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Number 383 May | June 2023

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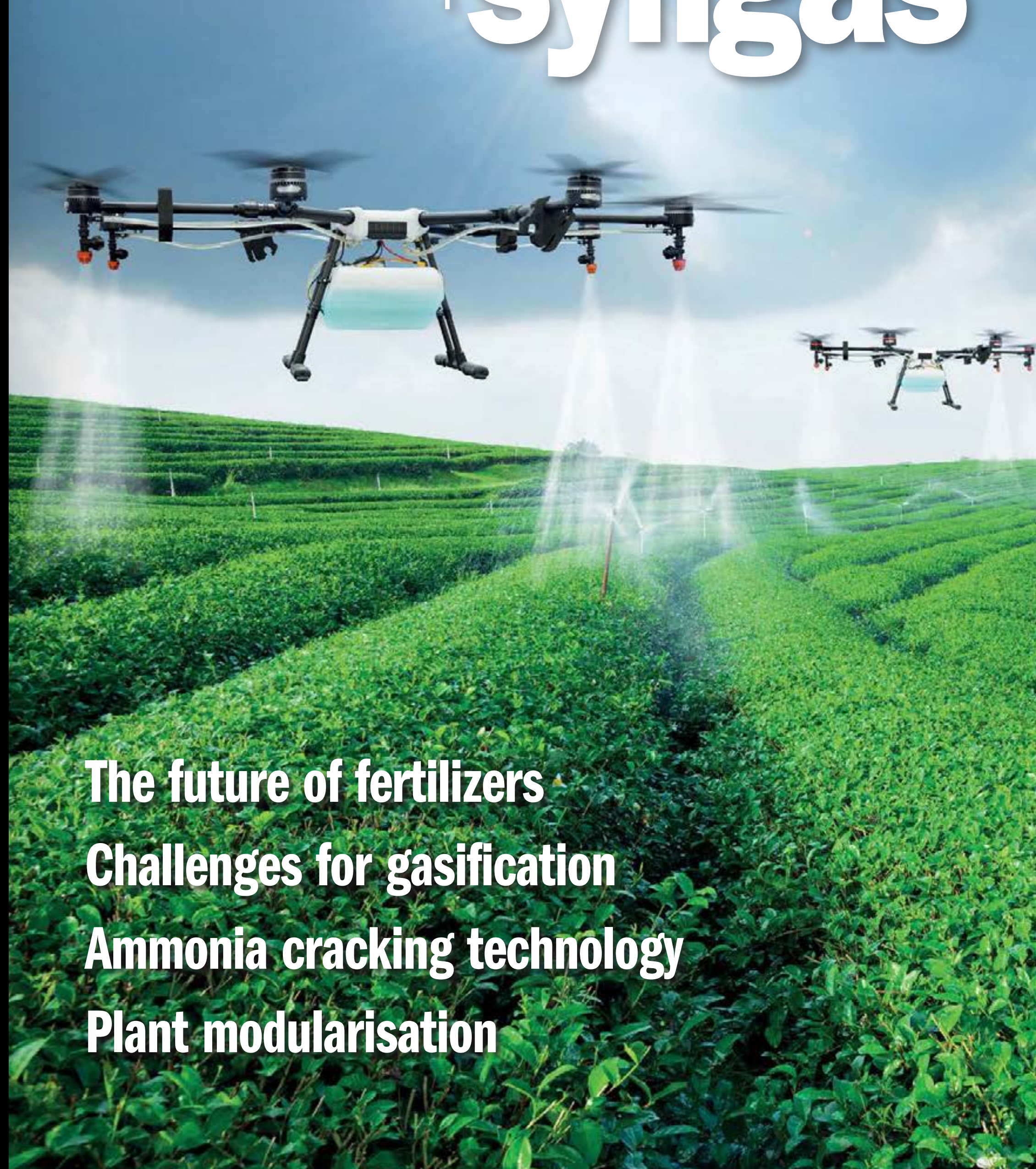

The future of fertilizers
Challenges for gasification
Ammonia cracking technology
Plant modularisation

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NITROGEN+SYNGAS
ISSUE 383
MAY-JUNE 2023

BCInsight
China Works, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Web: www.bcinsight.com
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Cover: Agriculture drone spraying fertilizer on a green tea field. Kinwun/iStockPhoto.com


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Black Sea deal in danger

Last year, in the wake of Russia's invasion of Ukraine and the associated disruption to fertilizer and grain exports from both countries, there were dire predictions of the impact upon global food supply. That the worst of these predictions have not so far come to pass is in no small part due to the deal brokered by the United Nations and Turkey in July 2022 to allow exports of grain and fertilizers from Black Sea ports. According to the UN, since last July, some 29.5 million tonnes of grain and foodstuffs have been exported from Ukraine via the Black Sea, including nearly 600,000 tonnes in World Food Programme vessels for aid operations in Afghanistan Ethiopia, Kenya, Somalia and Yemen. Before the war, Ukrainian grain fed the equivalent of up to 400 million people worldwide, and the deal ensured that Ukrainian grain exports 'only' fell by 5 million t/a over the past year.

> "Reopening the Togliatti-Yuzhnyy ammonia pipeline... has been one of Russia's key demands."

Now, however, the deal seems to be unravelling. Russia has stopped approving new vessels in order to put pressure on negotiations ahead of a May 18 deadline. Russia is seeking easier export of its own grain and fertilizer as a condition for allowing the flow from Ukraine to continue. In particular it is seeking the readmittance to the SWIFT international payments system of its state agricultural bank, and the lifting of individual sanctions on persons involved in the trade, such as fertilizer tycoon Dmitri Mazepin. It's often said that a negotiation with Russia is not a serious one unless one side threatens to walk out, but were that to happen, insuring vessels trading with Ukraine would effectively become impossible and the trade would stop. This comes at the same time that landward export routes via Poland, Hungary and Slovakia have been curtailed by new import restrictions designed to protect local farmers from a collapse in prices caused by a flood of cheap Ukrainian produce, causing much consternation within the EU.

Food price inflation has been an issue worldwide since the war. With fertilizer production disrupted by gas shortages, European food prices have risen by 7-20%, depending on location. But the situation is at its direst in the world's poorest countries. In Lebanon the figure is 140% according to the World Bank, in Venezuela it is 160%, and in Zimbabwe 285%, in spite of a $30 billion support package by the World Bank and the World Food Programme. Global food stocks remain tight, and the closure of grain exports from Ukraine would revive the fears of a devastating impact upon low and middle income countries.

One of Russia's key concerns in the current negotiations is to ensure continued export of ammonia, and there are plenty of voices in the west arguing that in order to calm food markets, Russia's exports of fertilizer should be allowed to resume, via Yuzhnyy/Odessa and Riga. The reopening of the Togliatti-Yuzhnyy ammonia pipeline, which used to carry 2.5 million t/a, has been one of Russia's key demands going into the current Black Sea Grain Initiative talks. But the omens are not good, with Ukrainian and Russian delegates to the Assembly of Black Sea Economic Cooperation actually physically coming to blows last week.

In the meantime, TogliattiAzot has begun work on a new export terminal at the Russian Black Sea port of Taman, on the Kerch Strait by Crimea. It aims to have 2 million t/a of ammonia export capacity up and running by December 2023, increasing to 3.5 million t/a of ammonia and 1.5 million t/a of urea by 2025, though how practical this timeline is remains to be seen. For now, much hinges on the talks to save the Black Sea Grain Initiative, with the stakes for the whole world remaining very high indeed. ■

Richard Hands, Editor

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Price Trends

Market Insight courtesy of Argus Media

NITROGEN

Ammonia prices dropped again towards the end of April across several regions, backed up by a $55/t drop in the latest monthly Tampa contract price, as the market continues to work towards its floor. Yara agreed the Tampa price with Mosaic at $380/t c.fr for May, representing a Caribbean netback of around $330-335/t f.o.b. But firmer demand from northwest Europe appears to be pointing towards some potential stability.

A series of outages and plant maintenance in the Americas and north Africa is moving the market more into balance for May and June. In the east, the focus remains on China, where negotiations are now heading below $300/t c.fr and increasing competition between Middle East and southeast Asian sellers to reduce stockpiles.

Recent market drivers include NW European demand; fresh sales are emerging in Europe. Discussions were below $400/t c.fr at the end of April, but a sale into France was reported above $400/t cfr. The details were not confirmed by the buyer. There are also curtailments on Trinidad; at least one plant on Trinidad has been forced to come offline because of issues over gas supply.

In Algeria, producer Sorfert has brought one plant offline today for maintenance, with the plant expected to come back online in mid-May. Algerian exports reached over 130,000 tonnes in April. In China, storage tanks at Zhanjiang are at full capacity, delaying cargoes and dampening recent buying interest. Around 70,000 tonnes are in the May line up, down from 120,000 tonnes in April.

Scarcity continued to drive prompt urea prices higher in some markets at the end of April, though sentiment remains weak for June cargoes. The US market remains short on urea at the front end of the curve and prices spiked to reflect this. Nola barges traded up to $450/st f.o.b. ($490/t c.fr) for April, up by 55% from this year's low-point. Southeast Asia remains short on urea amid planned and unplanned turnarounds and a cargo traded at around $345/t f.o.b., up by around $20/t on last business.

In Europe, producers began the 'new season' campaign for summer AN/CAN shipments into western Europe with apparently strong uptake. This, in turn is driving interest in urea and ammonium sulphate – though little activity on UAN as much was traded earlier.

Recent urea market drivers include the ongoing rally in the US, which continues to prompt short-covering and adjustment of shipping schedules but, when demand slows in May this will likely cool global markets and traders are already positioning around this. In China spot export trade in urea is picking up, albeit slowly, which should place a clear ceiling on urea prices.

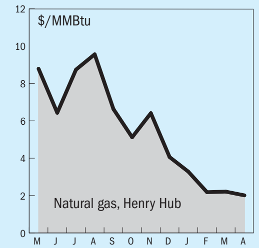
Table 1: **Price indications**

Cash equivalent	mid-Apr	mid-Feb	mid-Dec	mid-Oct
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	330-400	550-590	975-1,025	1,100-1,200
f.o.b. Arab Gulf	250-320	570-600	820-900	890-990
c.fr N.W. Europe	385-410	620-660	975-1,020	1,140-1,240
Urea ($/t)				
f.o.b. bulk Black Sea	250-335	320-380	420-530	n.m.
f.o.b. bulk Arab Gulf*	300-375	300-355	420-485	546-631
f.o.b. NOLA barge (metric tonnes)	360-385	310-335	495-520	550-585
f.o.b. bagged China	330-370	355-410	440-485	580-620
DAP ($/t)				
f.o.b. bulk US Gulf	627-699	646-678	660-710	756-808
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	275-310	392-403	575-600	683-693

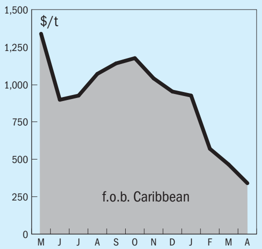
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

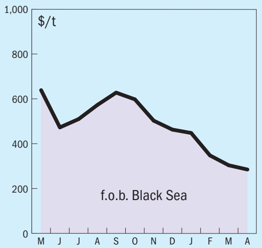
natural gas



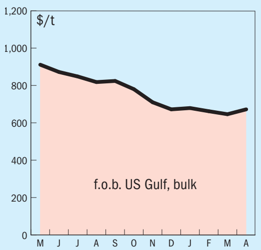
ammonia



urea

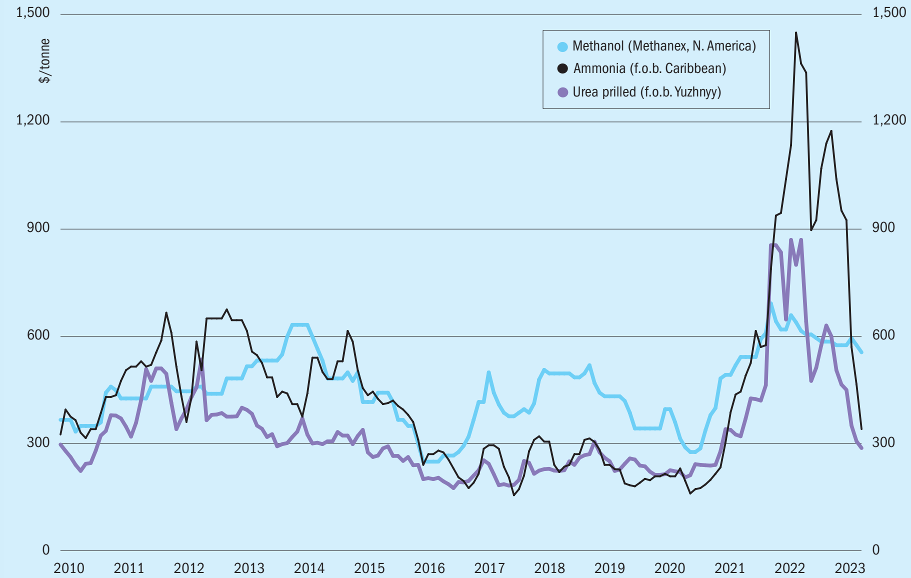


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Further downward corrections are possible but the rate of demand is stabilising, suggesting the market floor is in sight, though some have suggested that May could bring another sharp reduction in the Tampa contract price towards the mid-$300s c.fr. Demand remains sluggish in both eastern and western hemispheres.
- Exports from Trinidad remain lower, having fallen to around 300,000 t/month in March-April, down from 360,000 t/month in January-February.
- Meanwhile, interest in imports in western Europe has picked up, in part due to production curtailments and increased demand from nitrate producers. TTF natural gas prices also suggest gas costs for production of $460/t in May in compared to import prices heading towards the $400/t c.fr level, likely driving increased import demand.
- Yara has idled more than half of its European ammonia capacity due to the steep drop in fertilizer prices.

UREA

- Increased supply from China and the anticipated return from turnaround of urea plants in southeast and central Asia should be exacerbated by slow import demand in the northern hemisphere.
- The US market appears relatively balanced for May-loading cargoes, even tight in some regions, but importers and traders seem reluctant to take significant long-positions and the market is nearly through the natural peak of demand for the second quarter.
- The Russian ministry of industry and trade has prepared a draft resolution to implement export quotas on certain finished fertilizers, totalling 17.94 million tonnes, applicable from 1 June to 30 November.
- Urea market focus will shift to the timing of the next Indian import tender, which does not appear likely to arrive until June. Urea prices are falling rapidly.

