	5,225	CA	2023
UNITED STATES							
Proman	JM (DAVY™)	Big Lake Fuels	Lake Charles, LA	Methanol/MTG	4,200	UC	n.a.
n.a.	Relocated plant	US Methanol	Charleston, WV	Methanol	480	UC	2020
Fluor	Air Liquide	YCI Methanol One	Lake Charles, LA	Methanol	4,800	UC	2020
Linde	Linde	Praxair (Linde)	St James Parish, LA	Hydrogen	425	DE	2021
n.a.	Air Liquide	Air Liquide	Las Vegas, NV	Hydrogen	30	DE	n.a.
n.a.	Air Liquide	Air Liquide	California	Hydrogen	30	DE	2022
n.a.	Primus Green Energy	Primus Green Energy	Texas	Methanol/MTG	380	FS	2022
n.a.	Haldor Topsoe	Nacero	Casa Grande, AZ	Methanol/MTG	4,800	P	n.a.
Fluor	JM (DAVY™)	South Louisiana Methanol	St James Parish, LA	Methanol	5,000	DE	On hold
JH Kelly	JM (DAVY™)	Northwest Innovation	Kalama, WA	Methanol	5,450	DE	2024
n.a.	JM (DAVY™)	Northwest Innovation	Clatskanie, OR	Methanol	2 x 5,000	DE	n.a.
KBR	JM (DAVY™)	Methanex	Geismar, LA	Methanol	5,000	DE	2024
n.a.	HTI	DS Fuels	Point Pleasant, WV	CTL	1,470	P	2023
UZBEKISTAN							
Hyundai	Haldor Topsoe/Sasol	Oltin Yo'l GTL	Shurtan	GTL	5,000	UC	2020

KEY

BE: Basic engineering
C: Completed/commissioning
CA: Contract awarded
DE: Design engineering
FS: Feasibility study
n.a.: Information not available
P: Planned/proposed
RE: Revamp
UC: Under construction
Conversion:
1 t/d of hydrogen = 464 Nm³/h
1 t/d of natural gas = 1,400 Nm³/d

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A safe man-hours milestone celebrated at site.

PHOTO: MAIRE TECNIMONT

Making construction sites safer

Nitrogen+Syngas asked some of the industry's leading EPC companies what they are doing to make construction sites safer around the world in pursuit of the goal for zero incident safety performance. Read on to find out what approaches have been taken by Maire Tecnimont Group, thyssenkrupp, Toyo Engineering Corporation and Saipem.

MAIRE TECNIMONT GROUP

An HSE driven culture

Safety, a fundamental corporate value for those working with Maire Tecnimont Group, pursues a precise objective: to prevent accidents and mitigate the impacts on the ecosystem, with the commitment to provide workplaces, services and industrial plants in compliance with legal requirements and at the highest standards of Health Safety and Environment (HSE) protection. The Group model promotes working in safety, the protection of the environment and the well-being of people, for each operating area of the company and during all phases of project execution, both in the offices and out on the 30 construction sites currently active globally.

The monitoring and improvement of the HSE Management System along with a preventative approach allows Maire Tecnimont to confirm its commitment in excellence of injuries prevention. The five-year rolling average (2013-2019) of the Lost Time Injury Frequency (LTIF) index, according to the International Association of Oil & Gas Producers (IOGP), shows that the Group's performance indicator was consistently lower than the IOGP benchmarks. Maire Tecnimont Group also develops employees' professional competences and skills as well as incident prevention training as a core strategic activity. In this regard, in 2019 alone approximately 2.6 million training hours on HSE topics were provided to employees as well as to the sub-contractors involved in the execution of projects.

Over the last three years (2017-2019), a total of more than 349 million man-hours were worked at the Group home offices and on its construction sites worldwide, out of which approximately 326 million man-hours were on sites. A record peak was registered in 2018, with more than 140 million hours worked counting both home office and sites. The fluctuation of man-hours over the years is due to the fact that many projects in the construction peak phase in 2018 were followed by the closing phase in 2019. As for records, Maire Tecnimont can boost a significant achievement on a single megaproject: 100 million safe man-hours worked were successfully reached at ADNOC's Habshan 5 gas treatment plant site in Abu Dhabi, UAE. A record-breaking achievement with no precedents at that moment in the hydrocarbons plant engineering EPC industry.

As one of the major results of the commitment to further improving an already well rooted HSE culture, Maire Tecnimont Group recently acquired the multi-site certification according to the OHSAS 18001: 2007 and ISO 14001: 2015 standards, from Bureau Veritas Italia. This important certification enhances the synergies between companies, standardising procedures and methods, optimising audit times, thus increasing the competitiveness on the market of both individual entities and the entire Group. In a nutshell, it is a new approach to certifications, resulting in an important lever to integrate companies operating in different territories and social areas. This important milestone was reached for the Group's main companies

Fig. 1: **HSE Awareness Programme**

Source: MaireTecnimont

PHOTO: MAIRE TECNIMONT

Safety tip from the Safethink campaign.

working across very different areas, from Italy's offices to those in Russia and India, and for all of its construction sites around the world. It was a three-year challenging project, for a network of companies and construction sites spread across 45 countries, and eight time zones.

The Safethink campaign

The Group's zero incident target approach was recently developed in a four-step communication campaign: Safethink. A brand-new proprietary logo was born, together with a wide set of communication tools in order to both make everyone increasingly aware of "actively thinking about safety" before acting, and to maximise Maire Tecnimont's HSE culture. The actions required involvement from both home offices and sites, as the campaign was developed on four different areas, each focusing on its own workshop and training sessions on different aspects of safety embedded in everyday working life: tools, behaviour, and the rest still to be unveiled.

With Safethink the aim is to express in a concept the basis for every single action taken, to actively think about safety and reinforcing the shared HSE identity: the safety and protection of people is not only a priority but a fundamental value in every activity and step we take on a daily basis. These messages were highlighted and further developed in Maire Tecnimont's corporate magazine Evolve, an ideal dissemination tool to further spread the importance of maximising each and everyone's HSE attitude within the Group. Involvement and participation were already visibly present during the launch event of the "first leg" of Safethink, held in July 2019 at the Milan headquarters, which was enriched by several testimonies and best practices registered both in home offices and on sites.

Furthermore, a dedicated Safethink digital platform was established to keep tight focus on these topics. In this way, the HSE team is capable of disseminating all campaign material to all of the different company sites and, above all, directly to the construction sites: offline tools, branded site equipment combined with digital ones, such as "Safety tips"(above, right) on how to make each daily activity safer and the most updated communications on the new initiative helped to boost awareness among task forces, and at the same time provided a strong common identity driver, shared with everyone. Every worker who chooses to use these tools becomes a spokesperson for the wellness and safety of the Maire Tecnimont Group, while also being a distinctive element showing customers that the "HSE branding" operation has already proven extraordinary results.

As part of the campaign, training has played an essential role to create stakeholder value, develop employees' professional skills, prevent accidents and improve health, safety and environmental awareness. This resulted in devoting several million hours to courses, spread throughout all the value chain, including subcontractors. In addition to the classroom training for all workers, the Training Lab was also conceived as a best practice hub, performing theoretical and practical training dedicated to special hazards (e.g. work at height) carried out by subcontractors. The adoption of these practices is aimed at increasing all workers' risk perception.

During the second HSE communication campaign focused on behaviour, the "Safethink Rules for Life" project was launched in all operating sites. The campaign consists of a selection of ten safety rules that the Group considers of primary importance for the prevention of accidents. The rules were not just taken from those defined by IOGP, they have been customised to reflect Maire Tecnimont's context and ad hoc pictograms have been created to emphasise the distinctiveness of the Group safety culture.

Safethinkcovid-19

In response to the spread of coronavirus Covid-19, Maire Tecnimont immediately committed itself to ensuring that all work activities in offices and on sites are carried out in compliance with the maximum health and safety standards. The clear priority was to ensure the health and safety of its employees and collaborators and their families, while guaranteeing the continuity of the business in the countries where it operates.

Maire tecnimont's teams on construction sites immediately demonstrated a proactive approach and the ability to manage all aspects right from the initial phase of the crisis, taking, when necessary, autonomous initiatives applied and tailored according to the latest advice coming from

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the WHO and other medical organisations. They have been managing the situation while also educating the subcontractors in coordination with clients for the adoption of protocols to protect workers and personnel involved in the projects.

Furthermore, a HSE Crisis Coordination Team was set up in order to coordinate the actions to be taken in the countries where the Group is present and to issue guidelines defining the behaviour to be followed by all of the workforce. Starting in February, for example, a set of Covid-related safety and remote-working policies was defined and implemented, to keep staff and workers safe. Maire Tecnimont was able to rapidly virtualise several processes and working activities, thanks to significant investments made in smart working technologies and training in the last four years.

Transport and shared spaces have been swiftly reorganised, meeting the new dynamics of smart working in sites (where activities allowed this to happen) and offices. That said, introducing and implementing all the steps in such a challenging atmosphere where people from many countries and nationalities are working together was not an easy job, particularly as this action needs to be carried out on each operating site.

In the context of a global health emergency, correct information is essential to manage the risks and to face an ever changing situation effectively. Therefore, a structured communication campaign covering all aspects of the pandemic emergency and the correct measures to be taken to conduct daily activities both in the home office and on site was promptly implemented. On an operating level, the main procedures implemented were temperature control, provision of face masks, hand sanitisers and gloves in work environments, social distancing, and ensuring exceptional attention to the health and safety of local communities. At the same time, the spin-off of the Safethink brand, "Safethinkcovid-19" was rapidly conceived and used as the new HSE brand to apply the already well-known safety campaign to the urgent situation. This clearly helped boosting involvement of all colleagues and provided sound evidence of the Management's commitment to tackling the pandemic proactively.

A dedicated digital channel was created to provide daily communication and useful information relating to the Covid-19 emergency, where every colleague can find all the communication from the relevant focal points, a complete list of documents about policies and proper behaviour to be adopted by all of the workforce, together with the latest heath information documents provided by the competent authorities. Finally, insights on how to make each daily activity safer are continuously spread to all offices and sites through the well-known channel of "Safety tips". In this way, colleagues working in remote regions were able to feel closer to their base, by remotely getting the most up to date support. This central hub is constantly monitoring the information concerning Covid-19, taking preventative measures and all necessary actions.

Specific rules and guidelines were set to provide instruction and define preventative and control measures to be implemented in all Maire Tecnimont Group Construction working sites, including joint ventures, in order to minimise and reduce the risk of exposure to Covid-19 and to update site emergency procedures. This is reinforced by identifying a Maire Tecnimont Site Focal Point, tasked with issuing a recurrent detailed update on the site's workforce. After completing a training course provided by the Group's Headquarters, each focal point is required to swiftly align with all subcontractor project managers and HSE managers to jointly implement the MT Group Action plan. Subcontractors are also required to appoint a company focal point, to ensure that measures were observed throughout the entire project execution chain.

On April 29th Maire Tecnimont held a two-day workshop bringing together 20 construction sites totaling about 33,500 people, including Maire Tecnimont's construction team and direct and indirect workers, across eight time zones from North America, Europe, Africa, Middle East and Russia to South East Asia. The Group decided to organise this sharing event to mark the World Day for Safety and Health at Work 2020, sponsored by the International Labour Organisation, and at the same time to remind every construction team of the great challenge of the Covid-19 emergency – to maintain production and operational efficiency, in full compliance with the Health, Safety and Environment regulations.