METHANOL

- Methanol prices have fallen due to high stocks and falling natural gas prices in both Europe and North America. Demand remains relatively limited with traded volumes thin, and there is no pickup expected in the near term.
- As a result prices have been bearish in most major markets. European spot prices fell to $485/t on local oversupply. In North America, prices fell to $550/t f.o.b. Gulf Coast.
- Chinese methanol prices also dropped sharply in March, and fell another 10% to below yuan 2,500 ($360/t) in April. Demand has been weaker than expected with MTO operating rates low, and overseas supply has been plentiful. In particular, several restarts of Iranian methanol plants have led to an increase in shipments into China of more than 200,000 tonnes in March.
- Elsewhere in Asia downstream markets have been weak and freight rates relatively high.

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Nitrogen Industry News

UNITED KINGDOM

CRU, Argus launch new low-emissions ammonia price service

Mining, metals and fertilizer business intelligence company CRU has launched a new low-emissions ammonia (LEA) price assessment in its Fertilizer Week price reporting service. The price takes a value-based approach, whereby a premium on the Northwest European ammonia price is calculated on an emissions-mitigated basis, and leverages CRU's proprietary nitrogen asset emissions data combined with weekly European carbon prices to calculate the value of emissions mitigated. CRU says that it has leveraged its Emissions Analysis Tool to develop the premiums on an emissions-mitigated basis as opposed to a cost basis, allowing end-users to assess how the switch to LEA can deliver value to their business while contributing to their decarbonisation strategies. The Emissions Analysis Tool is a comprehensive asset-by-asset emissions dataset for the nitrogen industry.

Energy and commodity price reporting agency Argus has also launched a suite of new cost indicators for the production of ammonia made with renewable fuels or with fossil fuels where carbon capture, utilisation and storage has been applied. Argus says that it now publishes 312 costs of production for decarbonised ammonia at key locations around the world. This supplements the company's existing 'grey' ammonia market coverage, which assesses market prices for ammonia made with fossil fuels where the carbon is not mitigated. These new indexes are published in the Argus Hydrogen and Future Fuels service and complement the more than 470 decarbonised hydrogen costs already available.

GERMANY

Modular plants for green ammonia

Ammonia licensor thyssenkrupp Uhde and IDESA Industrial Plants SLU (IDIP) have signed a memorandum of understanding (MoU) to cooperate on developing a joint project within the sector for the design, procurement, fabrication, and construction of modularised green ammonia plants. The modularised solutions will be based on globally proven uhde® ammonia technology, which has already been applied in over 130 large-scale chemical plants across the world. The cooperation between the two companies will combine IDIP's extensive know-how in the fabrication of skids and modules with thyssenkrupp Uhde's wide experience in the engineering and procurement of ammonia plants, leading to synergies, cost savings, improved fabrication efficiency, increased competitiveness and risk mitigation. At the same time, it will unlock capacity constraints, improve supply chains and enable thyssenkrupp Uhde to prepare for the increased demand that is to come in the wake of the enormous future investments in green ammonia markets that are required to secure successful energy transition.

Liege Robson, COO thyssenkrupp Uhde said: "We at thyssenkrupp Uhde are committed to the success of the green transformation on a large scale. This includes forging new partnerships and developing our technologies to make a decisive contribution to the decarbonisation and CO_2 reduction process. The construction of numerous green ammonia plants is the key to a successful energy transition. By working together with IDIP on the modularisation of these plants, we can decisively shorten the construction time of these plants and thus accelerate the global energy transition."

ADNOC looking at low-carbon ammonia in Germany

The Abu Dhabi National Oil Co. (ADNOC) says that it is exploring opportunities to support the climate-neutral transformation of industry through the creation of a low-carbon ammonia value chain with state government and industry representatives in Germany's North Rhine-Westphalia region. Last year, the company completed its first shipment of low-carbon ammonia to Germany.

The announcement was made following the signing of a memorandum of understanding (MoU) between the government of North Rhine-Westphalia, ADNOC and Currenta GmbH & Co. OHG, a chemical industry services provider that manages and operates one of the largest chemical sites in Europe, Chempark, with locations in Leverkusen, Dormagen and Krefeld-Uerdingen, in North Rhine-Westphalia.

Mona Neubaur, deputy prime minister of North Rhine-Westphalia said: "We will do our utmost to expand the capacities for the generation of renewable energies and for the production of other climate-neutral energy carriers such as green hydrogen in this country as much as possible. However, it is also clear that we will have to import various green energy sources in large quantities in order to cover our needs and to achieve our climate protection goals. We are now building partnerships and a broad import infrastructure to supply our industry. The basis for our cooperations is diversification with many countries."

The primary focus of the agreement will be the production and transportation of low-carbon ammonia and its application as a fuel in energy generation, including industrial-scale testing at Currenta's site in Dormagen.

CHINA

Stamicarbon to license its largest ultra-low energy urea plant

Stamicarbon has signed a contract covering the process design package, licensing and equipment supply for an ultra-low energy grassroots urea plant in Jiangxi province, China. This will be the largest Stamicarbon low energy plant, with a design capacity of 3,850 t/d and the seventh plant based on this innovative design. Stamicarbon will deliver the process design package and the proprietary Safurex® high-pressure equipment and associated services for the urea melt and prilling plant. Unlike previous Ultra-Low Energy plants, which featured Pool Reactor technology, this design will apply the Ultra-Low Energy principle to the Pool Condenser. The Ultra-Low Energy design allows heat supplied as high-pressure steam to be used three times instead of two, reducing steam consumption by about 35% and cooling water consumption by about 16% compared to traditional CO_2 stripping processes, as demonstrated in two plants currently in operation.

"This award is significant, being Stamicarbon's largest Ultra-Low Energy urea plant to date and the first plant where this breakthrough technology is applied to a pool condenser. It shows Stamicarbon's commitment to innovation and technology development to improve the sustainability of the fertilizer industry," said Pejman Djavdan, Stamicarbon CEO.

CANADA

Pre-FEED study on renewable ammonia project

Hy2gen AG has commissioned Technip Energies to complete a pre-FEED study for its renewable hydrogen and renewable ammonia project, named COURANT, located in Baie Comeau, Quebec. The pre-FEED study began in March 2023 and will provide Hy2gen with the plant's process configuration, selected technologies, estimate the plant's capital requirements and clarify the site's operating costs. The study will provide necessary information to initiate the required environmental and stakeholder engagement steps, and is expected to be completed before the end of the year.

Following a completed FEED and positive final investment decision, Hy2gen expects the plant to be mechanically completed by mid-2028. Production of climate-neutral renewable ammonia is expected to start shortly thereafter, making it Hy2gen AG's first Canadian project. The hydrogen will be produced via electrolysers and the nitrogen will be produced in an air separation plant. The energy to operate both plants will supplied from hydropower. The expected production volume of ammonia is designed for 220,000 t/a.

SAUDI ARABIA

Aramco and Linde to develop ammonia cracking technology

Saudi Aramco and Linde Engineering have signed an agreement to jointly develop a new ammonia cracking technology. The collaboration between the two companies will combine Linde Engineering and Aramco's experience and capabilities in industrial research and development, lower-carbon hydrogen, and ammonia cracking technology.

A potential differentiator of this new technology is the ammonia cracking catalyst, jointly developed by Aramco and the King Abdullah University of Science and Technology (KAUST), which will be evaluated against other catalysts. Aramco and Linde Engineering plan to build a demonstration plant in northern Germany to showcase this new ammonia cracking technology. Linde Engineering intends to offer this technology to current and new customers, creating new commercial opportunities within the global lower-carbon energy supply chain. The emerging lower-carbon ammonia business may prove to be key in bridging the gap between a country's domestic renewable energy production capacity and total energy demand.

John van der Velden, Senior Vice President Global Sales & Technology at Linde Engineering, said: "Effective ammonia cracking technology supports the world's urgent need for decarbonisation. By completing the missing link in the export chain, cleaner energy can be shipped from regions with high renewable and clean energy potential to those with more limited resources. We look forward to working closely with Aramco to develop and commercialise this important technology, creating new business opportunities for Linde Engineering and Aramco."

BULGARIA

Unplanned outage at Neochim

Bulgarian fertilizer producer Neochim says that technical issues caused an unplanned stoppage at its ammonia plant. The emergency shutdown did not affect the operations of the plant's ammonium bicarbonate and nitric acid production units, Neochim said in a bourse filing. Since October, Neochim has had six unplanned stoppages due to technical issues, most recently shutting down three units in late March as a result of a technical failure at the nitric acid plant.

UNITED ARAB EMIRATES

Feasibility study complete on green ammonia plant

Brooge Energy Ltd says that a feasibility study of its proposed green hydrogen and ammonia plant, conducted by thyssenkrupp Uhde, has been completed and delivered. Brooge Energy engaged thyssenkrupp in September 2022 to undertake a technical concept study and cost estimate for the proposed green ammonia plant, which is based on thyssenkrupp nucera's alkaline water electrolysis and thyssenkrupp Uhde's ammonia synthesis technologies.

The plant is planned in two phases up to a total of 1,950 t/d export focused green ammonia production located in Abu Dhabi. The plant will produce green ammonia using green hydrogen from solar energy with water and air as raw materials. The study involved a comprehensive techno-economic analysis of the power-to-ammonia value chain using thyssenkrupp's proprietary modelling tool. The goal was to evaluate the influence of various factors on the overall cost-effectiveness of the green ammonia plant. This analysis explored multiple scenarios to identify optimal plant designs coming along with various supporting documentation dealing with technical and execution concepts on a fully integrated approach.

BELGIUM

Air Liquide to build ammonia cracking pilot plant

Air Liquide says that it will build an industrial scale ammonia cracking pilot plant in the port of Antwerp. The plant will make it possible to convert, with an optimised carbon footprint, ammonia into hydrogen, by combining a novel efficient process with Air Liquide's proprietary technologies. The facility is planned to be operational in 2024. The Flemish Government, through the VLAIO (Flemish Agency for Innovation and Entrepreneurship), has confirmed financial support to the project.

Michael J. Graff, Executive Vice President, Air Liquide Group, said: "Ammonia cracking complements Air Liquide's already thorough portfolio of hydrogen technologies and adds yet another technological solution to enable the development of a hydrogen global market. More than ever, the Group is committed to making hydrogen a key element of the fight against climate change, in particular for the decarbonisation of heavy industry and mobility."

UNITED STATES

Yara and Enbridge plan large scale blue ammonia plant

Norwegian fertilizer manufacturer Yara and Canadian pipeline company Enbridge say that they plan to invest up to \$2.9 billion to build a low-carbon blue ammonia plant in Texas. The plant, which would be Yara's biggest, would be built at an Enbridge oil storage and export facility near Corpus Christi, with production to start around 2027-28. Both companies have not yet made final investment decisions. The plant would supply 1.2-1.4 million t/a of low-carbon ammonia, with about 95% of the CO_2 generated from production captured and transported for nearby permanent storage.

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Yara intends to buy all of the plant's output for feedstock in its global production system, including Europe, as well as for new clean ammonia markets such as shipping fuel. The project was planned before last year's Inflation Reduction Act (IRA), but the increase in carbon storage tax credits in that law makes the plant more attractive, Yara says. The IRA offers companies a tax credit of as much as $85 per tonne of captured carbon stored underground.

Incitec Pivot sells US ammonia plant

Explosives and fertilizer maker Incitec Pivot has sold its US ammonia plant at Waggaman to CF Industries as part of a reported $2.0 billion deal. The plant will continue to supply at least 200,000 t/a of ammonia to Incitec's Dyno Nobel Americas ammonium nitrate plant; about 20% of Waggaman's output. The remainder is sold to other customers within the USA. The Waggaman plant was completed in 2016 at a cost of $850 million and has a nameplate capacity of 880,000 t/a.

"With the decision to sell this world-class asset, we will reduce our excess exposure to commodity and operating risks while maintaining Waggaman's strategic value," Incitec chief executive Jeanne Johns said. Incitec is planning to separate its Pivot Fertilisers and Dyno Nobel explosives businesses into two listed entities as it seeks to unlock shareholder value by sharpening each division's focus on capital allocation and growth opportunities. Cash from the sale will be used to pay down debt and provide options for the demerger of its fertilizer business.

KBR to license ammonia plants

KBR has signed a memorandum of understanding (MoU) with Atlas Agro AG to license KBR's K-GreeN® technology for Atlas' planned investment in a series of green ammonia plants. Under the terms of the MoU, KBR will provide technology licensing, basic engineering design, proprietary equipment and catalyst for the plants, which will produce zero-carbon nitrogen fertilizers. The engineering design for the first plant, located in the United States, began in March 2023.

Power supply agreement for green ammonia plant

NTPC Renewable Energy Ltd has signed an agreement with Greenko ZeroC Pvt Ltd to supply 1.3 GW of energy around the clock to power Greenko's green ammonia plant development at Kakinada. The energy company is a wholly owned subsidiary of state-run NTPC Limited. Greenko plans to export the green ammonia generated to the European market. Uniper SE, the German energy company, is in talks with Greenko to take 250,000 t/a of green ammonia. Signatories to the supply agreement included Rajiv Gupta, chief general manager, NTPC Renewable Energy, and Mahesh Kolli, founder and joint MD, Greenko Group.

SOUTH KOREA

Lotte Fine Chemical to tap OCI for low carbon ammonia

OCI has signed a memorandum of understanding (MOU) with Lotte Fine Chemical for the supply of low-carbon and green ammonia, with first shipments starting this year from OCI's US facilities. The companies are also looking to cooperate to build a global supply chain of bunkering for ammonia-powered vessels in Ulsan, Korea, which are expected to be commercialised from 2025 onwards. With this MOU, OCI will supply Lotte Fine Chemical from OCI existing low carbon ammonia production capacity in Texas starting this year. Lotte Fine Chemical will introduce OCI's ISCC Plus bio-ammonia, derived from biomethane, for the first time in Korea, for supply to its domestic customers. When bio-certified, plastic products made of this material will be eligible for tax benefits when exported to Europe.

Future supply is expected to come from OCI's new world-class large scale blue ammonia greenfield project under construction in Texas that is expected to be operational in early 2025, as well as from Fertiglobe's green ammonia production facility in Egypt (Africa's first green hydrogen project), which recently commissioned its first phase. Fertiglobe is a strategic partnership between OCI and Abu Dhabi National Oil Company (ADNOC). OCI, together with Fertiglobe, is one of the largest producers and traders of ammonia and methanol globally.

BANGLADESH

Carbon capture ammonia plant nearing completion

Construction work at the Ghorashal-Polash Urea Fertilizer Project (GPUFP) is nearing completion. More than 850 Chinese employees from the China National Chemical Engineering & Construction Corporation Seven Ltd. (CC7), in collaboration with its Japanese partner Mitsubishi Heavy Industries (MHI), have been working round the clock to complete the large scale project as scheduled. According to reports in the Chinese state media, 90% of construction work is now complete, and the project is running two months ahead of schedule, with completion now expected in December 2023. Once completed, it will become the biggest fertilizer plant in Bangladesh and one of the largest in South Asia, with an estimated daily production capacity of 2,800 t/d of urea and 1,600 t/ds of ammonia. The plant is sited in the Narsingdi district, 51 km northeast of the capital city of Dhaka. Current fertilizer demand in Bangladesh is around 2.5 million metric tons per year, of which this project will supply around 1.0 million t/a. It will also become the first-ever green fertilizer plant in Bangladesh, using carbon capture.

PAKISTAN

Gas supply agreement to end May

The Directorate General of Gas (Petroleum Division) has directed Sui Northern Gas Pipeline Limited (SNGPL) to supply gas to two urea fertilizer plants for a temporary period without subsidy as agreed by the cabinet Economic Coordination Committee (ECC). The ECC based its decision on a submission by the Ministry of Industries and Production regarding the country's urea fertilizer requirement for the 2023 kharif season. In order to produce sufficient fertilizer domestically the gas will be supplied to Fatima Fertilizers and Agritech to the end of May 2023. Pakistan's fertilizer production continues to be dogged by gas supply constraints. Demand for urea is estimated to be 3.2 million t/a, whereas production is estimated to be around 2.9 million t/a, with a shortfall of 0.3 million t/a.

INDIA

Larsen & Toubro to build IGAN plant

Chambal Fertilizers has awarded Larsen & Toubro the engineering procurement and construction contract to build an industrial grade ammonium nitrate (IGAN) plant as well as a an associated nitric acid plant at Gadepan near Kota in Rajasthan province. Capacities for the plants will be 240,000 t/a for the IGAN plant and 210,000 t/a for the nitric acid plant, both to license technology from Casale SA. ■

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UNITED KINGDOM

Johnson Matthey to license technology for low-carbon hydrogen project

Johnson Matthey (JM) has signed an *LCH*™ technology licence with Equinor and Linde Engineering for H2H Saltend, one of the UK's largest low carbon hydrogen projects. JM was selected alongside EPC partner Linde Engineering for the major FEED contract by Equinor. The licence counts towards JM's milestone of winning more than ten additional large-scale projects by 2023/24.

H2H Saltend is a 600 MW low carbon (blue) hydrogen production plant with over a 95% carbon capture rate, one of the first of its kind and scale in the UK, helping to establish the Humber as an international hub for low carbon hydrogen. This is the first phase of Equinor's 'Hydrogen to Humber' (H2H) ambition to deliver 1.8 GW of low carbon hydrogen production in the region, nearly 20% of the UK's national production target by 2030.

Due to be operational by 2027 and located at the energy intensive Saltend Chemicals Park, to the east of Hull, it will help to reduce the park's emissions by up to one third. To achieve this, low carbon hydrogen will directly displace natural gas in several industrial facilities reducing the carbon intensity of their products, as well as being blended into natural gas as the Equinor and SSE Thermal's Saltend Power Station. The amount of CO_2 captured will be around 890,000 t/a, equivalent to taking about 500,000 cars off the road annually.

Alberto Giovanzana, Chief Commercial Officer, Catalyst Technologies at Johnson Matthey said: "Hydrogen will play an important role in helping us reduce carbon emissions. Using Johnson Matthey's *LCH*™ technology for this project will enable the production of hydrogen with 95% less emissions and demonstrate the UK's leadership in low carbon technologies. We're excited our technology was chosen to be at the heart of this leading project, creating huge energy efficiencies for our customers."

Johnson Matthey (JM) has also extended its partnership with SFC Energy to include a commitment from JM to develop and supply proton exchange membrane (PEM) components to support SFC Energy's growth in hydrogen fuel cells. SFC Energy AG is a leading provider of hydrogen and direct methanol fuel cells for stationary and mobile hybrid power solutions. With more than 60,000 fuel cells sold worldwide, SFC is expanding its offering of higher power hydrogen fuel cells for stationary markets.

JM and SFC's long-term collaboration has to date centred around the supply of components for SFC's direct methanol fuel cell (DMFC) systems. Now SFC will receive assets and technology to produce these components for DMFC at SFC's new development and manufacturing site near Swindon, UK. JM and SFC plan for JM to supply catalysts for this application for at least 5 years. This agreement allows JM to focus on its strategic hydrogen fuel cells and electrolyser business, and SFC to secure the supply chain for this important part of their business.

Looking to the future, JM and SFC have signed a memorandum of understanding (MoU) detailing their intention to work together in the field of hydrogen fuel cells for stationary applications, where PEM components will be developed under a joint development agreement (JDA) with the intent that JM supplies these components for at least 5 years.

Mark Wilson, Chief Executive of Hydrogen Technologies at Johnson Matthey said: "The evolution of our partnership with SFC Energy to focus on PEM components demonstrates how our technology, manufacturing capabilities, and expertise make us ideal long-term partners for our customers. It is an important step in the implementation of our strategy." ■

DENMARK

Lego to buy green methanol for plastics production

Toy maker LEGO says that it will buy green methanol for use in manufacturing its colourful plastic bricks when the world's first large-scale plant starts operations next year. Privately owned renewable energy firm European Energy, which is developing the plant in Aabenraa, Denmark, says that Danish drugmaker Novo Nordisk will also buy its green methanol to substitute for fossil-based plastic in insulin pens and other medical devices.

The European Energy plant will begin producing 32,000 t/a of green methanol per year from next year, based on energy from wind and solar plants as well as biogenic carbon dioxide. Shipping company Maersk, which has 19 vessels on order that can sail on methanol, last year agreed to purchase half of capacity at the plant.

SPAIN

Técnicas Reunidas begins engineering work on green methanol plant

CETAER (Centro de Transición Andaluz de Energías Renovables) has signed a collaboration agreement with Técnicas Reunidas for the development of a green methanol plant to be built in Almería. The facility will produce 37,000 t/a of green methanol using 7,200 t/a of renewable hydrogen with 54,000 t/a of carbon dioxide captured in industrial processes. It is expected to start commercial operations in 2026.

The project, called "Nascar", includes in a first stage the configuration study of the plant, the preparation of the technical documentation for the permits and the development of a feasibility analysis. The second and third stages of the agreement will cover front-end engineering design and engineering, procurement and construction services, respectively.

Anticipated demand for green methanol as an alternative energy resource to non-renewable fuels in the transport sector will ultimately lead to the plant reaching a capacity of 300,000 t/a by 2030. Spain's Institute for Energy Diversification and Saving (IDEA) has awarded the project a "Pioneers 3 Plan" subsidy, recognising it as an "actual and effective integration of a large scale electrolyser in the context of an industrial solution to proof the viability of massive renewable hydrogen production".

SWEDEN

Gothenburg to develop methanol bunkering storage

The port of Gothenburg is partnering with Inter Terminals Sweden (ITS) to develop a methanol storage facility for bunkering by the end of 2023. ITS will rebuild tanks and other related infrastructure in Gothenburg. The management of the gases from methanol when loading into ships is that will be handled through a vapor recovery unit, ITS said. In January, ship owner Stena Line bunkered its methanol-powered ferry Stena Germanica in Gothenburg via ship-to-ship transfer. Previously, Stena Germanica received methanol from trucks when berthed at the port. The methanol was supplied from methanol producer Methanex.

PHOTO: SIPG

The port of Shanghai, the world's busiest.

CHINA

Maersk to bunker green methanol in Shanghai

Maersk has signed a memorandum of understanding (MoU) with Shanghai International Port Group (SIPG) on strategic cooperation for Shanghai port's methanol marine fuel project. The two parties will collaborate to explore green methanol fuel vessel-to-vessel bunkering operations after Maersk's green methanol container vessels arrive in 2024. Maersk and SIPG will deepen cooperation in stages, according to the shipping company.

In the first phase, SIPG, as Maersk's potential energy bunkering service provider, will carry out services of vessel-to-vessel bunkering and fuel tank storage at the port. In the potential second stage, the parties will explore how to form an all-round energy strategic partnership to promote the extension from bunkering services to the upstream of the green methanol industry chain.

Maersk has set a net-zero emissions target for 2040 across the entire business, and the delivery and operation of its 19 vessels – with dual-fuel engines that are able to operate on green methanol – is expected to accelerate the evolution of climate neutral shipping. Maersk says that establishing port bunkering infrastructure for methanol is thus imperative to achieve this goal.

"We are very pleased to form the partnership with SIPG, leveraging its strong capabilities in bunkering service and port operation," said Vincent Clerc, CEO of Maersk. "Through joint efforts, we can provide low-carbon logistics service for our customers, also contributing to China's pledge to be carbon neutral by 2060. Meanwhile, we also endeavour to cultivate synergies with SIPG and fuel manufacturers to optimise fuel infrastructure efficiencies."

Chairman of Shanghai International Port Group, Gu Jinshan, said: "As the demand for sustainable fuels increase, establishing the green fuel bunkering service will be another milestone for SIPG, improving port services and enhancing the competitiveness of Shanghai port, in a bid to transform the company into a low-carbon and eco-friendly energy hub in Asia Pacific."

INDIA

Jakson Green to set up small scale green methanol plant

Indian energy company Jakson Green has won a contact from state-run NTPC to set up a methanol synthesis facility at its Vindhyachal thermal power plant in Madhya Pradesh. The methanol plant will have a production capacity of 10 t/d (3,300 t/a). It will convert 20 t/d of CO2 to methanol through a catalytic hydrogenation process, using carbon dioxide captured from the power plant's flue gas together with green hydrogen produced by electrolysis, the company said.

Jakson Green will oversee the entire design, engineering, procurement, and construction of the project on a turnkey basis, in partnership with NTPC and their Japanese technology provider for the methanol synthesis process.

Tata Steel to set up a pilot green methanol plant

A similar sized (10 t/d) unit is also planned by Tata Steel at its Kalinganagar facility in Odisha to produce methanol using blast furnace flue gases. The project aims to explore the possibility of combining carbon dioxide from steel mill blast furnaces with hydrogen from electrolysers to produce green methanol. This will enable Tata Steel to test the feasibility of this process and potentially pave the way for a more sustainable approach to methanol production in the country.

FINLAND

Lhyfe buys into Flexens

Lhyfe, a French developer of green and renewable hydrogen projects, has announced that it has acquired a 49% stake in the Finnish company Flexens, also involved in renewable and green hydrogen as well as Power-to-X projects. This is Lhyfe's first major investment, and is part of its strategy to expand rapidly in countries with major plans for renewable and green hydrogen. The move will accelerate the commercial deployment and Finland-based projects for both entities.

Flexens was founded to capitalise on the expertise gained from the Smart Energy Åland (SMÅ) research programme, and has developed significant capabilities in energy system modelling and project development since 2018. It has a commercial pipeline with a total foreseen capacity exceeding 1.5 GW in Finland and abroad, including: a 300 MW project at Kokkola, backed by letters of intent with critical stakeholders and expected to be commissioned by 2027; Åland, where after many years of research in the Åland archipelago, the company has developed the world-leading Smart Energy Åland demonstration project to showcase a society based on 100% renewable electricity, using hydrogen and Power-to-X applications; and finally Lempäälä, where Flexens will launch an initial 2.5 MW green hydrogen production unit in 2025, which will be connected to Finland's first hydrogen refuelling station. The plant will be integrated into the local intelligent energy system LEMENE, owned by the energy company Lempäälän Energia.

Lhyfe inaugurated the world's first industrial site for the production of green hydrogen in direct connection with a wind farm in 2021 and, in 2022, the world's first offshore green hydrogen production demonstrator. The company aims to have more than 3 GW of installed capacity by 2030, and will have three new industrial sites in operation by the end of 2023 and has already announced several projects throughout Europe, including in Nordic countries, with GreenLab and GreenHyScale in Denmark, Storgrundet, Trelleborgs Energi and Harjedalen in Sweden and Horisont Energi in Norway. ■

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SABIC's general assembly has approved the appointment of **Abdulrahman Al-Fageeh** as SABIC CEO, and an executive member of the board of directors until April 9, 2025 – the Board's tenure end date. In its previous meeting, the Board of Directors, had agreed to appoint **Dr. Mohammed Yahya Al-Qahtani** as vice chairman. At the meeting, Khalid Al-Dabbagh, SABIC Chairman, noted that the past year had been difficult one, though "SABIC managed to face the challenges by intensifying its development programs to achieve record numbers in terms of production, sales, and revenues that exceeded the achievements of the previous year. However, its net profits have not met its aspirations and have shrunk compared to last year due to the worsening global conditions." He also said that SABIC is pursuing plans to manage working capital through the Cash Cost Transformation program, and is sparing no effort to achieve sustainable growth, adopt long-term strategic goals for sustainability, and reduce emissions related to the life cycle of its products across the value chain.

Abdulrahman Al-Fageeh, confirmed as SABIC CEO, highlighted that "SABIC has successfully faced the challenging global conditions, investing in its collaborative relations with Saudi Aramco, which led to the successful supply of the world's first commercial shipment of independently certified blue ammonia to South Korea. It is also focusing on strong capital discipline to enhance profitability and future growth opportunities, adding more investments to develop information technology infrastructure, benefit from digital transformation, and rely on the effective use of big data tools to be more proactive and data-driven."


Kazuhito Tojo.