During the two-day workshop, Maire Tecnimont's top management connected with HSE site managers as well as the teams involved in the daily operations for project implementation, in order to share best practices on how staff at each site, despite the distinct circumstances of its often very remote location, were carrying out its normal daily activities, facing the current global emergency proactively and with a strong spirit of adaptation. Colleagues traded thoughts about their experience, after construction teams demonstrated the ability to absorb shocks and respond not only promptly to a constantly evolving situation, but to actively contribute with real solutions.

Closing the workshop, Maire Tecnimont CEO Pierroberto Folgiero commented: "For us the priority is to ensure the health and safety of all colleagues and their families, while we maintain full operational continuity in the four continents in which we operate, from the United States to Malaysia. In recent years, our Group has made the HSE component a clear factor of competitiveness, and today we are further demonstrating that this is not rhetoric, but a tangible value helping us face the challenges that await us in the future – together with the passion that has always distinguished us."

PHOTO: MAIRE TECNIMONT

Safethinkcovid-19 communicating rules.

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Successful project delivery during the pandemic

In such a time of extreme life conditions, people's value of collaboration, discipline and engagement have been clearly more evident than in other circumstances. Not only that, but really encouraging signs of resilience have been witnessed, coming from different project teams and parts of the world, all under the same flag: keeping up the good work, notwithstanding the challenging times we are living in. Here are some examples:

When Covid-19 broke out in Egypt, at the beginning of March, the team at the Kima Fertilizer Complex in the remote area of Aswan was preparing for a nine-day performance test ahead of a May start for ammonia production. KIMA is a joint project of two sister companies within the Maire Tecnimont Group: Tecnimont as EPC contractor and Stamicarbon as urea technology licensor.

The team faced a really hard choice, whether to complete the test in a very limited amount of time, pushing forward, working in difficult conditions as the emergency was on the verge of spiking in the country, not knowing when they would have been able to come back to their families. Meanwhile, the International airport was shut down. But leaving would have resulted in the postponement of a long-awaited performance test, placing the plant and its assets at risk.

The first order of business was to brainstorm to provide a detailed risk analysis and to identify working solutions over and above the standard safety recommendation. Once identified, they were immediately implemented. The team decided to stay on-site to achieve the long-targeted goal, which was successfully completed with the performance test on March 22, demonstrating performance better than the guaranteed, as the plant ran fully operational far above its nameplate capacity.

The real commitment and great resilience, put in place by people during the Covid-19 pandemic, resulted in outstanding achievements in terms of safety milestones reached in different countries in lockdown. Among the main milestones was the Liwa Plastics Complex–EPC2 Project in Oman, the first producer of polyethylene in the country, reached 40 million safe man-hours thanks to the effort of all relevant parties involved in the project.

Different nationalities, different languages but with a common Safethink target. ■

THYSSENKRUPP INDUSTRIAL SOLUTIONS

Safety starts in the mind

In recent years, there has been a growing awareness of the importance of Occupational Safety and Health (OSH) around the world. If a construction project is completed safely, not only is it good for a company's reputation and reflects positively on their concern for their employees, but it's also good for their bottom line: the fewer lost time incidents (LTIs) there are, the quicker a construction project will be finished.

Safety is always a top priority for thyssenkrupp Industrial Solutions, not only for its employees but for all sub-contractors working with them too. With ongoing construction mega projects in different regions, there are many people on site everyday who come from different regions, with different cultures and safety backgrounds. They are coming into contact with moving machinery, working at height or in confined spaces, lifting heavy materials and handling electrical tools, all whilst wearing personal protective equipment.

Zero accidents goal

thyssenkrupp Industrial Solutions is coming closer to the goal of zero accidents at work by focusing on three pillars of OSH: internal safety management systems, monitoring of activities, and measures to heighten safety awareness levels amongst its own employees and contracted personnel. State-of-the-art OSH management systems help to minimise the risk of accidents at work.

Strict, regular monitoring of procedures and systems helps thyssenkrupp Industrial Solutions to evaluate how well they are working. Yet all that would be ineffective if people did not behave correctly. So a key focus of the OSH teams' work is on behaviour: enhancing safety awareness levels; changing perceptions of safety for the better; promoting relevant soft skills; and ensuring everybody speaks the same safety language.

Focus on behaviour

No matter how strong OSH management is, there is always one unpredictabl e component: human behaviour. In real life, around 90% of accidents are triggered by unsafe behaviour. That is why thyssenkrupp Industrial Solutions has developed a Behavioural Based Safety (BBS) program to positively influence safety-related behaviour. The BBS program focuses on four main pillars: pinpointing desired behaviour through means such as management staff leading by example, and pinpointing undesired behaviour by means of mandatory procedures and regulations; measuring progress using predetermined criteria that record behaviour, detect gains and recommend room for improvement; feedback involving everyone acting responsibly towards coworkers, intervening to stop unsafe actions, and discussing the potential risks; heightening awareness of the consequences to avoid negative ones and encourage positive ones.

OSH e-learning module

One of the challenges for a company that operates globally like thyssenkrupp Industrial Solutions is communicating key OSH messages to the entire workforce in a wide variety of industries worldwide. An e-learning module developed collaboratively by teams from OSH and Construction went online at the end of May 2017 and uses state-of-the-art learning techniques to solve this problem. Within an hour, all employees who visit or work at construction sites – everyone from new recruits to top management – can learn all about their roles and responsibilities in OSH, what procedures and tools exist, how incidents should be reported, where the main hazards lie, and how BBS works in practice. And they can do that at any time and in any place worldwide. One highlight of the module is a new assessment tool that makes use of cartoon pictures to help the e-learner spot unsafe behaviour at a construction site.

The BBS program and OSH module are helping to raise safety awareness and achieving the zero accident goal – with all the associated benefits for both the company and its customers, as well as the families and friends who look forward to their loved ones coming home from work safe and sound.

PHOTO: TKIS

Images (from top to bottom): Panoramic view of the Safety Park, electrical safety module, ladder safety module, and hoist crane module.

Safety Park

In order to train and educate all workers properly how to work safely, thyssenkrupp Industrial Solutions decided to invest more in training by adopting the Safety Park training concept as part of their site safety induction training programme. The induction programme includes both theoretical and practical elements that take place at the Safety Park.

thyssenkrupp Industrial Solutions started with implementation of the concept in two mega plants located in Brunei and Hungary.

All personnel related to a project are required to go through full safety training (induction training) before they start work on site. The Safety Park takes a unique format in that all personnel engage in simulations reflecting real life hazardous situations and conditions, where they can experience the risk and feel the consequences. In this way, they learn how to avoid these circumstances in an interactive, hands-on way, removing language barriers in the process. Feedback from workers and staff has been really positive; everyone is enjoying the experience and the safety message is remembered and understood.

The Safety Park at construction site covers many modules, each focusing on a different construction safety aspect: crushed by machinery safety simulator, confined space training, handrail and scaffolding collapse simulator, safety harness simulator, safety helmet/boots impact simulator, electrical safety simulator, hoist crane experience, A-type ladder experience and other modules. All simulations are conducted with the utmost care and are carried out under the watchful eye of fully trained health and safety personnel. ■

PHOTO: TKIS

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SAIPEM

Building a strong HSE management system

Making a construction site safer is not a matter of a single solution, but rather, like a very good cocktail, it is made by an effective and scientifically tested mix of various ingredients. With this view, to achieve the zero incident goal it is necessary to build a strong HSE management system commencing from planning and continuing through to the review phase, to properly assess all risks, eliminate those that are avoidable, implement the necessary control and prevention measures and to openly check if they have been effective or identify if further actions are necessary.

All of these concepts have been deeply embedded in the reference international ISO Standards for many years, so why are they not enough to reduce accidents to zero? In Saipem's experience there are some factors that are particularly important. The competencies and training efficacy, the capability of the organisation to collect and analyse data, a strong management system, preparedness in case of foreseen and unforeseen situations and, the safety culture of both the organisation and of the clients and subcontractors in the country in which the activity is performed appear to have the greatest impact on the ability to achieve the zero accidents goal.

Digging deeper into the aspect of training and competency, it is well known that due to communication and technical issues, providing effective training is not an easy task. However, past experience has demonstrated that offering trainers a dedicated 'train the trainer' (TTT) pathway and the provision of comprehensible and standardised materials in multiple languages that use a modern graphical approach has been effective.

Closing the gap related to competencies presents a greater challenge. This is attributed to the fact that technical, HSE and soft skills are different within different roles. It is only through a strong Competence Assessment and Assurance Program that begins at the hiring phase and continues through the entire working life of an individual that it can be assured that the right person has been assigned for each job and in doing so increase the level of safety of worksites.

While the issue of data collection and analysis could appear to be a trivial issue, Saipem has made significant investment in resources to strengthen its systems. Borrowing from a motto that is familiar in the world of finance – 'cash is king', Saipem recognises that 'data is king' and must be effectively collected, managed and analysed to identify any opportunities or weaknesses in the business. Through the examination of past data, incidents investigations, audits, inspection hazard observation cards, training trends and completeness, competency assessment results etc. Saipem is able to quickly and efficiently identify where the company must address its efforts and anticipate undesired events.

It is important to embrace the digital transformation to enhance systems and explore all innovative solutions that are already available in the industry as well as others, e.g. RFID, anti-collision systems, smart cameras, tags etc. These systems can of course present a substantial financial investment so it is imperative that contractors have strong, supportive, and sharing relationships with their clients as it is they who can be the real driver to effect this change.

HSE management systems, relevant procedures, definition of roles and responsibility etc. is perceived within many organisations as being unnecessarily bureaucratic. However, if these elements are properly structured and written they form the foundations of effective safety management in any activity. It is of paramount importance to set out what must be done and who is responsible so that these systems can be continuously optimised through application of the system itself.

The current Covid-19 pandemic presents an excellent example of the need to be prepared for both foreseen and unforeseen events. Saipem has a complete and robust set of procedures that allow it to effectively manage a crisis such as this one, yet which is also flexible enough to enable it to respond to other types of crisis without affecting its ability to act and react. Undertaking drills and exercises that test the efficacy of these systems is vital to ensure that to ensure that Saipem is ready and able to respond efficiently to these situations.

Industry has and continues to make numerous steps forward to ensure safety at work, drastically reducing the number of accidents that occur. However, due to the human factor, studies show a constant value – a "safety plateau", that seems impossible to reduce. It is therefore the culture, the behaviour and habits that are consolidated in the workplace that must be changed if the goal of zero accidents is to be achieved. It is unlikely that the systems and controls mentioned here will be implemented effectively unless they are supported by a clear vision, shared and adopted by every employee to achieve the ultimate goal of zero accidents.

But how do we arrive at a strong culture where the number one priority of everybody within an organisation is aligned with the same values and ethics in relation to safety? Robust safety cultures do not just emerge by accident! They require strong, visible leadership from those in positions of influence who demonstrate a relentless dedication to shaping the ideas, behaviours and actions of the people who operate within an organisation.

Sadly, sometimes business leaders lead with the success of their business as their primary and indeed their only focus, possibly to the detriment of safety, even though the two concepts are not mutually exclusive. Companies that possess a strong culture of safety are not only safer, they also perform financially more effectively. Businesses that understand, adopt, and internalise these ideals recognise that there really is no conflict between safety and efficiency. This concept has been fundamental for Saipem and it is embedded in the organisational health and safety vision. A "leadership in health & safety" strategy is highly recommended to be implemented in any organisation willing to shape a stronger safety culture and reach a zero accidents target. For this reason, in 2010 Saipem created the LHS (Leadership in Health & Safety) Foundation, a not-for-profit organisation, with the mission to help both industry and society in the attempt to raise the levels of safety culture, through leadership and unconventional communication media.

In conclusion, returning to the opening comment, to create a good cocktail requires quality ingredients, knowledge of the quantities that need to be mixed and how to incorporate them together, a dash of creativity and, in the case of achieving zero accidents, a lot of love for safety! ■

TOYO ENGINEERING CORPORATION (TOYO)

Improving safety with digital technology

The big wave of digital transformation that is spreading rapidly worldwide is also affecting construction sites in the EPC contracting industry and a digital technology approach to safety is also expected. Some of the ways in which TOYO is embracing this new approach are highlighted below:

- smartphone;
- digital signage;
- AI speaker.

Smartphone

TOYO has been working continuously to apply Health Safety Security and Environment (HSSE) efficiently for TOYO's workers at construction sites. The standard HSSE procedure was developed based on past knowledge and experiences, but the procedure was based on a traditional paper based route. A new paperless procedure was needed for the future.

TOYO's first response was to use Microsoft Power Apps, a standard tool for creating new applications that could be used easily without any special skills to develop a paperless solution. This can facilitate TOYO's dynamic culture change, switching to paperless work flow at construction sites.

As a first step, TOYO has recently developed a new application named BBO (Behaviour Based Observation) Report Application as shown in Fig. 1.

This application has been developed to completely eliminate the paperwork associated with reporting near miss accident reports at construction sites. Previously, BBO reports were submitted in a paper format by workers, supervisors and site personnel, and consolidated in Microsoft Excel spreadsheets by a data entry clerk. The task took a long time to complete and on occasions there were unexpected input errors.

The new app has features which allows users to take photos and input information from a dropdown list using a smartphone, tablet and/or laptop etc. The information is then submitted directly to a database. The information stored in the database is analysed by Microsoft Power BI, which is a business analytic service by Microsoft, so that anyone at the site can check event trends and also utilise them for HSE flash reports, weekly reports, safety awareness posters, and so on.

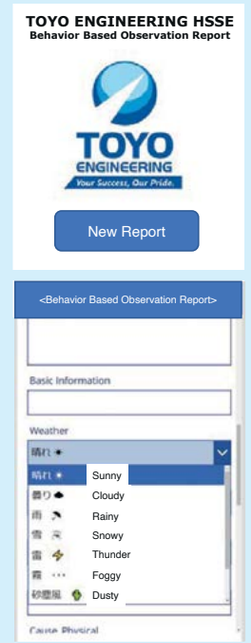
TOYO is also making use of several other apps at sites e.g. to request personal protective equipment (PPE), for transportation, and to input timesheets, amongst others. There is even an app for lunch boxes/midnight snacks, which allows construction site staff to make their requests from anywhere, making life more comfortable for everyone on the construction site, which has a positive effect on human health and good performance of daily tasks (see Fig. 2).

This application targets 500+ TOYO directly employed members of staff and has resulted in three unexpected positive results:

- an accurate log from users (staff) during working hours automatically
- time savings for both the applicant and administration
- prevents submissions and actions from being overlooked.

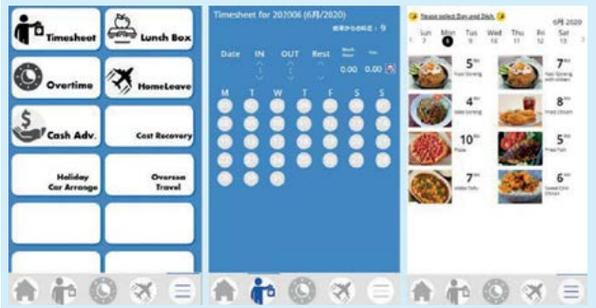
Switching from a paper based system to the new paperless app based system has provided an easy and timely method of collecting the data of field activities and behaviour which can be utilised for preventative measure for HSE. TOYO is now recommending the paperless system for all construction sites.

Fig. 1: **Main display of BBO report app**



Source: TOYO

Fig. 2: **Main display of new application for site life**



Source: TOYO

Digital signage

Throughout its EPC projects TOYO has always recognised the truth and importance of the proverbs "seeing is believing" and "one picture is worth a thousand words". Learning from these proverbs is highly effective, however, recently more optical tools, such as movies or videos, are being used in place of still images.

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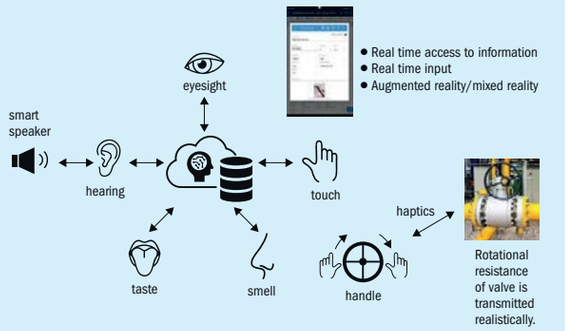
This trend is evident not only in construction sites but also in several situations where people need to deliver and visualise their message more clearly. Utilising better visual tools also has an important and positive impact in terms of Health, Safety, Security and Environment (HSSE) management for all of involved staff and workers at EPC construction sites.

Recently, to meet HSSE requirements, TOYO launched using an electrical display, so-called digital signage, at a construction site in Japan. This digital signage showed the important HSSE information that needed to be announced to all members in a daily morning toolbox meeting. At times it displayed construction progress with drone aerial video; it alerted staff and workers to prevent personnel from entering restricted areas by showing a map; and it announced major activities or site events such as heavy lifting, power receiving, steam blowing, or VIP visits (see photo, left).

PHOTO: TOYO

Daily toolbox meeting using digital signage.

Fig. 3: **Smart speaker concept at sites**



Source: TOYO

The digital signage allows all information to be shown effectively in a visible digital manner. In the conventional style of toolbox meeting, messages were delivered via a voice message only. Considering the translation issue into various languages for all involved persons, e.g. Japanese, English, Bangladeshi, Malaysian, Singaporean or Chinese, it was quite difficult to provide a clear message in some cases. Visualisation using digital signage can address some of these concerns and is a more effective way to provide information to members. In the near future, TOYO also plans to use projection mapping to make messages even more powerful and to keep all members at the site safe using good communication.

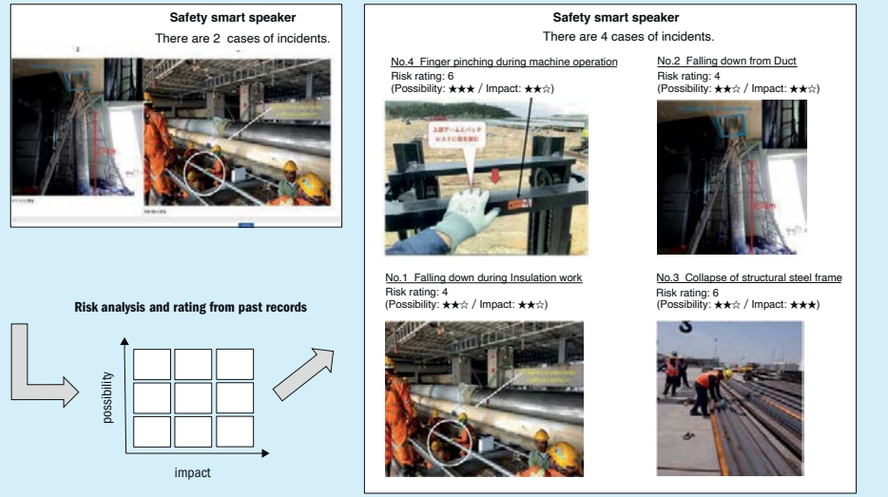
AI speaker (Safety Smart Speaker)

Due to the evolution of the Internet of Things (IoT) and artificial intelligence (AI), various ICT solutions that handle the five senses of human beings have been introduced in the industry. Especially at construction sites, speaking to a smart speaker is considered an effective way to enable hands-free operation. It is important for safety that construction crew can receive information without picking up paper, documents, or mobile phones. In addition, voice recognition is easy to achieve for construction crew. The concept of using smart speakers at sites is shown in Fig. 3.

In 2020, TOYO built a prototype Safety Smart Speaker. When users say some keywords into the speaker, the speaker gives alerts/reminders to users by showing past incident cases with appropriate safety measures that are highly relevant to the keywords. The Safety Smart Speaker not only displays the information but also provides a voice reading of incident cases. The smart speaker technology was introduced by NSE (Nippon Steel Engineering), which has a comprehensive collaboration agreement with TOYO. Currently, the screen for past incident cases is being improved further and the search result will be listed with a risk ranking (See Fig. 4).

This smart speaker can be applied as follows:

Fig. 4: **New screen for proposed safety smart speaker**



Source: TOYO

- At the safety training centre: Instead of reading a tough paper bulletin, workers can easily increase safety awareness by talking to a Safety Smart Speaker and getting a reply.
- For regular inspection: Not only for safety, the Safety Smart Speaker can also be utilised for regular inspection. The inspectors hold inspection tools in their hands. Where paper checklists are used, the inspectors need to stop working and hold the paper checklist. The Safety Smart Speaker provides a voice checklist which is hands free.
- Receiving feedback from site: To activate site safety awareness, not only giving workers past incident information, feedback input from workers is effective.

TOYO will soon introduce Safety Smart Speakers as standard in the settings mentioned above. Furthermore, TOYO will develop ICT solutions that fosters safety culture by appealing to the five senses of human beings. ■

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Process gas boilers with bypass for steam methane reformers

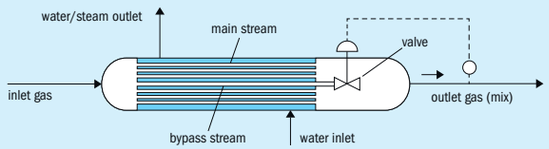
Process gas boilers with an internal bypass system are an important type of shell-and-tube heat exchanger installed in steam methane reforming units. For decades, two traditional designs have dominated the market: the "hot" and "cold" bypass process gas boiler. Today, a third option based on a new design concept is available: the "bayonet" bypass process gas boiler, with process and mechanical features that can provide superior performance, lower opex and improved reliability. **G. Manenti** of Alfa Laval Olmi SpA discusses the design and operating principles of the different designs.

Process gas boilers are a special type of shell-and-tube heat exchanger installed in hydrogen, ammonia and methanol plants for cooling hot process gas discharged from steam methane reforming (SMR) units. For instance, process gas boilers installed in ammonia plants receive the gas at 950-1,050°C and 3-4 MPa(a) and cool it down to 350-550°C by means of high-pressure boiling water. Due to the severe operating conditions and demanding process performance, process gas boilers are critical equipment for SMR units.

Frequently, control of the process gas temperature at the process gas boiler outlet is an essential requirement: the process gas boiler must be designed so that, at different operating loads and/or fouling levels, the outlet gas temperature is kept at a target value. Boilers are then equipped with a bypass system, mostly installed inside the boiler body. Conceptually, the hot process gas flowing in the process gas boiler is split into main and bypass streams (Fig. 1). The main stream exchanges a large amount of heat with the cooling boiling water and is therefore cooled down; on the contrary, the bypass stream has a reduced or negligible heat exchange and therefore it is only partially or marginally cooled. The two streams, at different temperatures, are then recombined before leaving the process gas boiler. Since the flow rate of the two streams is regulated by means of an internal valve(s) assembly, the overall heat exchange across the process gas boiler can be controlled. The internal regulating assembly, comprising moving parts, make process gas boilers in effect a singular heat exchanger.