Mitsubishi Heavy Industries Compressor International Corporation (MCO-I), a leader in the design and manufacturing of compressors, drive turbines, gear boxes and their control systems, has named **Kazuhito Tojo** as president and CEO. He succeeds Jun Fukuda, who will return as an advisor at MCO's facility in Hiroshima, Japan. Tojo will bring his leadership expertise to the MCO-I Pearland Works facility as part of the company's plans to increase its North American turbomachinery footprint and enhance after-sales capabilities.

Tojo began his career with Mitsubishi Heavy Industries, Ltd (MHI) in 1996, working in a variety of manufacturing positions, including shop operations. He has provided growth for both MHI and MCO through a range of investment opportunities. Tojo transferred as general manager to MCO-I's Houston office in 2015 to build the process foundation for the Pearland facility. He then returned to Japan to manage the manufacturing department as deputy general manager, and later general manager of manufacturing at MCO Hiroshima. In 2021, Tojo transferred to Houston where he has served as executive vice president.

Tojo commented, "As the world shifts to a carbon neutral society, MCO-I is a valued solutions provider for our customer's both new business and after-service needs. Our goal is to contribute to our customers' success by delivering cutting-edge technology and reliable compression systems."

BASF has announced that **Tobias Dratt**, President, North America, BASF Corporation, will assume responsibility for the Global Business Services division in Ludwigshafen, Germany, from May 1, 2023, while his counterpart **Marc Ehrhardt**, president, Global Business Services, Ludwigshafen, will, at the same time, assume responsibility for the North America division, BASF Corporation in New Jersey. ■

Calendar 2023

MAY

22-24

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

22-24

IFA Annual Conference, PRAGUE, Czech Republic
Contact: IFA Conference Service, 49 Avenue d'lena, Paris, F75116, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

1-2

33rd IMPCA Methanol Mini-Conference, DUSSELDORF, Germany
Contact: IMPCA, Avenue de Tervueren 270 Tervurenlaan, 1150 Brussels, Belgium
Tel : +32 2 741 86 64
E-mail: info@impca.be

8-9

NH3 Event, ROTTERDAM, Netherlands
Contact: Stichting NH3 event Europe, Karel Doormanweg 5, 3115 JD Schiedam, The Netherlands
Tel: +31 10 4267275
Email: info@nh3event.com

11-14

IMTOF 2023, LONDON, UK
Contact: Polly Murray, Johnson Matthey
Email: polly.murray@matthey.com

AUGUST

20-24

67th AIChE Safety in Ammonia Plants and Related Facilities Symposium, MUNICH, Germany
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363
Web: www.aiche.org/ammonia

SEPTEMBER

10-15

Ammonium Nitrate/Nitric Acid conference, VARNA, Bulgaria
Contact: Sam Correnti, DynoNobel, Karl Hohenwarter, Borealis.
Email: sam.correnti@am.dynonobel.com, karl.hohenwarter@borealisgroup.com, annaconferencehelp@gmail.com
Web: annawebsite.squarespace.com/

25-26

World Methanol Conference, VIENNA, Austria. Contact: David Coates, OPIS
Tel: +1 713 305 0116
Email: dcoates@opisnet.com

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Plant Manager+

Problem No. 67 Redrilling liquid holes in the ferrules of a CO_2 stripper

Petrus J. C. Kaasenbrood.

In 1967 Stamicarbon revolutionised the urea process by the invention of the high-pressure CO_2 stripper by Petrus J. C. Kaasenbrood (pictured, left). The high-pressure CO_2 stripper led to following benefits:

- **the ammonium carbamate could be recycled at synthesis pressure so extra water needed to be added to recycle the unconverted ammonium carbamate from the reactor;**
- **a medium-pressure recirculation section was no longer needed;**
- **with the condensation of strip gases in the high-pressure carbamate condenser, low-pressure steam could be produced which could be used in the downstream sections approximately halving the steam consumption of a urea plant.**

At the same time, however, the performance of the CO_2 stripper has become possibly the most critical parameter in these urea plants. A new stripper that is properly designed will provide good performance (stripper efficiency). But during its lifetime fouling, passive corrosion and other corrosion failure modes impact the stripper efficiency in a negative way.

One critical parameter for the stripper efficiency is the size of the liquid holes in the ferrules. There are typically three holes per ferrule. The diameter and shape of these holes slowly change due to cross cut end attack corrosion. The diameter increases and the shape changes from round to oval as the rate of cross cut end attack corrosion differs depending on the rolling direction of the applied steel during its fabrication process.

For high stripper efficiency it is very important that the liquid holes of each tube ferrule have the same dimensions. This is checked by delta-P measurements of each ferrule: Air is blown through the three holes and the delta-P is measured. The range in the delta-Ps of all ferrules should be as small as possible in order to assure a high stripper efficiency.

Older strippers show a larger range than a new stripper and over time the diameter of the holes eventually become too big and the range of the delta-Ps become too large to realise a sufficient stripper efficiency. A low stripper efficiency in a Stamicarbon urea plant leads to higher loads/pressures in the low-pressure recirculation section and higher recycle rates of unconverted ammonium carbamate, reducing the maximum possible plant load.

Replacing ferrules is quite expensive and therefore many plants try to extend the lifetime of the ferrules by redrilling the liquid holes. Some experiences are discussed in this discussion.

Abdul Samad of Fauji Fertlilizer Bin Qasim Limited in Pakistan kicks off the discussion: As per recommended practice, we perform the delta-P check of all ferrules of the urea stripper during turnaround and replace those that have failed the delta-P check as per Stamicarbon procedure. We intend to carry out the repair of used ferrules (with enlarged holes). Can anyone suggest the recommended method to repair used ferrules and what inspection checks need to be followed during and after completion of the repair?

Sunil Kulkarni of Mangalore Chemicals and Fertilisers in India replies: We have done this repair on stripper ferrules by drilling three different holes at 120 degrees apart and closing the old holes. This was with ferrules made of 2RE69 (Alleima 25-22-2) material.

Mark Brouwer of UreaKnowHow.com in the Netherlands asks some further questions: Would you be so kind to share with us your general experiences like:

- Was the redrilling exercise successful?
- How much time it did take?
- What delta-P range did you achieve?

Sunil replies: The exercise of redrilling the liquid holes of the stripper ferrules was successful and we used the redrilled ferrules for another 7-8 years. The delta-P after redrilling was in the range 400-450 mm WG. The whole drilling operation after blocking the old holes was done carefully with a new jig in a time period of about 10 days (1,680 ferrules).

Ali Azhar of Fauji Fertlilizer Bin Qasim Limited in Pakistan asks a further question: After welding the old holes, was the surface smooth inside of the welded area or was there any cavity left at the inner surface of the ferrules?

Ahsan Sarfraz of Fatima Fertilizer Ltd in Pakistan shares his experience with another solution: Another procedure we have done successfully at PAFL (Pak-American Fertilizer Ltd) is to measure the hole size of all holes of a single ferrule. Now close any of the holes based on the size so that the overall hole size across a single ferrule remains the same. This practice was also very successful, and we used these ferrules for three more years before overhauling the whole stripper as part of an upcoming plant revamp. The whole activity was completed in two days (1,846 ferrules). This is the simplest method requiring less time and accuracy and the results are also pretty good. In case you have replaced the ferrules with new ones you have sufficient time to redrill the holes.

Majid Khan of Pakistan follows up with another question: What happens if we shorten the length of ferrules due to corrosion in the lower part (fitted inside the tube)? I have come across a case study where shortening of the ferrule led to stripper flooding at high load.

Prem Baboo, Expert at UreaKnowHow.com joins the discussion: Please refer to my Technical Paper "Energy saving in Urea Plant by equipment modifications.pdf" available in the E-Library of UreaKnowHow.com.

Majid replies: I have gone through the paper. It clearly mentions that the ferrules were shortened and the liquid hole size was increased from 2.8 mm to 3.1. Why did you do that?

Prem responds: The thinned bottom portion of the ferrules are removed due to the adverse effect on making the heat transfer film. It is so thin that it can easily bend and disturb the flow of solution.

The tangential hole diameter was increased due to load limitation. 2.8 mm was designed for a plant load of 1,100 t/d. The plant load had increased to 1,500 t/d, hence the tangential hole diameter needed to be increased according to the load otherwise flooding would occur in the stripper tubes. The total area of the tangential holes needs to be increased by about the same ratio as the plant load increase or with 90% of plant load increase, e.g., plant load increase is 26%, then total tangential hole area increase should be 90% X 26% = 24%. 2.8 mm diameter with three holes per ferrule and 1,677 ferrules means a total tangential hole area is 30,962.8 mm². The hole area is to be increased by 30,962.8 X 1.24 = 38,393.9 mm². The area of one hole = 7.63 mm². Hence each hole diameter is 3.11 mm.

Wasif Qazi of Engro Fertilizer Pakistan asks a further question: Will the decrease in ferrule length have any impact on the stripper efficiency? If yes, how it can be improved?

Prem replies: No, the efficiency will not decrease.

Mark adds some further comments: The flow through the liquid holes is dependent not only on the hole diameter or hole area but also on the liquid height. With the same hole area the liquid height will increase with a larger plant load. There could be a moment when overflow of liquid of the ferrules occurs, which will obviously lead to a bad falling film formation and low stripper efficiency.

When the hole area increases, the liquid height will reduce at the same plant load. One must assure a minimum liquid height to realise that each ferrule receives the same amount of liquid taking into account that the stripper may not be installed perfectly vertical, the liquid may not be perfectly divided over the complete tubesheet surface and sufficient buffer capacity of the liquid should be assured. In practice this means that a stripper with larger liquid hole areas will have a higher turndown ratio than its original design.

This series of discussions is compiled from a selection of round table topics discussed on the UreaKnowHow.com website. UreaKnowHow.com promotes the exchange of technical information to improve the performance and safety of urea plants. A wide range of round table discussions take place in the field of process design, operations, mechanical issues, maintenance, inspection, safety, environmental concerns, and product quality for urea, ammonia, nitric acid and other fertilizers.

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Challenges for gasification technology

Gasification, particularly of waste and biomass, is seeing interest as sustainable sources of syngas. But there are both technical and commercial challenges to wider adoption.

As the world seeks more sustainable ways of producing the everyday chemicals that we have come to rely upon, from fertilizers such as ammonia and urea to methanol, fuels and polymers, generation of synthesis gas from unconventional sources has become a particular area of interest. Many agricultural processes generate waste biomass, and major municipalities generate large volumes of domestic waste which cannot be easily recycled. In both cases, gasification of these waste streams has been seen as a more sustainable alternative way to generate usable synthesis gas. However, waste and biomass gasification units have sometimes had an unhappy history with a number of failed and abandoned projects, especially in the UK.

The Bioenergy Infrastructure Group (BIG) waste gasifier at Hoddesdon, near Hull, UK; a failed gasification project.

Gasification

Gasification involves feeding finely pulverised waste material into a high temperature (>700°C) gasifier with a restricted oxygen flow to partially oxidise carbon components into CO and H_2 over a catalyst bed. The catalyst bed may be fixed, or fluidised using the gas flow, or use an entrained flow where the feed and oxidant/steam are co-fed together into the gasifier, generally at higher temperatures (1,200-2,000°C). Fixed bed gasifiers are mechanically simple but suffer from poor mixing and heat transfer and are not widely used. Entrained flow gasifiers generate high quantities of ash which deposits on the gasifier walls depending upon the feedstock. Depending on the operating conditions of the gasification process, the molten ash deposits often solidify, causing plugging and the blockage of critical parts of the gasifier thereby hindering process efficiency. Fluidised bed gasifiers are the most efficient and widely used, but can produce high particulate levels which can cause erosion.

Fluidised bed gasifiers are operated at high pressure, which can result in operational complications such as defluidisation from particle agglomeration, particularly when agricultural crops and wastes are used as feedstock in the gasification process. This is because agricultural crops and wastes contain an increased amount of ash/alkali and, the alkali content of ash (sodium and potassium) can form low-melting mixtures with silica in the sand which is the most common bed material in an FBG process. Under this condition, agglomeration and sintering will occur, triggering the formation of a thin sticky substance around the bed particles with an instant loss of bed fluidisation. This can be avoided by using aluminium oxide or magnesium carbonate instead of silica, but this increases the cost of the process.

Gas cleaning

One of the issues with biomass and gasified municipal waste is the wide mix of components that can be found in the gasified waste stream including, but not limited to, ammonia, nitrous oxides, sulphur oxides and hydrogen chloride, BTX (benzene/toluene/xylene) and heavy metals. These can be cleaned by suitable gas cleaning processes. HCl, H_2S and SO_2 are highly soluble and can be removed via water scrubbing. Ammonia can be decomposed using iron, nickel or ruthenium-based catalysts, but again these all add cost and complexity to the process.

Another major problematic component is tar. This is a mixture of polyaromatic hydrocarbons which exist as a gas at the high temperatures of the gasifier, but which at lower temperatures condense and can deposit in downstream equipment, blocking and fouling pipes, valves and turbines. Compared to a fixed bed gasifier, fluidised bed gasifiers, especially circulating fluidised bed reactors, have high gas speeds to keep the catalyst bed fluid, leading to shorter residence times for tar molecules in the reactor and lower conversion. Simple filtration of tar blocks the pores of a filter and creates a pressure drop. Tar also contains toxic chemicals, making its handling and disposal a health and environmental issue. The best way to tackle tar formation is to oxidise it to lighter components which remain as gases. This can be done via catalytic conversion. Different types of catalysts have been proven to be active for tar and ammonia decomposition. However, the utilisation of catalyst in the primary bed is problematic because it deactivates rapidly due to the fouling of ash and carbon on the surface.

Teething troubles?

Some of the initial enthusiasm for waste and biomass gasification has been tempered in the past few years by a number of high profile project failures, particularly in the UK, which had bet heavily on the technology. Both process and economic issues remain, with tar and ash formation remaining technical challenges still yet to be fully overcome. However, the technology continues to develop and has been operated successfully in some installations, and may yet hold the key to dealing with the volumes of waste that our society generates. ■

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NITROGEN+SYNGAS
ISSUE 383
MAY-JUNE 2023

BCInsight

China Works, Black Prince Road
London SE1 7SJ, England
Tel: +44 (0)20 7793 2567
Web: www.bcinsight.com
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Sustainable fertilizer production

Pejman Djavdan, CEO of Stamicarbon looks at the ways in which the fertilizer industry must grapple with issues such as decarbonisation, sustainability and more efficient use of nutrients.