Today, two state-of-the-art technologies for process gas boilers with internal bypass are available: the so-called "hot" and "cold" bypass. Both technologies have been used for decades and have proved to be reliable and effective; yet, each one suffers from specific limitations as well.

Fig. 1: **Control of process gas temperature at process gas boiler outlet**



Source: Alfa Laval Olmi

The "hot" bypass dates back to the 1960s[1]. It comprises a single large pipe installed in the tube bundle, a regulating valve(s) assembly installed in the outlet channel and an external actuator (Fig. 2). The pipe is internally insulated to protect it from overheating; the bypass valve is installed at the outlet of the pipe. The bypass pipe carries the hot gas from the inlet directly to the outlet channel with negligible heat transfer. As a result, the bypassed gas discharged into the outlet channel, through the bypass valve, is hot. This leads to some advantages:

- A limited bypass flow rate (10% to 20% max) is necessary to control the final gas outlet temperature. The bypass system is inherently designed to carry a limited gas flow rate, therefore overheating due to inadvertent bypass opening is mitigated or avoided.
- Hot metal parts in direct contact with bypassed gas are inherently protected from carburisation since the gas temperature falls outside of the upper limit of the Boudouard reaction range.

However, bypassed gas impinges on the valve assembly at high temperature. Continuous research on high nickel alloys and surface treatments are aimed at mitigating aging and extending the design life of the valve.

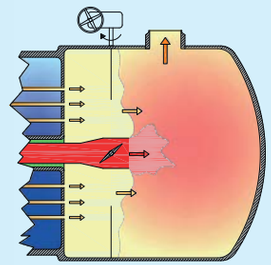
The "cold" bypass first appeared in the 1990s[2] and is based on operating principles which are the reverse of the "hot" bypass. The "cold" bypass system comprises a bundle of bypass exchanging tubes concentrically arranged around the main exchanging tubes, a bypass valve(s) assembly installed in the outlet channel and an external actuator (Fig. 3). The bypass valve is installed at the outlet of the bypass tubes. The bypass tubes exchange a significant portion of heat duty (minimum approx. 10%) with boiling water; however, the bypass tubes have a larger diameter than the main tubes and therefore the former has a reduced heat transfer rate compared to the latter. As a result, there are some benefits:

- The bypassed gas is discharged into the outlet channel, through the bypass valve, at low temperature (for instance, 370°C-430°C). The valve(s) assembly in the outlet channel then works in cold conditions; aging is avoided, design life of components is extended.
- Hot metal parts in direct contact with bypassed gas are inherently protected from carburisation since the gas temperature falls outside the lower limit of the Boudouard reaction range.

On the other hand, the low temperature of the bypassed gas imposes a large bypass flow rate to fulfil the required control range of gas outlet temperatures; consequently, the "cold" bypass system is inherently designed to carry a large gas flow rate (>50%). This design feature represents an operating and safety concern since inadvertent bypass opening/closing can lead to overheating and corrosion. On-site adjustment of the bypass range, according to operating conditions, is therefore necessary.

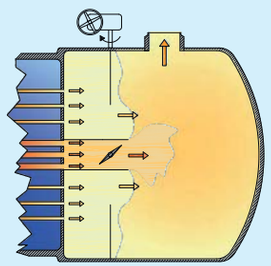
Figs 4(a) and 4(b) show typical temperature flow rate profiles for "hot" and "cold" bypass process gas boilers respectively, for an equal tube length and heat duty. These profiles are like a fingerprint of the two designs.

Fig. 2: **Hot bypass**



Source: Alfa Laval Olmi

Fig. 3: **Cold bypass**



Source: Alfa Laval Olmi

Process gas boiler technology

The "cold" bypass has been widely adopted among process gas boilers for hydrogen production units, whereas the older "hot" bypass is still the preferred technology for ammonia and methanol plants. Besides the operating principles and pros and cons of the different designs already mentioned, technology uptake depends on having a relevant mechanical design and technical commercial competitiveness. The main and bypass exchanging tubes installed in the "cold" bypass process gas boiler work at different thermal mechanical conditions; such conditions may also vary significantly due to the large bypass flow rate range. It should be noted that the bypass exchanging tubes are thicker than the main exchanging tubes. This leads to differential and variable thermal mechanical stresses during operation of the "cold" bypass design; as a result, stresses along the tubesheet radius are not uniform and steady, and the flatness of the tubesheet is questionable. On the contrary, the bypass pipe installed in the "hot" bypass process gas boiler works, regardless of the bypassed gas flow rate and temperature, at practically constant thermal and mechanical conditions, comparable to the boiler shell ones. The bypass pipe is large (min. DN 150) and therefore inherently thick; it is connected to the tubesheet by a specific welding joint, usually of butt-end type. On the other hand, its internal insulation has a complex design, and maintenance and inspection are time consuming.

Water-side pressure and inlet gas temperature and pressure can be considered major parameters for selecting technology. For the "cold" bypass design, the higher the water pressure, the thicker the bypass exchanging tubes; and the higher the process gas heat transfer coefficient, the larger the differential thermal mechanical conditions between the bypass and main exchanging tubes. This means that for severe operating conditions, typical of ammonia and methanol process gas boilers, the "cold" bypass is conceptually more critical and challenging from a thermal mechanical standpoint. Conversely, the "hot" bypass design is largely unaffected by pressures, temperatures, and SMR unit type; although, it should be mentioned that the maximum size of the "hot" bypass pipe could make it prohibitive for large capacity SMR units.

A new process gas boiler

As a key item of high-level equipment, process gas boilers are subject to continuous technological improvements and research. Carburisation resistant alloys represent a major field of academic and industrial research. Also, on-line monitoring and digitalisation have recently raised technological interest. However, base R&D is always aimed at improving current technological solutions for heat transfer and thermal mechanical design.

Recently, a new design of process gas boiler for SMR units was proposed by Alfa Laval Olmi SpA, named the "bayonet" bypass process gas boiler. The new boiler is the first new conceptual design in more than 25 years and brings to the market a third option besides the "hot" and "cold" designs. The "bayonet" bypass system (Fig. 5) comprises tubular bayonets inserted into the exchanging tubes from the rear end, a bypass box which connect to the bayonets, with a valve(s) assembly installed in the outlet channel, and an external actuator. The operating principle is totally different from the "hot" and "cold" bypass:

- The total amount of hot process gas is pre-cooled in the first portion of the tube bundle, then, at the bayonet tip, the gas is split into a main stream (or annulus flow – flowing in the annulus formed in between the tube and bayonet) and a bypass stream (or bayonet flow – flowing in the bayonet).
- The annulus flow provides substantial cooling along the remaining portion of the bundle since it is in direct contact with the cold tube wall, whereas the bayonet flow has limited heat transfer.

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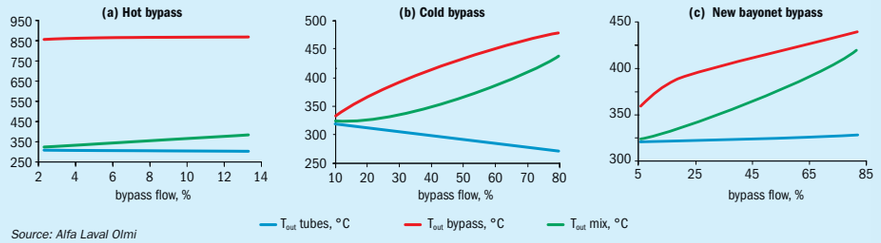
Fig. 4: **Typical temperature flow rate profiles**



Source: Alfa Laval Olmi

- The hotter bayonet flow is discharged into the outlet channel, through the bypass box and valve, and is then recombined with the colder annulus flow.

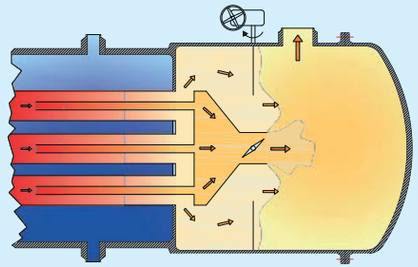
The characteristic temperature flow rate profile is shown in Fig. 4(c), for a boiler of the same tube length and heat duty as in Figs 4(a) and 4(b).

From a conceptual viewpoint, the "bayonet" bypass behaves like a "cold" bypass, and therefore it inherits its relevant pros and cons. The bypassed gas is subject to an extensive heat transfer and therefore is discharged into the outlet channel at low temperature (for instance, 370-410°C): the bypass box and valve assembly in the outlet channel work at a low temperature, with the bayonet tip being the hottest part of the bypass system. On the other hand, the bypass system is also inherently designed to carry a large gas flow (>50%), and this leads to concerns and requires bypass adjustment as previously described. However, the new process gas boiler has additional important process and mechanical benefits:

- The gas flow rate at the tube inlets is unaffected by the bypass opening: the inlet heat flux is unaffected and the inlet thermal hydraulics are inherently steady.
- The process gas boiler is somewhat less sensitive to inadvertent bypass opening: the risk of downstream overheating is mitigated.
- The gas flowing in the annulus has a notable higher velocity (min. 150% higher) than the corresponding gas flowing in the traditional "hot" and "cold" designs, and this results in a threefold advantage:
  - heat transfer rate is boosted in the portion of the boiler bundle where, typically, transfer rate is poor (low velocity portion);
  - risk of fouling deposition is mitigated or eliminated where there are bayonets;
  - option to use exchanging tubes of larger OD, to reduce the number of tubes.
- All exchanging tubes have equal geometry and thermal mechanical working conditions, therefore:
  - stresses along tubesheet radius are uniform and invariant to bypass opening, therefore the tubesheet stays intrinsically flat,
  - severe operating conditions, like high water pressure, do not affect the mechanical design of the bypass system,
  - tube-to-tubesheet welds are equal and have same operating conditions,
  - inlet ferrules are identical.

The installation of the bayonet into a portion of the exchanging tube has a turbocharging effect: the overall heat transfer performance is enhanced, and the process gas boiler exchanging area can be reduced by 10-25% compared to a traditional design. For a small gas-to-water temperature pinch point, the turbocharging can be very effective in reducing the tube length. Of course, the turbocharging has a cost in terms of gas pressure drop: the higher the allowable pressure drop, the more competitive the "bayonet" bypass.

Fig. 5: **Bayonet bypass**



Source: Alfa Laval Olmi

Again, the mechanical design and manufacturing layout of pressure parts are remarkably simpler and more robust than traditional the "hot" and "cold" designs thanks to the uniform bundle. The bypass system is constituted of internals only and is not subject to pressure vessel code or NoBo; the bayonet bypass is just inserted into the process gas boiler body once the pressure parts are completed. For maintenance or inspection of the bypass system, a manhole or a channel cover can be selected according to the client or end user's preference.

The new bayonet bypass process gas boiler design offers process and mechanical features which may lead to superior performance, lower opex and improved reliability. Thanks to its experience and know-how, Alfa Laval Olmi SpA is in the position to design and supply all three process gas boiler types depending on clients' requirements, preferences and affordability. ■

References

1. US Patent No. 3199577 (1965).
2. European Patent No. 0617230 (1998).

Lean duplex improving on-stream times

Many fertilizers plants are looking to reduce the overall maintenance costs of their critical heat exchangers. **Barinder J. S. Ghai** of Sandvik Materials Technology takes a look at the life cycle costs of tube materials for heat exchangers in ammonia plants.

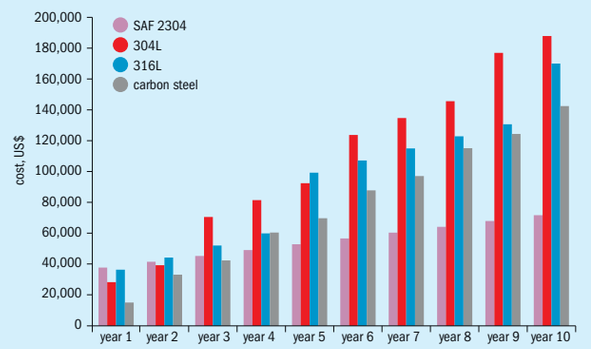
It is no secret that huge amounts of money are spent every year on the replacement of materials which corrode in ammonia plants. The extent of corrosion varies depending on numerous factors. One way of dealing with this problem is to control the process parameters, which is an ongoing process. An alternative solution is to replace the materials that are failing with more corrosion resistance alloys. When selecting alternative materials of construction, both material cost and life of the equipment need to be considered.

Heat exchangers, e.g. waste heat recovery boilers, shift conversion heat exchangers, lean amine coolers, carbon dioxide stripper overhead condensers, compressor inter-stage coolers, ammonia condensers, convertor effluent coolers etc. play a vital role in the ammonia production process. The tubes used in heat exchangers constitute more than 60% of the cost of these heat exchangers. Any premature failures of the tubes can lead to loss of production, higher maintenance and replacement costs and, not least, safety risks.

The most commonly used materials for heat exchangers in ammonia plants are carbon steel followed by 304L stainless steel. While duplex stainless steel has been used extensively in many chemical plants due to its superior properties, its initial investment cost has been a major obstacle to replacing traditional materials in ammonia plants.

The cost of lean duplex stainless steel, however, falls between low cost carbon steels and austenitic stainless steels and the more expensive and highly alloyed steels, making it an attractive solution for lowering maintenance costs and reducing tube replacement frequency e.g. in plants where heat exchangers with low alloys such as carbon steel have to be re-tubed every two to four years.

Fig. 1: **Life cycle cost analysis of SAF 2304™**



Source: Sandvik

Sandvik's SAF 2304™ lean duplex stainless steel was developed as a cost effective solution for various industries, including refining and petrochemicals, but is particularly suitable for applications in ammonia plants. Thanks to its dual phase (50% austenitic and 50% ferrite), it also possesses very high mechanical strength. When replacing carbon steel tubes with duplex tubes, the wall thickness is reduced because corrosion allowance is no longer needed. Wall thickness reduction is also possible compared to 304L and 316L.

The initial cost for carbon steel/304L tubes is cheaper compared with SAF 2304™, however SAF 2304™ outperforms these materials in the long term, subject to no re-tubing and no maintenance or replacement costs. Fig. 1 shows the life cycle cost of SAF 2304™ compared to 304L, 316L and carbon steel over a ten year period.

Chloride-containing water is one of the most common causes of corrosion in heat exchangers. Depending on the level of chlorides and the temperature, this can lead to stress corrosion cracking, pitting corrosion and/or crevice corrosion. Resistance to pitting and crevice corrosion largely depends on the amount of chromium, nitrogen and molybdenum in the material of construction. Here, due to its high chromium and nitrogen contents, lean duplex performs much better than carbon steels and 304L.

As for all duplex stainless steel, SAF 2304™ exhibits a high resistance towards chloride-induced stress corrosion cracking, performing much better than 304L and 316L.

Sandvik SAF 2304 duplex heat exchanger tubes have been installed, amongst others, in an ammonia plant in India where they have been successfully in service for more than 12 years. ■

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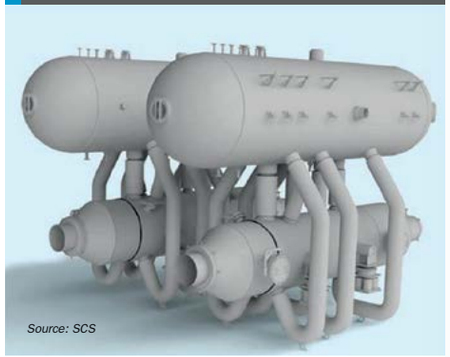
Impact of heat recovery arrangement on package reliability

Dr M. Olbricht and **Dr J. Weidenfeller** of Schmidtsche Schack I ARVOS (SCS) discuss the impact of the heat recovery equipment arrangement in an ammonia plant downstream of the secondary reformer on reliable boiler operation. A detailed investigation was performed by SCS in response to an operator experiencing difficulties in maintaining water quality in this critical equipment. Water quality has a crucial impact on the lifetime and reliability of the equipment.

Fig. 1: **Recommended heat recovery package arrangement**

Source: SCS

Fig. 2: **Process gas cooler customer arrangement**



Source: SCS

The economic viability and process efficiency of an ammonia plant strongly depends on the reliability of the heat recovery system downstream of the secondary reformer for high pressure steam generation for the overall plant steam system. This heat recovery equipment typically consists of a process gas cooler and a steam drum operating in natural circulation. To increase the efficiency a steam super heater is integrated downstream of the process gas cooler. To benefit from the economy of scale, ammonia plants with capacities greater than 5,000 t/d have a parallel process gas cooler arrangement downstream of the secondary reformer.

The case presented here describes such a parallel arrangement. Schmidtsche Schack I ARVOS (SCS) as designer and fabricator of the process gas coolers was requested for support by a plant operator due to difficulties in maintaining the water quality and water level of each steam drum of both process gas coolers. Since the water quality has a crucial impact on the lifetime and reliability of this critical equipment a detailed investigation was performed by SCS.

Heat recovery package arrangement

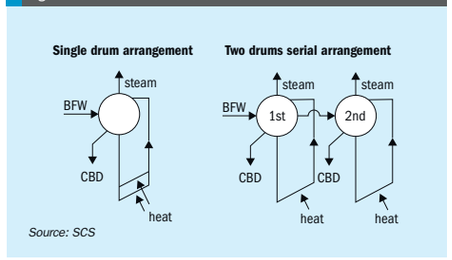
SCS recommended arrangement

For a typical waste heat boiler package for two parallel ammonia trains SCS recommends an arrangement consisting of one process gas cooler and one steam super heater per train. Both process gas coolers are connected to a common steam drum as shown in Fig. 1. An arrangement with two individual steam drums, one per process gas cooler, is also possible. In that case, SCS recommends an individual boiler feed water supply for each steam drum. The process gas coolers work as natural circulation boilers which means that the water circulation between process gas cooler and steam drum is driven by gravity only and no additional pump is needed. This proven, robust design saves investment and operational costs and leads to a reduced maintenance effort. The steam superheater is either designed as a U-tube heat exchanger or bayonet tube heat exchanger, depending on the particular process conditions and customer demand.

Fig. 3: **Water steam separation in the steam drum**

Source: SCS

Fig. 4: **Schematic view of the simulation models**



Source: SCS

Customer arrangement

The set-up at the customer site is shown in Fig. 2, whereas SCS provided two process gas coolers and two steam drums. In contrast to the above mentioned recommendations the final set-up was realised based on the plant operator's philosophy. The focus was on further cost reduction and therefore both steam drums were serially connected to the single boiler feed water (BFW) line. As a consequence, the boiler feed water flows through the first steam drum before it enters the second one. The assumption of this setup was that it behaves similar to a single drum thereby reducing the total instrumentation cost. Only one drum was originally equipped with sensors because equal process conditions were assumed for both drums due to the direct hydraulic connection. However, the operator observed different water levels in the steam drums and reported problems with water quality which was shown by an insufficient pH value. Water quality is a critical issue in boiler operation and has a huge impact on lifetime. The wrong chemical conditions in the boiler water can cause serious corrosion of the equipment even over a short period of operation.

Water quality and composition during operation

The quality of the steam and boiler water is set up in the steam drum. The water steam mixture generated in the process gas cooler is separated into liquid water, which is utilised again in the process gas cooler, and high quality saturated steam, which is provided to the downstream equipment. This process is illustrated in Fig. 3. Both the quality of the water and the steam is maintained by the addition of chemical additives to the boiler water in the steam drum. The pH value of the water is an important indicator for water quality and is adjusted by additives within a narrow range to ensure a long lifetime. Thus, it is crucial to frequently monitor the additive concentration and pH value in the boiler water. This is even more important for non-volatile components in the boiler water because these can be easily enriched in the boiler water by steam production. Besides the amount of chemicals that are added, the concentration of additives in the boiler water can also be controlled by the continuous blowdown (CBD). The continuous blowdown is a small mass flow of liquid boiler water which is drained from the steam drum. A typical range for the continuous blowdown is 1 to 2% of the steam mass flow that is produced by the process gas cooler. Correct continuous control for good water quality is mandatory to ensure long lifetime of the boiler and to protect the entire water steam system from corrosion damage. A high mass flow of the continuous blowdown has a negative effect on overall steam production.

To support the plant operator in this water quality related issue SCS simulated the water steam system of the entire heat recovery package to identify critical operation conditions. This involved individually analysing the water composition in every apparatus. A schematic view of the models used for the simulation is shown in Fig. 4. The boiler arrangement consisting of two process gas coolers with a common steam drum as recommended by SCS is illustrated on the left hand side. The arrangement at plant operator site consisting of two process gas coolers with two serially connected steam drums is shown on the right side. The simulation focuses on the non-volatile constituents in the boiler water owing to their higher potential to get enriched in the boiler water.

Within the simulation the dosing of additives and the continuous blowdown flow rate as well as the heat recovered by the process gas cooler were varied to get an overview of the system behaviour in a wide range of possible operation parameters.

Results

To provide insight into the typical effect of the water composition on different parameters the SCS heat recovery package arrangement was simulated as a baseline case. The results of the investigation of the customer's arrangement with two serially connected steam drums were then compared with this baseline case. Both simulations were performed with the same boundary conditions regarding the process gas side of the heat recovery package. The results were presented in a normalised form. Critical operational areas were highlighted. In this way, the impact of a change in operating conditions and the flexibility of the individual concepts becomes obvious.

Simulated SSC arrangement

The steam production and the normalised concentration of chemical additives in the steam drum, depending on the continuous blowdown rate for the SCS arrangement, are illustrated in Fig. 5. It is shown that the pH value can be adapted over a wide range by a slight change of the continuous blowdown. The chemical additives remain within a concentration range which is adequate for boiler operation even when the continuous blowdown rate is significantly changed. This configuration also enables easy and safe control of the water chemistry in the system. Consequently, this promotes a long lifetime of the heat recov-

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ery equipment. Another positive effect is that the steam production is only very slightly affected by the pH value and additive control due to the good controllability of the water chemistry. Generally the steam production is reduced with increasing continuous blowdown. Thus, the slight change of the continuous blowdown, which is necessary for additive concentration control, leads only to an almost negligible reduction of the steam production. This ensures an efficient use of water and recovered energy.

Simulated customer arrangement

The simulation results of the additive concentration and steam production for the serial drum customer arrangement are shown in Figs 6 and 7. Since the arrangement consists of two serially connected steam drums, in principle, two continuous blowdown rates can be adjusted and every steam drum has its individual steam production and additive concentration. The impact of changing only the continuous blowdown (CBD) rate of the first drum is shown in Fig. 6. The concentration of additives is set up to be optimal for the first drum in case of a low CBD of 0.5% as shown by the green line. It can be observed that the additive concentration in the second drum is significantly higher than in the first drum. Furthermore only 20% of the total steam produced is released from the first drum whilst 80% of the steam comes from the second drum.