One of the most urgent problems confronting humanity this century is how to feed a growing global population in a sustainable way, in harmony with the planet and its finite resources. The second United Nations Sustainable Development Goal is to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture." It is an important and ambitious goal, especially as the world's population continues to increase rapidly – from around two billion in 1927 to three billion in 1960 and more than doubling to seven billion in 2011. By 2055, this figure is predicted to be around ten billion. In addition to exponential population growth, we also see an increase in the amount of food consumed per capita. The Food and Agriculture Organisation (FAO) of the United Nations has estimated that global crop production needs to increase by more than 45% by 2050 if we want to end hunger and malnutrition[1].

It is clear that we need to intensify crop and food production to be able to feed the world population and achieve food security. The urgent and challenging question is how to do this in a sustainable manner. How do we make sure that we grow sufficient crops and produce sufficient food that has better quality, is economically available for everyone and has less impact on the environment and our planet?

Mineral fertilizers play a significant role in the intensification of agriculture – responsible for more than half of the world's food production – but their production and application also present several challenges. Stamicarbon, MAIRE's innovation and licensing company engaged in nitrogen technologies believes that technological innovations are vital in contributing to solving global food challenges by intensifying agriculture while at the same time protecting the environment.

Opening of the controlled-release fertilizer plant in Sylacauga, Alabama, USA.

PHOTO: STAMICARBON

The company aims to decrease emissions and energy consumption and increase fertilizers' nutrient use efficiency (NUE). To achieve that, Stamicarbon is focusing its strategic research and development efforts on two main areas:

- Sustainable production of nitrogen-based fertilizers from sustainable feedstocks and renewable energy sources;
- Making fertilizers more efficient and effective to increase their NUE.

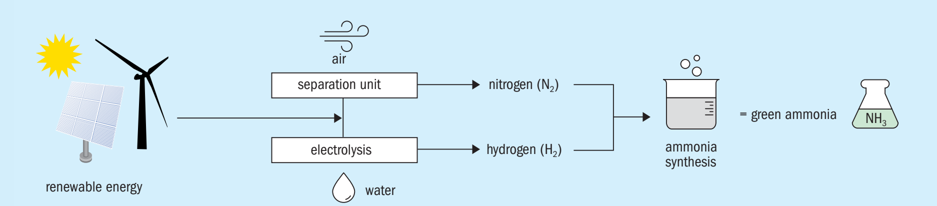
Sustainable fertilizer production

In the past, most technological innovations in the fertilizer sector were driven by economies of scale and capacity increases. Today, the industry must focus on producing and using fertilizers with the lowest possible environmental impact. Adding nutrients to plants allows them to grow faster and stronger, resulting in higher yields and wider availability of certain foods. But this comes with a price for the environment, with global fertilizer production responsible for about 1.4% of CO_2 emissions yearly[2].

There is an evident need to balance using fertilizers for intensifying agriculture and reducing their carbon footprint. Conventional processes that rely on fossil fuels (such as coal and natural gas) for fertilizer production must be redefined to ensure a sustainable, environmentally-friendly future. To address this challenge, Stamicarbon introduced its Stami Green Ammonia technology while further investigating the production of nitrates directly from renewable energy and renewable resources.

Green ammonia production relies on water electrolysis to produce green hydrogen instead of using natural gas or coal as feedstock. In the green ammonia process, green hydrogen from electrolysis is used together with nitrogen from air, and the entire ammonia production is powered by renewable or carbon-free energy resources (see Figure 1). The resulting green ammonia is then used to produce nitrogen fertilizers such as ammonium nitrate.

Fig. 1: Stami Green Ammonia production process



Source: Stamicarbon

Considering that ammonia production causes about 1% of total greenhouse gas emissions, green ammonia represents a significant leap forward for sustainability in the fertilizer industry while also offering opportunities for collaboration between the fertilizer and energy markets. This collaboration is already being explored by Stamicarbon in the EU-funded INITIATE project to use carbon-rich off-gases from steel mills as feedstock for fertilizer production.

Green ammonia project highlight

Stamicarbon has recently completed a pre-feasibility technical study with Minbos Resources to determine the most suitable plant configuration for producing green nitrate products from renewable electricity in Angola. The green ammonium nitrate production complex is to be located in Malanje Province, east of the capital Luanda.

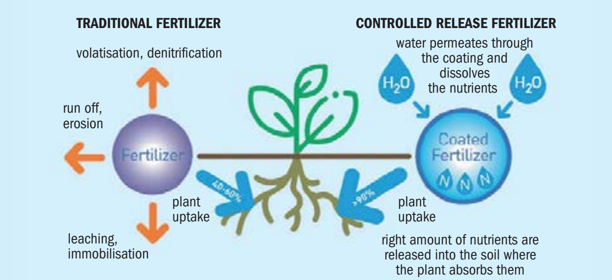
The study assessed the production of two types of nitrates: calcium ammonium nitrate to be used as a fertilizer in the domestic market and low density ammonium nitrate for the mining industry in neighbouring countries. The production complex combines Stami Green Ammonia and Nitric Acid technologies, including the nitrates finishing in partnership with INCRO. The complex will use up to 200 MW of 100% renewable electricity from the nearby Capanda hydroelectric dam.

Sustainable fertilizers

Not only will the production of fertilizers become increasingly more sustainable in the future, but fertilizers themselves need to become more effective, efficient and environmentally friendly. Here NUE plays an important role. NUE can be described as the ratio between the nutrient input of fertilizers and the nutrient output of harvested crops.

The challenge with existing fertilizers is that many nutrients are lost to the environment as they volatilize into the air or leach into the soil. Consider that: up to 60% of nitrogen ends up in the surface water[3]; up to 85% of phosphorus is unused in the first year of application[4]; up to 80% of potassium is not taken up by cereal crops[5]; and up to 80% of sulphur is immobilised or lost to surface water[6].

Fig. 2: How controlled-release fertilizer prevents nutrient losses



Source: IFA[3]

These losses can have undesirable consequences for the environment and human health, such as high levels of nitrates and phosphorus in groundwater, ammonia volatilisation, and emissions of nitrogen oxides and nitrous oxide. Enhanced efficiency fertilizers (EEFs) and multi-nutrient fertilizers are essential in mitigating nutrient losses from fertilization and improving the NUE.

Enhanced efficiency fertilizers

EEFs include controlled-release, slow-release and inhibited fertilizers. These innovative fertilizers prevent nutrient losses by inhibiting the biological transformations in the soil (inhibited fertilizers) or controlling the release of nutrients (slow- and controlled-release fertilizers). Most commonly EEFs are nitrogen products. For example, urea can be coated with sulphur, supplying nutrients at the same rate as the uptake by the plant, with the added benefit of delivering a small amount of sulphur. Another example is a coating where a membrane around urea facilitates the controlled release of nutrients to the soil, preventing the oversupply of nutrients after fertilizer application and minimising nutrient losses to air or ground water.

Innovative fertilizers apply the 4R principle: they deliver the right nutrients at the right time, place, and rate. Stamicarbon partnered with Pursell Agri-Tech in the USA to further develop and license controlled-release fertilizer technology in 2018 (see photo). This technology minimises nutrient losses during fertilization, improving the NUE (see Figure 2) and helping to address the challenge of feeding the growing population with – and decreasing the environmental impact of – fertilizer use. As a next step, the company is currently working

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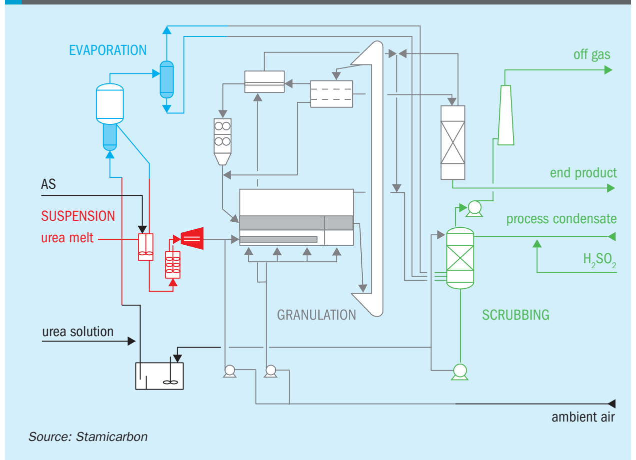
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27

Fig. 3: **Process flow diagram of Stamicarbon's UAS design**



Source: Stamicarbon

with partners on developing biodegradable coatings for controlled-release fertilizers and adding (micro)nutrients to fertilizers.

Multi-nutrient fertilizers

For a long time, farmers relied on single-nutrient applications, most commonly with a nitrogen-based fertilizer. However, different crops require different macronutrients (e.g., potassium, phosphorus, calcium, magnesium and sulphur) and micronutrients (e.g., boron, iron, zinc and copper) for optimal growth. The required amounts and ratios of those nutrients change during the growth cycle. Adding the necessary macro- and micro-nutrients in a single fertilizer granule could help improve the NUE.

Flexible technologies for compounding urea or ammonium nitrate with other nutrients can increase the NUE by offering the plants the right nutrients at the right time. Stamicarbon has developed a process for producing granular urea ammonium sulphate (UAS) that will help to reduce nutrient loss due to ammonia volatilisation (see Figure 3). UAS applied to the soil will improve crop quality and yields and can be used for various crops, such as barley, wheat, oats, grassland, rapeseed, etc. The UAS process is flexible and enables the production of urea with the addition of other macro- and micronutrients.

Geographic location, type of crop and soil conditions will determine the economic advantages of improved NUE for farmers. In China, where the overapplication of nitrogen has presented a challenge, farmers can benefit from savings on fertilizer usage. In areas with nutrient depletion and lower crop yields, such as sub-Saharan Africa, improving NUE will help increase yields. And in Europe and the USA, where yields are high and the NUE is improved, reducing the environmental impact of fertilizers could play a decisive role in the choice of fertilizer.

A new era

On March 2, 2023, MAIRE announced its 2023-2032 strategic plan; "Unbox the Future." The strategic plan maps out a new phase in the Group's industrial cycle, building on its innovative technologies and engineering capabilities based on more than 100 years of history in chemistry. The Group is accelerating its positioning in the energy transition by leveraging its two new business units: Sustainable Technology Solutions and Integrated Engineering and Construction Solutions.

Stamicarbon is ready to further accelerate the energy transition in the fertilizer industry, leveraging cutting-edge technologies for future-proof fertilizer production. The future demands a high level of sustainability and industries are stepping up their investment in the production of sustainable fertilizers. Sustainability involves transitioning from a traditional fossil-based industrial model to a new low-carbon-based model through transforming processes and economic systems. This transition is also supported by governmental incentives and regulations.

The future of fertilizers

There is awareness both in the fertilizer industry and wider society about the increasing need to boost agricultural productivity while at the same time reducing its environmental impact. These two may seem contradictory when viewed from a polarizing angle, however, both are important and need to be addressed simultaneously.

A change is needed to build a future where humanity, industries and the planet can thrive. This involves continuous transformation aimed at solving global challenges with breakthrough solutions.

Stamicarbon is determined to be part of the solution by continuously innovating and improving technologies, collaborating with its partners, customers and suppliers and challenging the status quo.

Stamicarbon is pioneering with a higher purpose to enable the world to feed itself and improve quality of life. ■

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PROJECT LISTING

Nitrogen project listing 2023

Nitrogen+Syngas's annual listing of new ammonia, urea, nitric acid and ammonium nitrate plants.