Both phenomena can be explained by the fact that the boiler feed water entering the first drum is usually subcooled and needs to be preheated to steam drum temperature. This process occurs mainly within the first process gas cooler and steam drum. The recovered heat from the first process gas cooler is utilised to preheat the total amount of boiler feed water that is needed in both the first and second steam drum. Thus only a minor part of the recovered heat from the first process gas cooler is used for export steam. Consequently less steam is released from the first drum and in this way the chemical additives are only slightly enriched in the first drum. This leads to a higher demand for chemical additives in the first drum to reach the desired pH value for the first process gas cooler and steam drum.

After preheating of the boiler feed water to saturation temperature in the first drum all of the recovered heat from the second process gas cooler is used for export steam. The chemicals in the boiler water are enriched by the higher steam production. This causes a significantly higher concentration of chemicals in the second drum compared to the first drum by a factor of 150, which is shown in Fig. 6. The resulting pH value is too high to ensure a long lifetime of the heat recovery equipment and reliable process gas cooler operation. It is also obvious that no significant reduction of the additive concentration in the second drum is achieved with increasing continuous blowdown rate of the first drum. That means that adjusting the continuous blowdown of the first drum is not a sufficient control measure to achieve sufficient water quality. The only effect is a loss of steam.

The better control strategy is to adjust the additive concentration in the second drum with the continuous blowdown rate of this drum as illustrated in Fig. 7. Although there is also a huge range of operation conditions where adequate water quality cannot be achieved, it is possible to decrease the additive concentration to a level at which the pH value is adequate to achieve an acceptable water quality. However, this is done at the cost of steam production and flexibility. To achieve safe operational conditions the continuous blowdown rate must be increased so drastically (>7.5%) that a further rise has literally no further effect on the water quality.

During this investigation the observations made during operation were discussed with the plant operator, who reported a shift of the pH value between both steam drums. The different pH values are a result of the unequal enrichment of chemical additives in the two steam drums as already explained. It was also reported by the operator that different water levels in the two steam drums were observed during operation which were hard to control. This phenomenon is related to the unequal steam production in both process gas coolers due to the serial connection of the steam drums as predicted by the simulation model. The average density of the water steam mixture is lower by the higher steam production in the second drum than the one in the first drum. This effect enables the water level in the second drum to rise above the level in the first drum despite their hydraulic connection.

The model used for investigating the water steam system accurately describes qualitatively the observations made by the operator. That means that the simulation provides physical plausible information and is able to predict the distribution and enrichment of chemical additives during operation under consideration of different arrangements. The model is a suitable tool for failure analysis in water quality related issues.

Recommendation for action

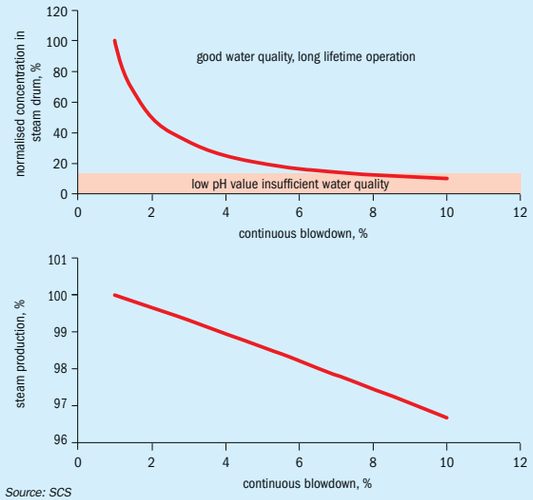
Even though a possible combination of parameters for reliable process gas cooler operation was identified for the arrangement of two serially connected steam drums, SCS advised against operating the heat recovery package over a longer time under these conditions. The aforementioned drawbacks of the arrangement are too limiting to satisfy the flexibility and reliability demands of an industrial heat recovery application. SCS recommended completely instrumenting the second steam drum and changing the serial connection of the two steam drums to a parallel one. Each steam drum must be equipped with its own individual flow control valve for boiler feed water supply. These measures are of limited cost and complexity and can be done during the next turnaround of the plant. The two parallel steam drums will then essentially act like two individual steam drums and will provide a similar flexibility to the recommended arrangement.

Conclusion

In general, water quality and water circulation have a huge impact on the performance and lifetime of the heat recovery package. The simulation of the water steam system supported the troubleshooting requested by a plant operator. For the installed heat recovery package arrangement the results indicated additive enrichment in one of the two steam drums caused by the arrangement and interconnections. It turned out that operating with the customer arrangement is possible but only over a small and limited operation range. The operation involves the risk of reduced lifetime due to suboptimal water quality. The control of water quality is less flexible compared to the SCS setup. Water and energy are wasted during operation with this arrangement. Thus, SCS advised the plant operator how to change the current arrangement with minimal effort. It was recommended to rebuild the serial drum arrangement to a parallel setup with individual boiler feed water supply for reliable and safe operation.

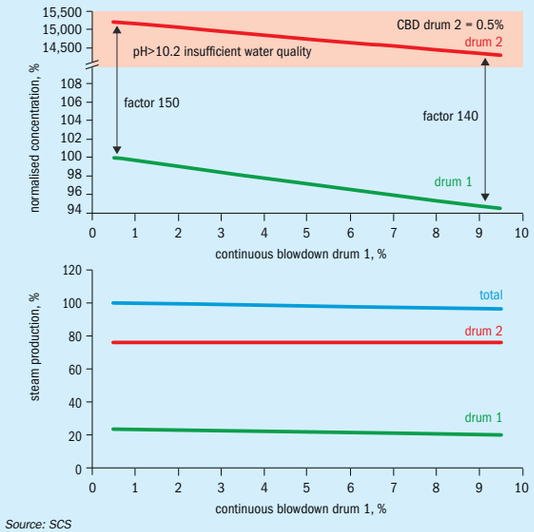
The arrangement recommended by SCS, which is based on long term experience in process gas cooler design and water quality related questions, ensures easy and safe water quality control over a wide operation range, efficient boiler operation with maximum steam production and a long lifetime of the heat recovery equipment. ■

Fig. 5: **Additive concentration and steam production as a function of the continuous blowdown for the single drum arrangement**



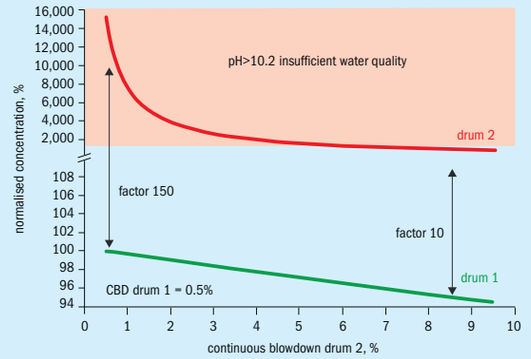
Source: SCS

Fig. 6: **Additive concentration and steam production as a function of the continuous blowdown of the first drum for the customer arrangement**



Source: SCS

Fig. 7: **Additive concentration and steam production as a function of the continuous blow down of the second drum for the customer arrangement**



Source: SCS

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Reducing the CO_2 intensity of hydrogen production

There is an urgent need to limit the rise in global temperatures to avoid severe environmental and societal impact. This can be expressed as a target to achieve net zero carbon emissions by 2050. The provision of decarbonised hydrogen at scale is an essential step in helping to achieve net zero. Johnson Matthey's Low Carbon Hydrogen (LCH) technology permits the needs of scale and urgency to be met. **J. Pach** of Johnson Matthey presents a serious response to a serious threat.

Johnson Matthey's vision is for a world that's cleaner and healthier, both today and for future generations. As a global leader in sustainable technologies, Johnson Matthey (JM) uses cutting-edge science to create solutions with its customers that make a real difference to the world around us.

Global average temperatures are rising above pre-industrial levels, with severe environmental and societal repercussions. There is an urgent need to deploy technologies at scale that will arrest this rate of rise by reducing greenhouse gas (GHG) emissions and contribute towards net-zero carbon emission-based economies by 2050.

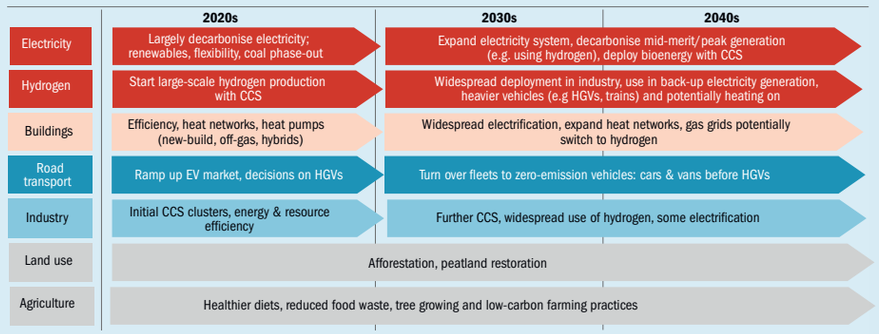
Nearly 50% of global GHG emissions are produced by industry and in connection with the provision of fuel for generation of heat and power. The provision of decarbonised hydrogen is essential to achieving significant reductions in emissions from these segments.

The use of JM's LCH technology facilitates the production of decarbonised carbon at scale using proven technology.

Hydrogen production

There are numerous strands of activity that need to be addressed to mitigate or reduce carbon emissions (Fig. 1). The key takeaway from the chart in Fig. 1 is the aggressive timescale over which each of these issues must be addressed. The ultimate goal is the most efficient use of the world's natural resources with minimal associated environmental impact. In the long term this will mean the large-scale generation of hydrogen from renewable energy and electrolysers. However, much work is still to be done to realise an acceptable cost base for deployment of this technology, at the scale required, in the short to medium term. The hydrogen provision roadmap is summarised in Fig. 2. Although the fundamental driver is emissions reduction at scale, a blend of decarbonised technologies will be required due to location and cost drivers. There will also be a transition to ever greener hydrogen over time.

Fig. 1: **UK Committee on Climate Change – pathway to mitigate emissions and actions required to achieve net zero by 2050**



Source: Johnson Matthey (Based on "Net Zero – the UK's contribution to stopping global warming", May 2019)

Today, hydrogen is predominantly made by steam reforming of natural gas, which produces carbon dioxide as a byproduct.

The reforming reaction for methane is:

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \qquad (1)$$
$$\Delta H = +206 \text{ kJ/kmol}$$

In addition, the water gas shift reaction generates further hydrogen:

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad (2)$$
$$\Delta H = -41 \text{ kJ/kmol}$$

Around 55 million tonnes of hydrogen is produced globally each year. The majority of this is produced from steam methane reforming and partial oil oxidation with the remainder produced from coal gasification and electrolysis.

Around half of current hydrogen consumption is in the petroleum refining and recovery sector, in which hydrogen is used to crack heavier oils into lighter oils for use as petroleum and petroleum products. The second largest use of hydrogen is in the production of ammonia for fertilizers, in which hydrogen is combined with nitrogen as part of the Haber-Bosch process. The remaining 10% of hydrogen use is split across the food, methanol, metals and electronics industries.

Growth is forecast across all these markets and, to reduce GHG emissions to acceptable levels, substantial reductions in carbon dioxide emissions associated with hydrogen manufacture are required over the short to medium term. In addition, displacement of methane by pure or blended hydrogen for industrial and domestic purposes will lead to a significant increase in the demand for hydrogen. A low carbon solution for hydrogen production is therefore required to minimise climate change.

There are three main options for producing low-carbon hydrogen:

- electrolysis using low-carbon electricity;
- bioenergy with carbon capture and storage (CSS);
- natural gas reforming with CCS.

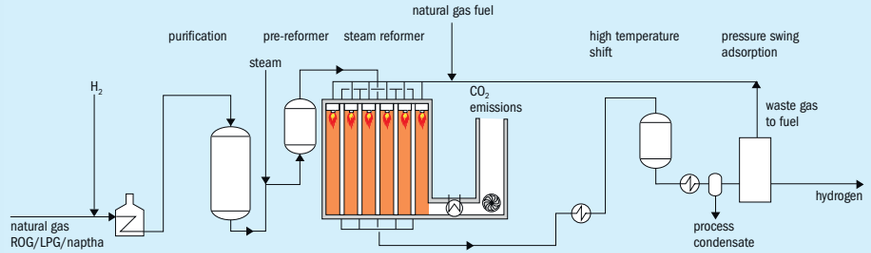
Electrolysis and bioenergy are likely to be limited by resource availability and the economies of scale, at least in the near term. In contrast, the production of hydrogen from natural gas reforming with CCS is not resource-limited in the same way and can be deployed at an impactful scale to deliver low carbon hydrogen in which more than 95% of the carbon dioxide is captured. Hydrogen produced in such a manner is often termed 'blue' (Fig. 2).

Fig. 2: **Terminology for hydrogen production with reducing GHG emission impact**

TODAY		TOMORROW		FUTURE
Brown H_2	**Grey H_2**	**Blue H_2**	**Turquoise H_2**	**Green H_2**
Coal	Natural gas	Natural gas	Grid electricity	100% renewable electricity
Gasification	Steam methane reforming	Advanced gas reforming	Electrolysis	Electrolysis
No carbon capture utilisation and storage (CCUS)	No CCUS	CCUS		
Highest GHG emissions 19t CO_2/tH_2	High GHG emissions 11t CO_2/tH_2	>95% reduction in GHG emissions from production	GHG emissions of the grid	Potential for 100% GHG reduction

Source: Johnson Matthey

Fig. 3: **Hydrogen production using SMR technology**



Source: Johnson Matthey

Conventional hydrogen production

The majority of the world's hydrogen is produced in a steam methane reformer (SMR) in a flowsheet similar to that illustrated in Fig. 3.

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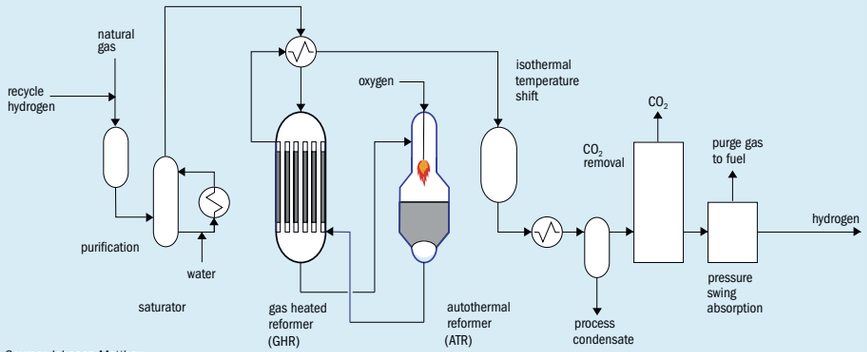
Fig. 4: **LCH process**



Source: Johnson Matthey

Natural gas is purified in a hydrodesulphurisation step in which organo-sulphur compounds are hydrogenated to form hydrogen sulphide which is then removed by absorption onto zinc oxide.

The SMR is a large refractory-lined box containing many pressurised tubes in which natural gas is converted to hydrogen across a nickel-based catalyst per equations (1) and (2). The reaction produces a mixture of hydrogen, carbon monoxide and carbon dioxide, which is often termed "syngas". The steam reforming reaction is endothermic, so a source of heat is required and this is obtained by burning additional natural gas. Various waste gas streams can also be used. Depending on the flowsheet and final product, typical reformer exit temperatures are usually in the range 700-930°C.

The syngas leaving the SMR then passes across one or more beds of water gas shift catalyst which increases hydrogen production (equation 2). The water gas shift reaction is exothermic and energy is recovered by steam generation and as boiler feed water pre-heat.

SMR flowsheets have been optimised over many years and, with production capacity ranging from 1 to 330 kNm³/h of hydrogen, have become the technology of choice for the production of high purity hydrogen on a reliable basis. However, very few hydrogen plants capture carbon dioxide emissions.

If hydrogen is to play a role in reducing the impact of climate change, it needs to be produced with concomitantly low carbon dioxide emissions which, when using natural gas as a feedstock, implies coupling it with carbon capture and storage (CCS). The combustion process in an SMR produces carbon dioxide at low concentration and at atmospheric pressure which inevitably leads to high capital cost (capex) due to the low partial pressure of carbon dioxide. In addition, post-combustion capture of the carbon dioxide and/or the use of process-produced hydrogen as the fuel in the reformer introduce significant efficiency losses.

Accordingly, for blue hydrogen to be cost effective, high purity hydrogen must be produced in a process, which also makes high pressure/high purity carbon dioxide, without an excessive capital or variable cost penalty.

Low carbon hydrogen technology

In JM's low carbon hydrogen (LCH) flowsheet (Fig. 4), heat is recovered at maximum exergy (the highest possible quality) with commensurate efficiency benefits. This is achieved by coupling a gas heated reformer (GHR) with an autothermal reformer (ATR). The main difference between LCH and SMR flowsheets is that the energy used to drive the steam methane reforming reaction is provided by introducing oxygen to the ATR rather than burning natural gas in an SMR. At the scales envisaged, the oxygen can be obtained from an air separation unit (ASU). By-production nitrogen from the ASU could be utilised to feed an ammonia loop.

ATRs are already used in the production of syngas and are an integral part of most modern schemes for production of methanol and of liquid fuels from Fischer-Tropsch processes. These plants are very large and demonstrate thatthe technology can produce hydrogen at large scale, thereby eliminating scale-up risk.

GHRs have operated on a commercial basis for over 100 cumulative plant years and have demonstrated best in class reliability. The technology has been scaled to facilitate a 5,000 t/d methanol project in the US. In 2016, JM's technological breakthrough was awarded the top prize at the IChemE Global Awards (Outstanding Achievement in Chemical and Process Engineering). Therefore LCH, with its high degree of technology readiness, is optimally placed to address the current need to deploy best-in-class low carbon hydrogen production both at the scale required and with immediate effect.

Purified natural gas is pre-heated and reformed in the GHR before entering the ATR. In the first stage, the GHR, around 30% of the hydrocarbon feedstock is reformed by reaction with steam to form syngas. In the second stage, the ATR, oxygen is added and reacts with some of the partially-reformed gas to raise the process gas temperature to more than 1,500°C. The resulting gas then passes across a bed of steam reforming catalyst inside the same reactor for further reforming. Since the reaction is limited by equilibrium, operation at high temperature and steam flows minimises the methane content of the product gas which, in turn, minimise overall carbon dioxide emissions. The hot gas exiting the ATR passes back through the GHR shell side providing the heat necessary to drive the reforming reaction in the GHR tube side. The gas then passes through an isothermal water gas shift reactor and carbon dioxide removal, before final purification in a pressure swing adsorption (PSA) unit.

Table 1: **Hydrogen production technology comparison**

Parameter	SMR flowsheet	LCH flowsheet
Natural gas as feed, kNm³/h	39.74	38.31
Natural gas as fuel, kNm³/h	5.36	0
Total natural gas, kNm³/h	45.10	38.31
Natural gas energy*, MW	439	400
Hydrogen production, kNm³/h	107.4	107.4
Hydrogen Energy*, MW	322	322
Natural gas efficiency, %	73.3	80.6
CO_2 captured, t/h	83.7	76.3
CO_2 emitted, t/h	4.4	3.7
CO_2 captured, %	95.0	95.4
ISBL + OSBL capex, %	100	60

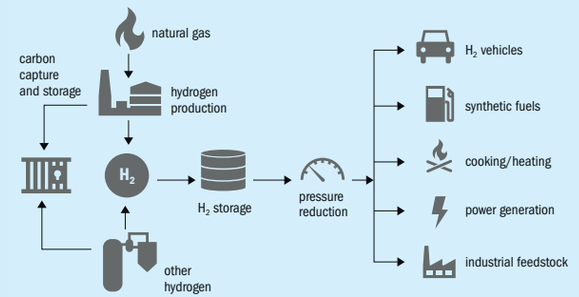
(Energy is stated on a lower heating value basis)* *Source: Johnson Matthey*

Comparison of the technologies

The advantages of an LCH flowsheet over an SMR flowsheet include (Table 1):

- **Inherently greater efficiency:** High grade heat is recycled back into reforming reactions at a higher quality (exergy) than is possible in an SMR flowsheet which degrades the energy quality (exergy) by raising medium pressure steam as a heat transfer medium;
- **Improved feedstock conversion efficiency:** The use of the gas heated reformer in series with the ATR means that reforming reactions are conducted at a higher temperature, leading to higher conversion of hydrocarbon feedstock to product hydrogen. This reduces the amount of carbon dioxide produced per unit of hydrogen made.
- **Reduction in capex and opex:** In the LCH flowsheet, all carbon dioxide is contained within the product stream at relatively high pressure. High purity carbon dioxide can therefore be removed easily using standard carbon dioxide removal technologies. This leads to a significant reduction in capex and opex compared to the alternative of carbon dioxide recovery at low pressure, as is the case with flue gas carbon dioxide recovery in an SMR based flowsheet. In addition, the reduction in the amount of carbon dioxide produced per unit of hydrogen made leads to a reduction in CCS costs and carbon tax.
- **Ability to utilise renewable energy:** The energy required for the air separation unit and for carbon dioxide compression can be provided by renewable electrical energy.

Fig. 5: **Decarbonised industrial cluster**



Source: Johnson Matthey

LCH technology can therefore accommodate renewable energy import and provide a flowsheet with dramatically reduced greenhouse gas emissions, lower capital cost and lower natural gas consumption.

Deployment of LCH technology

LCH technology has been independently assessed to be the most cost-efficient technology capable of achieving greater than 95% carbon capture at scale and it forms the cornerstone of a number of projects in the UK that seek to decarbonise regional industrial clusters (Fig. 5). One such project is Hynet which seeks to decarbonise a proposed industrial hydrogen cluster in North West England

If a cluster is located close to an existing ammonia plant, additional synergies are possible

- carbon dioxide that is already being extracted from the ammonia plant can be sent to the CCS facility;
- Tte LCH plant can be used as a source of additional, low carbon hydrogen for ammonia manufacture;
- by-product nitrogen from the ASU as a source of additional nitrogen for ammonia manufacture.