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
AUSTRALIA							
Daelim	KBR	NeuRizer	Leigh Creek, SA	Ammonia	1,600	DE	2025
Daelim	Stamicarbon	NeuRizer	Leigh Creek, SA	Urea	2,850	DE	2025
Technip FMC	Topsoe	Strike Energy	Garaldton, WA	Ammonia	2,400	DE	2026
Technip FMC	Saipem	Strike Energy	Garaldton, WA	Urea	4,200	DE	2026
Saipem, Clough	Topsoe	Perdaman	Karratha, WA	Ammonia	3,500	BE	2027
Saipem, Clough	Saipem, TKFT	Perdaman	Karratha, WA	Urea	2 x 3,100	BE	2027
n.a.	n.a.	H2Perth	Kwinana, WA	Ammonia	1,800	DE	2027
n.a.	n.a.	CSBP	Kwinana, WA	Ammonia	900	P	2027
BANGLADESH							
MHI, CNCIC	Saipem, TKFT	BCIC	Ghorasal Polash	Urea	2,800	UC	2023
BRUNEI							
thyssenkrupp IS	thyssenkrupp IS	Brunei Fertilizer Ind.	Sungai Liang	Ammonia	2,200	C	2023
thyssenkrupp IS	Stamicarbon, TKFT	Brunei Fertilizer Ind.	Sungai Liang	Urea	3,900	C	2023
CANADA							
Black & Veatch	Stamicarbon	Confidential	n.a.	Urea	+300	RE	2024
CHILE							
TOYO	KBR	HyEx	Tocopilla	Ammonia	55	DE	2025
Wood Group	n.a.	Total Eren	San Gregario	Ammonia	2,600	FS	2027
CHINA							
n.a.	Casale	Oriental Energy	Binhai	Ammonia	900	UC	2023
n.a.	Casale	Hubei Yihua	Yichang, Hubei	Ammonia	2,000	UC	2023
n.a.	Casale	Shanxi Qingshui	Yulin, Henan	Ammonia	2,000	UC	2023
n.a.	Saipem	Shanxi Qingshui	Yulin, Henan	Urea	3,300	UC	2023
n.a.	Casale	Anhui Haoyuan	Fuyang, Anhui	Ammonia	1,540	UC	2024
n.a.	Casale	Henan Jindadi	Luohe, Henan	Ammonia	1,800	UC	2024
n.a.	Casale	Jiangsu Huachang	Zhangjiagang	Ammonia	1,800	UC	2024
n.a.	Casale	Henan Shenma Nylon	Pingdingshan	Ammonia	1,200	UC	2024
n.a.	Casale	Hubei Jinjiang	Jingzhou, Hubei	Ammonia	2,000	UC	2024
n.a.	Casale	Jiangsu Jinmei	Xuzhou	Ammonia	2,000	UC	2024
n.a.	Casale	Shanghai Huayi	Shanghai	Ammonia	860	DE	2025
n.a.	Casale	Anhui Haoyuan	Fuyang, Anhui	Ammonia	1,540	DE	2025
n.a.	Stamicarbon	Confidential	Dongping, Shandong	Urea	2 x 2,330	DE	2024
n.a.	Stamicarbon	Henan Xinlianxin	Jiangxi	Urea	2,330	UC	2024
n.a.	Topsoe	Mintal HET	Baotou, Mongolia	Ammonia	1,800	CA	2025
DENMARK							
n.a.	n.a.	CIP	Esbjerg	Ammonia	910	FS	2028
EGYPT							
thyssenkrupp IS	thyssenkrupp IS	NCIC	Ain Sokhna	Ammonia	1,200	C	2023
thyssenkrupp IS	Stamicarbon, TKFT	NCIC	Ain Sokhna	Urea	1,050	C	2023
thyssenkrupp IS	thyssenkrupp IS	NCIC	Ain Sokhna	Nitric acid	500	C	2023
thyssenkrupp IS	thyssenkrupp IS	NCIC	Ain Sokhna	Ammonium nitrate	635	C	2023
thyssenkrupp IS	thyssenkrupp IS	NCIC	Ain Sokhna	CAN	835	C	2023
thyssenkrupp IS	thyssenkrupp IS	MOPCO	Damietta	Ammonia	3 x 113%	RE	n.a.
thyssenkrupp IS	thyssenkrupp IS	MOPCO	Damietta	Urea	3 x 113%	RE	n.a.
Tecnimont	KBR	EHC	Ain Sokhna	Ammonia	1,320	UC	2023
n.a.	n.a.	Suez/EDF	Ain Sokhna	Ammonia	425	P	2026
GERMANY							
n.a.	Topsoe	First Ammonia	n.a.	Ammonia	300	P	2025
HUNGARY							
n.a.	Casale	BorsodChem	Kazincbarcika	Nitric acid	660	UC	2023
INDIA							
n.a.	Casale	Chambal Fert & Chem	Gadepan	Nitric acid	600	RE	2024
n.a.	Casale	Chambal Fert & Chem	Gadepan	Ammonium nitrate	700	RE	2024
TechnipFMC/L&T	Topsoe	HURL	Sindri	Ammonia	2,200	C	2022
TechnipFMC/L&T	Saipem	HURL	Sindri	Urea	3,850	C	2022
TechnipFMC/L&T	Topsoe	HURL	Barauni	Ammonia	2,200	C	2022
TechnipFMC/L&T	Saipem	HURL	Barauni	Urea	3,850	C	2022
TOYO	KBR	HURL	Gorakhpur	Ammonia	2,420	C	2022
TOYO	TOYO	HURL	Gorakhpur	Urea	3,850	C	2022
TOYO	KBR	Deepak Fert & Chem	Taloja	Ammonia	1,500	UC	2024
thyssenkrupp IS	thyssenkrupp IS	Deepak Fert & Chem	Vadodara	Nitric acid	250	UC	2023
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Nitric acid	900	UC	2024
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Ammonium nitrate	970	UC	2024
Wuhuan Engineering	KBR	Talcher Fertilizers	Talcher	Ammonia	2,200	UC	2025
Wuhuan Engineering	Stamicarbon	Talcher Fertilizers	Talcher	Urea	3,850	UC	2025
n.a.	n.a.	ACME	Mangalore	Ammonia	360	P	n.a.
INDONESIA							
n.a.	Casale	PT Pupuk Kalimantan	Bontang	Ammonia	1,800	RE	2025
IRAN							
PIDEC	Casale	Masjid Soleyman	Masjid Soleyman	Ammonia	2,050	UC	On Hold
PIDEC	TOYO	Masjid Soleyman	Masjid Soleyman	Urea	3,250	UC	On Hold
PIDEC	Topsoe	Hengam Petrochemical	Assaluyeh	Ammonia	2,050	UC	n.a.
PIDEC	Saipem, TKFT	Hengam Petrochemical	Assalyueh	Urea	3,500	UC	n.a.
Namvaran	KBR	Kermanshah Petchem	Kermanshah	Ammonia	2,400	UC	n.a.
Namvaran	Stamicarbon	Kermanshah Petchem	Kermanshah	Urea	2,000	UC	n.a.
Hampa	Casale	Zanjan Petrochemical	Zanjan	Ammonia	2,050	UC	n.a.
Hampa	Stamicarbon	Zanjan Petrochemical	Zanjan	Urea	3,600	UC	n.a.
ISRAEL							
Saipem	Topsoe	Haifa Chemicals	Mishor Rotem	Ammonia	300	UC	2024
n.a.	KBR	Haifa Chemicals	Mishor Rotem	Nitric acid	+35%	RE	2024
KAZAKHSTAN							
Tecnicas Reunidas	n.a.	KazAzot	Aktau	Ammonia	2,000	CA	2027
Tecnicas Reunidas	n.a.	KazAzot	Aktau	Urea	1,750	CA	2027
Tecnicas Reunidas	n.a.	KazAzot	Aktau	Nitric acid	1,200	CA	2027
Tecnicas Reunidas	n.a.	KazAzot	Aktau	Ammonium nitrate	1,500	CA	2027
NIGERIA							
n.a.	n.a.	OCP	n.a.	Ammonia	3,300	P	n.a.
NORWAY							
n.a.	Topsoe	Barents Blue	Markoppneset	Ammonia	3,000	DE	2026
n.a.	Technip	Iverson eFuels	Sauda	Ammonia	600	P	2027
OMAN							
SNC Lavalin	KBR	OQ	Salalah	Ammonia	1,000	C	2022
n.a.	KBR	Green Hydrogen & Chem	Duqm	Ammonia	300	UC	2025

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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Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
POLAND							
thyssenkrupp IS	thyssenkrupp IS	Grupa Azoty	Pulawy	Nitric acid	1,000	C	2023
thyssenkrupp IS	thyssenkrupp IS	Grupa Azoty	Pulawy	Ammonium nitrate	1,300	C	2023
thyssenkrupp IS	thyssenkrupp IS	Anwil SA	Wloclawek	Nitric acid	1,265	C	2023
thyssenkrupp IS	thyssenkrupp IS	Anwil SA	Wloclawek	Ammonium nitrate	1,200	C	2023
n.a.	Casale	Grupa Azoty	Kedzierzyn	Urea	780	RE	2023
QATAR							
thyssenkrupp IS	thyssenkrupp IS	Qafco	Mesaieed	Ammonia+CCS	3,500	BE	2026
RUSSIA							
CNCCC	Topsoe	ShchekinoAzot	Pervomayskyy, Tula	Ammonia	1,500	UC	n.a.
CNCCC	Stamicarbon	ShchekinoAzot	Pervomayskyy, Tula	Urea	2,000	UC	n.a.
NIIK	Casale	JSC Metafrax	Gubakha	Ammonia	1,000	UC	2023
NIIK	Casale/MHI	JSC Metafrax	Gubakha	Urea	1,700	UC	2023
n.a.	Stamicarbon	Acron	Novgorod	Urea	2,000	C	2023
Tecnimont	KBR	EuroChem	Kingisepp	Ammonia	3,000	UC	On Hold
Tecnimont	Stamicarbon	EuroChem	Kingisepp	Urea	4,000	UC	On Hold
SAUDI ARABIA							
Daelim	thyssenkrupp IS	Ma'aden	Ras al Khair	Ammonia	3,300	C	2023
Larsen & Toubro	Topsoe	Neom	Neom	Ammonia	3,500	DE	2026
SOUTH KOREA							
thyssenkrupp IS	thyssenkrupp IS	Hu-Chems	Yeosu	Nitric acid	1,150	C	2023
n.a.	KBR	Hanwha	Yeosu	Nitric acid	1,200	UC	2024
TURKEY							
Tecnimont	Stamicarbon	Gemlik Gubre	Gemlik	Urea	1,640	UC	2023
Tecnimont	n.a.	Gemlik Gubre	Gemlik	UAN	500	UC	2023
UNITED STATES							
Black & Veatch	Stamicarbon	Confidential	n.a.	Urea	+660	RE	2023
n.a.	Casale	Coffeyville Resources	Coffeyville, KS	Urea	1,100	RE	2023
n.a.	Stamicarbon	Confidential	n.a.	Urea	+1,180	RE	2025
n.a.	Stamicarbon	Confidential	n.a.	Urea	1,500	CA	2025
n.a.	KBR	Monolith Materials	Hallam, Nebraska	Ammonia	830	DE	2025
Tecnimont	KBR/Linde	OCI	Beaumont	Ammonia+CCS	3,300	UC	2025
n.a.	Topsoe	Air Products	Ascension, LA	Ammonia	n.a.	P	2026
thyssenkrupp IS	thyssenkrupp IS	Nutrien	Geismar, LA	Ammonia+CCS	3,500	DE	2027
thyssenkrupp IS	thyssenkrupp IS	CF Industries	US Gulf Coast	Ammonia+CCS	3,300	DE	n.a.
UNITED ARAB EMIRATES							
thyssenkrupp IS	thyssenkrupp IS	Fertiglobe	Ruwais	Ammonia	x125%	RE	FS
UZBEKISTAN							
n.a.	Casale	Ferkensco	Yangiyer	Ammonia	1,500	DE	2026
n.a.	Casale	Ferkensco	Yangiyer	Urea	1,800	DE	2026

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

Pictured, right: Delivery of a Stamicarbon pool reactor for the Gemlik urea plant, under construction in Turkey.

PHOTO: BELLELI ENERGY

Optimising methanol production

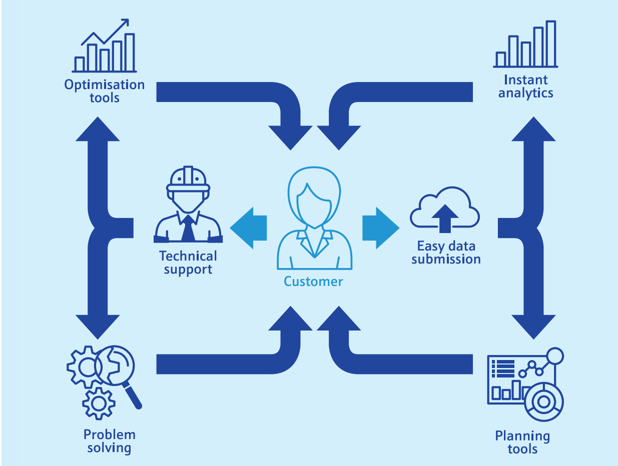
Combining a deep scientific knowledge, engineering and field experience with state-of-the art technology, Johnson Matthey is proud to introduce its next generation of digital simulation tools via its JM-LEVO™ digital portals to further support customers in achieving their operational and sustainability targets.

Daniel Sheldon, Philippe Thevenin and Alex Chalmers, Johnson Matthey.

Johnson Matthey (JM) is a global leader in sustainable technologies, catalysing the net zero transition. With over 200 years of sustained commitment to innovation and technological breakthroughs, JM improves the performance, function and safety of its customers' products. JM's science has a global impact in areas such as low emission transport, energy, chemical processing and making the most efficient use of the planet's natural resources.

JM is known for its process technologies and catalysts, but it is its scientific knowledge and experience to ensure its products perform optimally in its customer plants that differentiates it. To enhance its technology and catalyst offer, JM offers a suite of services to ensure customer success and maximise plant performance. This includes asset life and reliability studies, reformer monitoring and surveys, reduction and start-up assistance, plant flowsheet designs and modelling capabilities[1]. However, as markets evolve and operational performance and sustainability are at the forefront of everyone's minds, the need for more agile digital solutions has become apparent.

Fig. 1: **Diagram illustrating customer centric technical services**



Source: Johnson Matthey

Digital transformations can be used to solve some of the toughest problems that face the chemical industry today and as the world continues to transition to a net zero future, it is important to have the right tools in hand to support and adapt quickly to customer's needs.

The JM-LEVO digital portal, is a plant model and communication tool that intelligently collects and evaluates operating data to enable real-time monitoring and provide detailed insights through automated data validation and analysis. The dynamic portal allows operators to identify opportunities to improve operation and maximise the utilisation of available feedstock, catalyst and equipment. With the introduction of enhanced digital services to JM's portfolio, customers can share dynamic content with JM technical service representatives to support with unusual operating data. These representatives can then offer tailored recommendations based on 60+ years of experience. This is shown in Fig. 1.

A key priority for JM in building a digital product portfolio was to enhance existing services, help drive the implementation of customer sustainability goals, and enable customers to quickly pivot to changing priorities and business requirements. Building on JM's experience in the catalyst and process technology markets, the company launched its first digital product, JM-LEVO Formaldehyde, in 2020 for its FORMOX™ catalyst customers.

The digital portal was developed with direct customer input to offer a unique solution to support specific customer and production needs. A machine learning tool has been developed to further supplement the technical support team's knowledge bank. This approach has led to many customer successes and is a prime example of how digital tools can be leveraged to support technical services.

The JM-LEVO Formaldehyde portal set much of the groundwork for JM's digital journey, demonstrating the value of the

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Fig. 2: **Components of the JM-LEVO solution**

Source: Johnson Matthey

approach and providing a robust platform to expand the offering across other markets. Building upon this experience and customer input, a machine learning model has been developed that continually improves capabilities and functionality, helping customers deliver higher performance across reactors and plants. For example, the model is able to use historical data and customer insight to improve load comparison and compare larger data sets, thereby enabling customers to analyse larger volumes of data to support optimisation and make better-informed decisions.

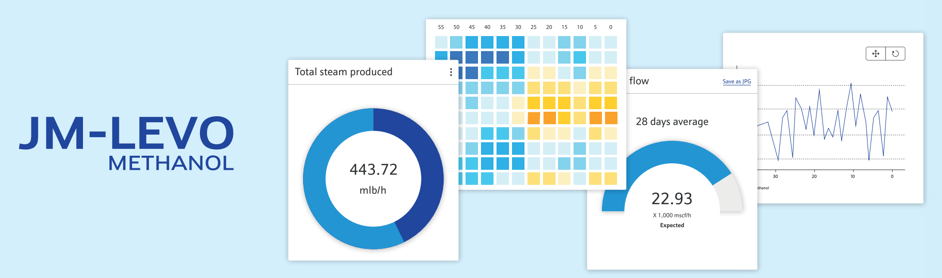
JM-LEVO Methanol

JM has been at the forefront of methanol technology (through ICI heritage) since it developed the modern 'Low Pressure Methanol' process in the 1960s, and is a world leader in the development of methanol technology and catalysts. With a background in methanol plant design, operation and optimisation, JM is uniquely positioned to deploy enhanced digital tools in this market to offer more reliable, sustainable customer-centric plant optimisations. The JM-LEVO Methanol digital portal was released last year with the first customers now onboard, benefitting from a new approach to reporting and communicating methanol plant operating information. The JM-LEVO digital portal can cut through the noise generated by vast data volumes from a chemical plant to offer clear and concise ways of filtering, evaluating, and storing valuable information, driving more efficient operation and lowering environmental impact. Additionally, the JM-LEVO portals simplify the retrieval of detailed reports and technical guidance from an online library, providing easy access to key information and JM technical expertise, whilst meeting the end-to-end security requirements.

The JM-LEVO digital portal allows more frequent assessment of plant performance, giving plant engineers the opportunity to identify areas of improvement earlier than ever before, and to achieve operating targets more consistently. The goal of the JM-LEVO digital portal is to optimise production and meet customer sustainability objectives, whether it be product yield, catalyst life, cost or capacity, as illustrated in Fig. 2.

Methanol plants today are highly optimised facilities, with fine margins separating good and great performance, whether this is measured by production, efficiency, or more complex indicators such as carbon intensity, the methanol industry is continually working to improve efficiency of production towards a net-zero carbon emission goal. In a world that is currently moving and changing at pace, the JM-LEVO digital portal can facilitate these objectives by giving better access to JM expertise to troubleshoot problems and find solutions quickly.

Fig. 3: **Examples of JM-LEVO KPI/dashboards**



Source: Johnson Matthey

JM-LEVO digital portals are intended to complement existing technical services, providing an easy way to share data with JM and receive feedback and recommendations on plant operation. They are the basis for a new generation of technical service, processing larger volumes of data through more advanced models and analysis. This is a necessary step to open the opportunity to use technologies such as machine learning driven optimisation on all plants, not just those being designed today.

The portal's dynamic charts, insights and valuable information, examples of which are shown in Fig. 3, can be easily shared with colleagues, and JM technical representatives, enabling benchmarking and performance monitoring across loads and reactors for multiple sites and plants. JM has access to the dashboards and reports, enhancing the support that JM can offer its customers using the JM-LEVO services.

Responding to customer feedback and market dynamics, JM has recently developed an automated data ingestion tool, offered as additional functionality via the JM-LEVO digital portal. This solution enables the JM technical service team to access up-to-date plant data direct from the customers to provide rapid reporting. The customer can control what data they make available to JM via the JM-LEVO digital portal.

With the success of the JM-LEVO digital portals for formaldehyde and methanol customers, JM is planning to develop this for other industries too including nitric acid.

Summary

With the success of its most recent digital portals, JM is at the forefront of offering digital solutions for chemical production in syngas markets. Leading this digital revolution, the JM-LEVO digital portal enables effective and efficient data integration to provide the insight customers require to maintain optimum high efficiency.

In conclusion, online analytics can help improve plant efficiency by: providing real-time data, allowing for proactive monitoring and control of the process; identifying areas of inefficiency; and providing insights into process changes and optimisation opportunities. By utilising online analytics, chemical plants can more effectively utilise their resources and operate more efficiently.

The JM-LEVO Methanol digital portal is available now, and is already supporting Johnson Matthey customers to improve production capabilities, maximise plant efficiency and achieve sustainability goals. ■

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Converting clean ammonia back into hydrogen

Advances in clean hydrogen and ammonia production is fuelling worldwide interest in a new market for hydrogen and ammonia to provide a reliable low-carbon energy future. Ammonia cracking, the dissociation of ammonia back into hydrogen, delivers a pathway to large-scale sustainable hydrogen production. In this article KBR, Johnson Matthey, thyssenkrupp Uhde, Duiker, Proton Ventures and Casale report on their technologies and approaches to ammonia cracking in a low carbon economy.

The world is facing an incredible challenge in the race to decarbonisation, imposing a change of landscape in the technologies and fuels used to support sustainable modern-day life in the future.

The journey towards Net Zero by 2050 requires double digit trillion dollars investment in technologies and infrastructure for low carbon fuels and electrification.

Both hydrogen and ammonia are predicted to play a major role in this journey, to support the decarbonisation of industries and regions which are either hard or uneconomical to electrify. Clean hydrogen is taking a leading position as a sustainable fuel of the future, while ammonia can serve as a clean fuel on its own or as a carrier of hydrogen.

The majority of these key molecules are expected to be produced via renewable power and electrolysis, often designated green, but a significant share will be produced via reforming of fossil fuels and carbon capture, often designated blue, as a cost-effective first step to a sustainable future.

Ammonia as an energy vector

Ammonia is the most promising clean hydrogen carrier for long distances in the short to medium term.

Advantages

Ammonia has a high hydrogen storage density and can be liquefied at -33°C at atmospheric pressure, providing a low energy intensity means of hydrogen storage and transportation. Ammonia production technologies are mature and efficient, already operating at large scale. Ammonia can rely on well-established and rapidly advancing infrastructure for storage, loading, unloading and transportation. Both ammonia production and transportation are already expanding to the growing demand for ammonia as an energy vector. An additional advantage of ammonia is that it can be used directly as fuel, such as in co-firing with coal, helping to abate existing coal-based power plants.

Safety

Ammonia toxicity is similar to other hydrogen carriers such as methanol, methylcyclohexane (MCH) and toluene. Ammonia may be a toxic chemical, but one that is already produced, stored and transported safely around the world today. It is harmful to health at concentrations in excess of 400 ppm but its odour is an advantage in leak detection, with the pungent smell of ammonia in the air detectable at concentrations as low as 5 ppm. It is lighter than air, so it rapidly diffuses and oxidises on leakage making inhalation or contact less likely. Ammonia flammability is lower than other hydrogen carriers, with a high auto-ignition temperature of 650°C, rendering it safer to transport.

Comparison to other hydrogen carriers

The ammonia carrier value chain has the lowest levelised cost and carbon intensity, with energy output similar to liquefied hydrogen. Today, liquid hydrogen is limited by the liquefaction step, with train capacities ~30t/d limiting the ability for vessels to scale past 10,000 m³. Methanol is constrained due to its need for carbon capture, utilisation and storage while MCH has significantly higher cost and carbon intensity, with lower energy output and technology readiness.

The ammonia dissociation reaction

Ammonia decomposition is an endothermic reaction (1), needing 46 kJ for one mole of ammonia to dissociate into nitrogen and hydrogen.

$$2NH_3 \rightleftharpoons N_2 + 3H_2 \quad (\Delta H° = 92 \text{ kJ mol}^{-1}) \qquad (1)$$

Thermodynamically, equilibrium is favoured by high temperature and low pressure. Theoretically, the reaction is near completion:

- at > 550°C @ 1 bara
- at > 800°C @ 5 bara
- at > 1,000°C @ 30 bara

Catalysts can be used to improve the rate of reaction and lower reaction temperature, improving the efficiency of the ammonia cracking process. Both base and precious metals can be used to promote the reaction, with nickel-based catalysts in successful commercial operation today. ■

KBR

From clean energy source to sustainable hydrogen supply

Elena Stylianou

As a technology powerhouse with decades of know-how in efficient ammonia processes and reliable equipment design, coupled with market proven capability for scale-up and commercialisation, KBR offers technologies across the full sustainable hydrogen and ammonia value chain, completed by the advent of KBR's ammonia dissociation technology, H2ACT℠ (Fig. 1).

H2ACT℠ new market, established technology

Today, ammonia dissociation technology is available in the market serving a different purpose. The installed units are fully electricity driven, very small capacity and operate at equilibrium-favoured conditions (low pressure, high temperature) to supply hydrogen or nitrogen as utilities in remote locations and without emphasis on energy efficiency or carbon intensity. While these units serve the installed purpose, they are not suitable for what industry is demanding for energy transition, with new technology required to produce at larger scale, sustainably and efficiently.

While the market for ammonia dissociation for decarbonisation is new, the technology elements to dissociate ammonia at scale are established and proven in operation, bearing great resemblance to steam methane reforming of natural gas for syngas generation.

KBR's ammonia cracking technology, H2ACT℠, is built on a legacy of technology innovation and industry records in ammonia production. It completes the pathway to large scale, sustainable hydrogen production, with efficiency and high technology readiness at the heart of the process.

Process flow scheme overview

In a typical ammonia cracking unit, liquid ammonia from storage is pumped to the required pressure, vaporised and preheated in preparation for decomposition to hydrogen and nitrogen.

Ammonia cracking is largely driven by a fuel-fired cracker, leveraging on decades of KBR experience in furnace design in industrial steam methane reforming. The furnace design is based on the well-proven KBR down-fired primary reformer design with hundreds of references from small to large scale capacity and decades of experience and know-how in robust, safe and efficient design of this equipment.

The cracking reaction is performed under the presence of catalyst with heat supplied by combustion of clean fuel via the down-fired burners. The heat source for the cracker is fuel from the process, consisting of tail gas from the hydrogen purification section, supplemented by cracked gas (H_2/N_2) if necessary.

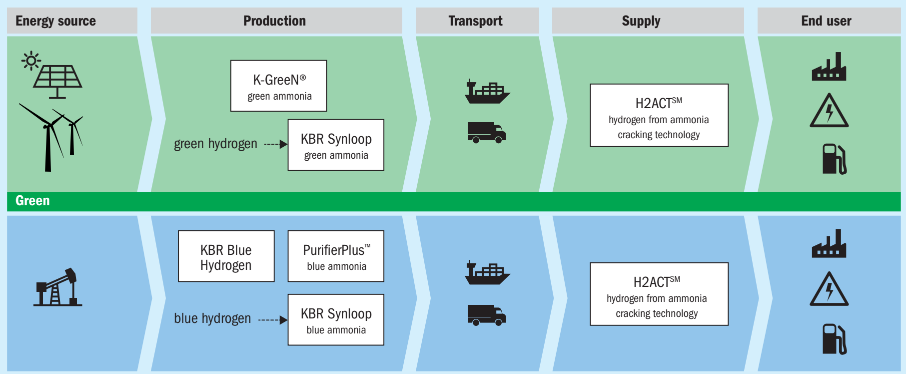
The ammonia cracking furnace is designed to attain maximum thermal efficiency by utilising process waste gases as part of the fuel, as well as by recovering heat in the convection section from the flue gases, to drive dissociation, feedstock vaporisation and preheat.

The furnace convection section is furnished with a selective catalytic reduction (SCR) system as standard, able to meet the most stringent environmental emission requirements.

Cracked product purification, where necessary, is based on well-proven and commonly used industrial processes:

- Ammonia recovery: Remove ammonia by simple water-based ammonia absorption/distillation unit – designed and in operation in a multitude of KBR ammonia plants worldwide;
- Product purification: Remove nitrogen by Hydrogen PSA technology – proven, reliable cost-effective and used in a variety of industries.

Fig. 1: **KBR clean ammonia and hydrogen technologies**



Source: KBR

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Table 1: H2ACT℠ technology readiness level (TRL)

System	Technical maturity	TRL	Remarks
Ammonia storage tank and refrigeration	Well proven	9	System available in many operating ammonia plants around the world.
Pump and vaporiser	Well proven	9	System available in many operating ammonia plants, where ammonia is used as (vaporised) refrigerant within the ammonia plant.
Ammonia cracking reactor	Proven in similar service	7	Equipment design and large-scale operation proven in similar service in steam methane reforming in KBR ammonia plants. Down-fired furnace design with 200+ references. Catalyst proven at small scale in commercial units. Optimised and improved catalyst for large scale application proven in testing by leading catalyst manufacturers.
Ammonia purification	Well proven	9	System available in many operating ammonia plants, with similar operating conditions.
Nitrogen purification	Well proven	9	PSA-based, commonly used in a variety of industries and scales
Hydrogen compression	Well proven	9	Hydrogen compressors commonly used in hydrogen plants, refinery units, etc.

Source: KBR

Typical hydrogen delivery pressure of around 30-40 barg is achievable without additional hydrogen compression. If higher delivery pressure is required, compression can be added, and the flowscheme will be optimised for the higher delivery pressure.

Technical maturity level

Table 1 presents an evaluation of the technical maturity for each system (block) within the H2ACT℠ ammonia cracking plant.

Key performance data

H2ACT℠ can deliver hydrogen at any purity required depending on the industrial application the ammonia cracking plant is serving.

Key performance indicators such as efficiency, hydrogen yield and levelised cost of production will vary depending on the industry the cracking unit is serving, carbon intensity requirements and opportunity for integration with existing facilities.

Nonetheless, for a given application, the performance of the H2ACT℠ ammonia cracking plant is consistently maintained across the entire capacity range, from small to mega-scale production.

Indicatively, Table 2 presents typical performance for an H2ACT℠ ammonia cracking unit, based on zero direct carbon intensity production, using only proven technology elements (i.e., using most proven commercially available nickel-based catalysts, no ammonia co-firing, conventional PSA unit, etc).

Table 2: H2ACT℠ key performance indicators

KPI	Value
Capacity, t/d H_2	5 to 1,200
Product specification – H_2 purity, mol-%	75 to 99.97+
Product specification – NH_3 content, ppmv	as low as <0.1
Product specification – H_2O Content, ppmv	as low as <1
Product specification – delivery pressure, barg	as required (40 barg without compression)
Carbon intensity (direct), kg CO_2/kg H_2	0
Typical hydrogen yield[1], wt-%	76-78
Typical energy efficiency (HHV)[1,2], %	85-88
Electricity demand[1], kWhr/t H_2	100
Availability[3], %	>95
Turndown, %	<50
Flexibility (load change), % per hour	20+

Notes:
1. *For stand-alone unit, self-sufficient in terms of steam demand, H_2/N_2 fuel, hydrogen delivery pressure of 40 barg.*
2. *Energy efficiency = (Energy out as H_2) / (Energy in as NH_3 + Power). Power efficiency is 50% or 1,720 kcal/kWhr.*
3. *Including planned turnaround of 30 days every 4 years.*

Source: KBR

Flexibility and turndown

The typical turndown capacity for the H2ACT℠ cracking unit is 50%, however the plant can be designed to be operated at lower turndown if necessary.