Conclusion

As businesses, and as societies, we face a serious threat in the guise of GHG emission driven climate change. Decarbonised hydrogen is essential for achieving net zero carbon emissions. Johnson Matthey's LCH, proven technology with flexibility to integrate ever increasing amounts of renewable energy into its flowsheet, stands ready to play its part. ■

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Hydrogen for fuel cell vehicles and stationary power

As the world focuses on clean fuels for the 21st century, there is an emerging opportunity to use ammonia as a source of hydrogen. Hydrogen fuel cells are expected to play a significant role as part of a clean energy portfolio. T2M Global and its development partner, SAFCell, are collaborating to develop a modular system to produce hydrogen from ammonia using a novel solid state separation system that does not require pressure or solvents. **P. Patel** of T2M Global, **C. Chisholm** of SAFCell and **V. Pattabathula** of Incitec Pivot explain the challenges, the opportunities and the current status of this new technology.

The quest for clean energy for stationary and transportation sectors with zero emissions is now focusing on hydrogen fuel cell systems, which has become a multi-billion dollar industry worldwide. From kilowatt to multi-megawatt, fuel cell power plants are being deployed in USA, South Korea, Japan, and Europe. Fuel cell powered forklifts, cars, buses, trucks, ferries, and trains are becoming common. China is entering this rapidly emerging market in a very ambitious fashion with multi-billion dollars of investments in fuel cell technology and hydrogen infrastructure. Hybrid engines coupling fuel cells with batteries have shown robust performance and enhanced economic viability. The cumulative market for hydrogen fuel cells has grown from MW/year to GW/year.

In parallel, government mandates and incentives for clean renewable energy have resulted in unprecedented growth in solar and wind installations worldwide. While highly beneficial, these renewables are highly intermittent. As their penetration increases, so does the imbalance between supply and demand in the electric grids. These intermittent renewables must be supplemented with synergistic and transportable energy sources. The emerging energy storage portfolio includes batteries for rapid response and hydrogen for long-duration response. Hydrogen as energy storage is particularly attractive for low-cost renewable energy. During peak output renewable energy can be converted on-site to hydrogen and stored as chemical fuel for transportation and stationary power applications. This distributed capability enables production cost reduction with minimal environmental impact. Hydrogen infrastructure has now become an important requirement to sustain growth in the clean and green energy arena.

Hydrogen infrastructure challenges

The unique advantage of fuel cells is distributed generation of clean electricity on-site and on-demand. This requires on-site hydrogen refuelling stations, typically about one tonne/day in capacity. These refuelling stations are expensive. The first challenge is that fuel cells require high-purity hydrogen for efficient performance (99.99+ %). Carbon monoxide must be below ppm level.

The second challenge is the cost of delivered hydrogen being too high. It has come down from a level of $20/kg to about $10/kg, but to be competitive, it must come down further to below $5/kg. This is a huge challenge for distributed users of hydrogen since they are not buying it in bulk (kg/day, not tonne/day). The low-density hydrogen is notorious for being hard to store. High pressure compressed hydrogen storage (5,000 to 10,000 psi) or liquid hydrogen storage is used to increase the capacity range of fuel cells in different applications (forklifts, cars, buses, or trucks). The hydride-type hydrogen storage has limitations of lower capacity, typically around 5% by weight, which limits their economic viability for fuel cell use.

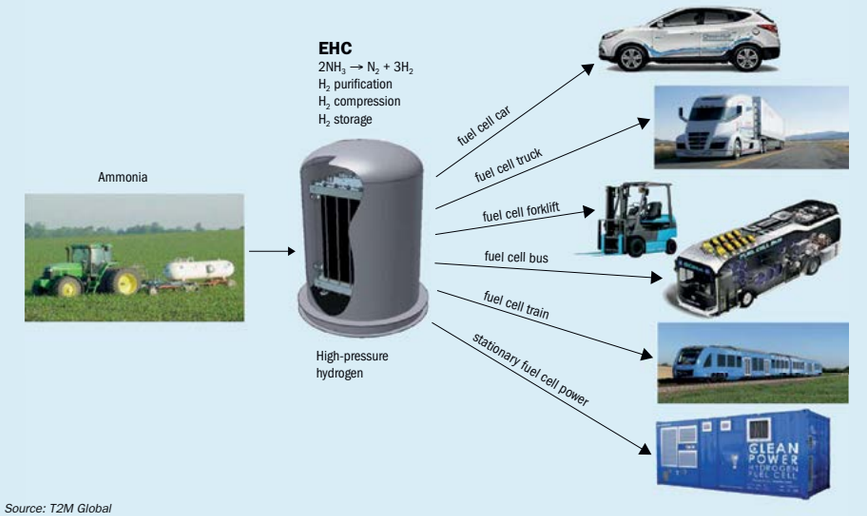
On-site production of hydrogen using water electrolysis has been in use at some sites, with typically less than one tonne/day production capacity. The operating cost of electrolysers is highly dependent on the cost of electricity and the amount of electricity needed per kg of hydrogen produced (50-60 kWh/kg hydrogen). This mode of hydrogen production cost is typically over $10/kg.

Ammonia as opportunity energy carrier

Ammonia offers a number of unique advantages as a source of hydrogen. It has an extensive distribution network worldwide, through pipelines, ships, trucks, and barges. All safety and user protocols are well established. It is a carbon-neutral liquid fuel and produces no GHG emissions. It produces no carbon monoxide, a serious advantage for fuel cell applications. Since there is no combustion in fuel cells, the nitrogen present in ammonia does not produce any harmful NOx emissions. It offers the highest energy density (~18 wt-%) among all other hydrogen carriers. Ammonia in liquid state (at room temperature and at reasonable 10 atm pressure) allows for easy transportation and cost-effective storage. Liquid ammonia can be easily compressed to desired high pressures with much lower energy consumption than gaseous hydrogen. Thus, ammonia is a highly promising carrier of hydrogen for fuel cells for both transportation and stationary power applications. At $300 per tonne of ammonia, it will contribute less than $2/kg of hydrogen.

Ammonia opens a pathway to cost competitive hydrogen infrastructure for the multi-billion dollar emerging fuel cell industry. For one MW of fuel cell operating continuously at full load it is estimated that approximately 10 t/d ammonia will be needed. A fuel cell bus or truck (100 kW-class) will need up to 1 t/d ammonia. Anhydrous ammonia is already produced as a fertilizer and transported for agricultural use worldwide. It might already make economic sense in some areas to use some of the ammonia supply for producing hydrogen.

Fig. 1: **EHC technology is an attractive solution to multiple H_2 applications**



Source: T2M Global

Technology development for ammonia to hydrogen

The first step is to crack ammonia into its components, hydrogen and nitrogen, followed by separating hydrogen from ammonia and nitrogen. Advanced materials such as membranes and catalysts and new electrochemical processes are required to efficiently generate hydrogen at higher conversion rates needed for competitive costs. Subsequent hydrogen purification processes like pressure swing adsorption (PSA) suffer from poor capacity to separate nitrogen cost-effectively. Under US Department of Energy (DOE-ARPA E) sponsorship, SAFCell, Inc. and T2M Global Team are developing advanced technology to extract hydrogen from ammonia in a single step using solid state electrochemical hydrogen separator and compressor (EHC). Fig. 1 shows different fuel cell applications that can be serviced by the EHC Module. It is highly scalable to service kW-class applications as well as MW-class with multiple modules. The EHC operating principle is illustrated in Fig. 2.

The electrochemical hydrogen compressor (EHC) is a single stage hydrogen separator and compressor. With catalyst embedded within the cell layer, it can crack ammonia internally, thus eliminating the need for an external cracker. The working principle is extremely streamlined as a result of this all-in-one feature (Fig. 2): A hydrogen carrier such as ammonia enters the stack (1). It cracks into hydrogen and the associated by-product internally (2). The catalyst advancement has enabled the cracking temperature to be reduced significantly, lowering the thermal energy requirements and maintenance costs associated with high temperature operation. Hydrogen ions are moved with >99.999% selectivity from one electrode (3) to another via a proton conducting membrane (4). The separated hydrogen ions form hydrogen gas on the catalyst layer (5). The product hydrogen is internally compressed to the desired pressure (30-100 bar) for direct on-demand fuel use.

Unique features and benefits

The key innovation is the use of a solid acid electrolyte as a proton conducting layer, a type of electrolyte that is stable in the presence of ammonia while under the operating conditions needed for reactions. Solid acid stacks operate at intermediate temperatures (around 250°C) and demonstrate

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high tolerance to typical anode catalyst poisons such as carbon monoxide and hydrogen sulphide without a significant decrease in performance. The system also aims to realise the conversion of ammonia along with the purification and compression of hydrogen in a single, cost-effective system, thus greatly simplifying the infrastructure required to transport and store hydrogen. These properties give solid acid EHC advantages over other membrane technologies in cost, durability, start/stop cycling, fuel flexibility, and simplified system design. If successful, EHC technology will be an enabler for the multi-billion dollar hydrogen fuel cell industry and create new markets for the ammonia industry, potentially doubling its capacity worldwide. It will enhance energy security and promote greater use of solar and wind energy for greater sustainability. It will create new higher paying jobs and enhance energy security.

Current status

Tremendous technology advancement has been made validating the EHC technology in single cells followed by scale up to multi-cell stacks. Stable stack operation at elevated pressures (up to 35 bar) has been successfully demonstrated for the first time ever using the solid acid membrane (Fig. 3).

EHC stack operation showed lower electricity consumption (<10 kWh/kg of hydrogen compared to 50+ kWh/kg of hydrogen for conventional water electrolysis). Ammonia cracking internally at lower temperatures (250°C) has been successfully demonstrated. In addition, a low-cost system design has been developed to recover and reuse the uncracked ammonia via patent pending R-3 technology.

Next step

Leveraging promising test results, technology scale up (single stack module for 40-100 cell stack with product hydrogen storage) is currently being conducted. This will be followed by prototype module design, fabrication, and testing (Target: 5 kg/day hydrogen from ammonia for home refuelling). The commercial system goal per US DOE is about 500 kg/day hydrogen (approx. 3 t/d ammonia).

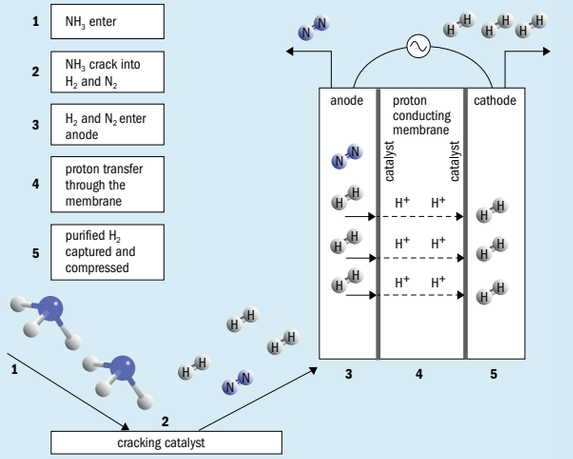
Ammonia industry perspective

It is believed the newly developed low cost hydrogen from ammonia would increase the demand for ammonia production worldwide once H_2 fuel cells are commercialised. With no GHG emissions when ammonia is cracked, many countries could move to ammonia as fuel as soon as the technology is available.

The development team could work with global fuel-cell and vehicle manufacturers to bring hydrogen fuel cell technologies to operate forklifts, buses, light & heavy vehicles, and ferries.

Acknowledgement: Financial support from US DOE is gratefully acknowledged. Contributions from Dr Ludwig Lipp, Ed Ko for EHC, test station work, and SAFCell members for ammonia and EHC cell-stack are recognised.

Fig. 2: **EHC operating principle**



Source: T2M Global

Fig. 3: **Test Facility for EHC at T2M**

PHOTO: T2M GLOBAL

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