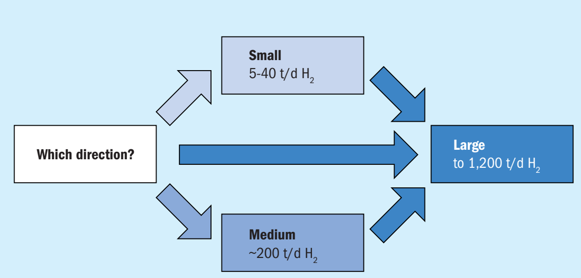
The typical ramp-up/ramp-down rate is 20% per hour, suitable for most industrial applications. The plant load can vary frequently and daily between nominal capacity and turndown without adverse impact on plant integrity. This can be improved significantly if additional operational flexibility is required (e.g., for power generation industry) to match offtaker variability, minimising or eliminating hydrogen storage requirements.

On-stream time, reliability and availability

KBR ammonia plants are among the most reliable in the industry, with records in on-stream time. As compared to an ammonia production facility, nearly all critical equipment in the ammonia cracking plant operates at milder conditions. The ammonia feedstock quality is consistent, without catalyst poisons such as sulphur or chlorides and no side reactions. Hence, maintenance and replacement costs are expected to be comparatively lower and plant reliability equal or higher to ammonia production.

Generally, time required between turnaround is dependent on maintenance demands for rotating equipment (such as the hydrogen compressor if applicable) and the catalyst life. The typical recent benchmark for turnaround period for similar industrial plants including reformers is four years with 30-40 days for maintenance works, therefore on-stream time for the ammonia cracking unit of 8,400 hours per calendar year is realistic and easily achievable for KBR design and technology.

Fig. 2: Routes to commercial-scale cracked hydrogen production



Source: KBR

Scale-up and commercialisation

KBR offers optimised designs to the market for capacities ranging from 5 to 1,200 t/d hydrogen production. H2ACT℠ is versatile, with design features tailored to individual project requirements such as carbon intensity, product quality and pressure, delivering the lowest levelised cost of cracked hydrogen product for each client and industry application.

KBR can support clients taking different routes for technology scale-up and commercialisation of ammonia cracking technology. Fig. 2 presents three routes to reach commercial scale hydrogen production via a KBR H2ACT℠ plant.

A small-scale ammonia cracking plant refers to a demonstration or a pilot ammonia cracking plant. Depending on budget allocated and specific demonstration objectives required, the design of this small-scale plant can range from a full to a simplified process scheme.

- A simplified pilot plant could demonstrate ammonia dissociation in a fired tube (or radiant tube) furnace under chosen catalyst at projected operating pressure and temperature, proving catalyst performance.
- A full design pilot plant could additionally prove equipment design, energy efficiency and product purity.

A medium-scale ammonia cracking plant is a commercial unit engineered and constructed based on a complete process scheme. It can serve decentralised ammonia cracking applications e.g., for decarbonising existing industrial sites. The medium-scale plant is an ideal candidate for phased approach to centralised world-scale cracking applications, staggering the production in line with feedstock supply availability or offtaker demand. Lessons-learned from commercial operation of the medium-scale plant can be applied to improve the next generation units, both in terms of technology and operation.

KBR is ready to license and guarantee H2ACT℠ at large scale today, as technology features are well-proven and ammonia cracker equipment design is already available. As with any new technology, cracking ammonia is expected to advance rapidly in the short-to-medium term. KBR anticipates a flexible and pro-active approach to engineering and design of the first commercial units, ensuring that technology advances (such as catalysts or burner technology) can be incorporated in the design or easily retrofitted in existing units. As a result, KBR's low risk, maximum opportunity flowscheme can support first-mover advantage in this new market, leveraging on experience of successful technology commercialisation over 80 years. ■

THYSSENKRUPP UHDE

Getting the optimum from ammonia cracking

Johannes Elischewski and Alexander Kleyensteiber

The cracking of ammonia is a technology almost as old as its synthesis. The study of this reaction commenced as early as the 1920s, and for the last about five decades, small scale cracker units have been commercially available. But with the wide availability of industrial hydrogen, ammonia cracking was used for niche applications only.

With growing interest in ammonia cracking, this article discusses different process options and optimisation approaches for large-scale decomposition applications considering investment, operation cost, product yield and greenhouse gas (GHG) emissions.

Process options

Factors shaping the final ammonia cracking process, depicted in a simplified manner in Fig. 1, are, amongst others, shown in the following:

Source of reaction heat and selection of temperature profile

Same as the steam reforming reaction, the cracking reaction is a strongly endothermic reaction that is best carried out at elevated temperature (above 600°C) in one single pass. Therefore, the mechanical and thermal design of the cracking reactor, the furnace and its energy supply can also be selected in analogy to the

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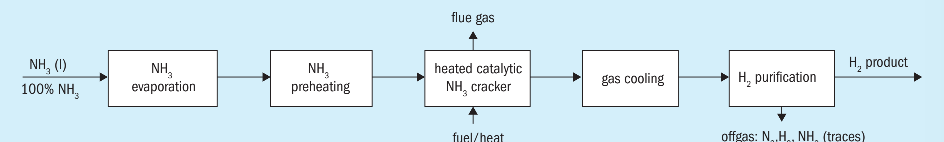
Fig. 1: **Ammonia cracking process**



Source: thyssenkrupp Uhde

well-proven design of the steam reformer. In the fired version, this is the optimum approach for large commercial-scale crackers.

Selection of catalyst

The catalyst to drive the ammonia cracking reaction is a field of intense study at present. Historically, nickel and ruthenium are known to be efficient catalysts and are commercially available. Nickel currently seems to be the catalyst of choice with reaction temperatures of 500 to 900°C. Ruthenium is more active at lower temperatures of less than 500°C. However, its scarcity and cost currently do not make its large-scale application seem feasible.

Reaction parameters

The optimal process conditions seem to be an elevated, but not very high pressure to cap the capital cost of the plant, but also to avoid the detrimental effect of pressure on the kinetics of the reaction, and high, but not extreme temperature to achieve high reaction rates, but also to avoid the worst of the adverse material effects of both, feedstock and product.

Process comparison

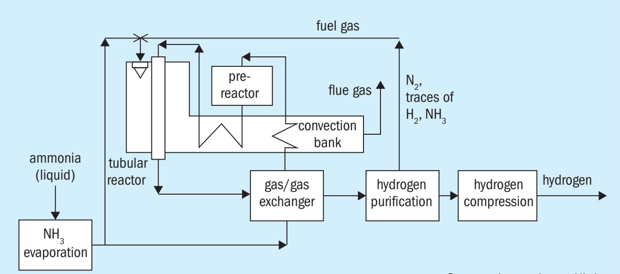
From the parameters discussed above a range of possible plant configurations arise. The following have been investigated in more detail by thyssenkrupp Uhde and distinguished by energy supply:

- Case 1: Self-sustaining process: The required energy is provided by combustion of a part of the feed and/or product stream. Two versions were evaluated as Cases 1a and 1b (with or without fixed-bed pre-reactors)
- Case 2: Process with external fuel source.

Process efficiency

The basic process from Case 1 is greatly improved with regard to its efficiency by adding an adiabatic pre-reactor, referred to as Case 1b, see Fig. 2. This efficiency

Fig. 2: **Simplified flowsheet for the cracking process, Case 1b**



Source: thyssenkrupp Uhde

increase mostly originates from lower overall firing duty and less heat loss with the flue gas.

It is obvious that the molar efficiency from Cases 1a and 1b can be increased if less feed/product is used for heating by replacing it by another fuel like natural gas (Case 2). The theoretical maximum plant yield is therefore determined by the hydrogen yield of the pressure swing adsorption unit. However, this does not necessarily increase the energy efficiency. For a fair comparison, the additional fuel must be accounted for by its heating value, in the same way as the other contributions.

CO_2 emission

Another way to compare process efficiency is to look at the CO_2 emission of the whole process chain of ammonia production and cracking. This is done by assuming different ammonia production pathways (green and blue). For Case 2, comparison with 1b shows that heating by natural gas increases the specific CO_2 emission despite increasing the total production of hydrogen.

Heating with electrical power was not considered. One has to bear in mind that the purpose of using ammonia as a hydrogen carrier is based on the idea that ammonia is produced in a place where renewable power is abundantly available at low cost and it is transported to a place where such renewable power is expensive (like Europe). Therefore, it is realistic that at the cracker location renewable power is available in limited amount at high cost only and hence not applicable for large scale commercial crackers.

Summary

Ammonia decomposition or cracking to hydrogen is an important process step in the context of CO_2 avoidance in a future hydrogen economy and the use of ammonia as transport medium for hydrogen. All steps of this process chain (green hydrogen, green or blue ammonia technology, ammonia decomposition to hydrogen) are offered by thyssenkrupp Uhde.

The ammonia cracking process requires a minimum consumption of the energy contained in the ammonia. This energy can be obtained by combustion of a part of the feed or product or from an external fuel source. While the latter variant increases the hydrogen yield per tonne of ammonia input, it also increases the specific CO_2 emission.

For future centralised clean hydrogen production, ammonia cracking in large centralised units are the optimum, due to process economics and avoidance of CO_2 emissions. ■

JOHNSON MATTHEY

Ammonia cracking technology and its place in the low carbon economy

Julie Ashcroft

As part of a global focus on reducing greenhouse gas (GHG) emissions, there is significant interest in the use of hydrogen as a carbon-free fuel. Green hydrogen can be manufactured through electrolysis and transported from areas with excess renewable electricity to areas with less abundant renewable electricity. However, there are significant challenges associated with the transport of hydrogen; compressed hydrogen gas has a relatively low energy density (42 kg H_2 per m³ at 700 bar), resulting in a reduction in energy density per shipment, and liquefied hydrogen, while having a higher energy density at 72 kg H_2 per m³, must undergo inefficient and expensive liquefaction prior to transport.

As a result, other hydrogen transport vectors are being considered with ammonia a favoured hydrogen transport vector due to a high hydrogen density (108 kg H_2 per m³) and the existing technologies for storage and transportation at scale developed within the mature fertiliser and chemicals industry. Ammonia cracking will therefore play a key role in allowing ease of transport of green hydrogen, as green ammonia, around the globe from regions with sufficient renewable energy to manufacture green hydrogen. An important step to unlock ammonia's potential as a hydrogen vector is the development of an efficient ammonia cracking process at large scale, given the large amount of energy that is required to decompose ammonia. The efficiency of the ammonia cracking process is critical to the success of ammonia as a hydrogen carrier.

The development of ammonia cracking flowsheets requires novel process technology combined with optimised catalysts to maximise the hydrogen recovery and energy efficiency for each unit operation within the supply chain.

Ammonia cracking

Chemistry

Following transportation of green or blue ammonia to the desired location, the ammonia must be converted back to hydrogen. The cracking reaction (equation 1) is endothermic, requiring an input of 46 kJ per mole of ammonia, and the equilibrium position favours hydrogen production at high temperatures.

$$NH_3 \rightleftharpoons {}^3/_2\, H_2 + {}^1/_2\, N_2 \qquad (1)$$

The combination of an endothermic reaction and operation at relatively high temperatures results in an energy intensive process. To minimise the external energy input required to maintain the cracking reaction, there will be a requirement for significant heat integration and for optimal design of high temperature equipment within the flowsheet.

Flowsheet

The basic flowsheet requirements for ammonia cracking, shown in Fig. 1, include a vaporisation and pre-heating stage before the ammonia cracking reactor which is based on Johnson Matthey's (JM) proven top-fired furnace design. As ammonia cracking is an equilibrium-limited reaction, there will be residual ammonia in the cracked gas feed. The cracked gas will undergo a separation stage, to produce a hydrogen stream at the required purity that can be compressed to the required pressure. The separation stage will generate a tail gas that has the potential to be used as a fuel source.

Industrial ammonia cracking

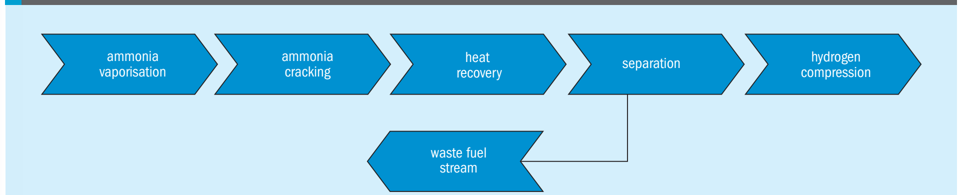
It is likely that a portion of ammonia decomposition will occur close to the import location with hydrogen being fed into a gas grid, whilst some ammonia will be transported further inland and undergo decomposition at the location where hydrogen is required. These two scenarios, illustrated in Fig. 2, will have distinct benefits, drawbacks, and challenges, as summarised in Table 1.

For centralised ammonia cracking, the ammonia is transported to an import facility situated at a port, where Johnson Matthey can offer a market leading high efficiency ammonia cracking process for the conversion of ammonia to hydrogen at scale. The technology builds on over 90 years' experience with ammonia cracking and high temperature fired reactor designs for hydrogen, ammonia and methanol production, including the world's largest modularised tubular furnace reactors, which have been selected as they offer the opportunity for the most efficient construction at a port site.

The process offers best in class environmental performance with a low emission process in which off-gases are fed back to the crackers as a fuel for the endothermic reaction. At the heart of the process is the interaction between Johnson Matthey's industrially proven KATALCO™ 27-series catalyst and its top-fired ammonia cracking reactor.

The hydrogen is distributed through new or repurposed pipelines, with this hydrogen grid replacing the conventional natural gas

Fig. 1: **Schematic showing the main unit operations with the ammonia decomposition flowsheet**



Source: Johnson Matthey

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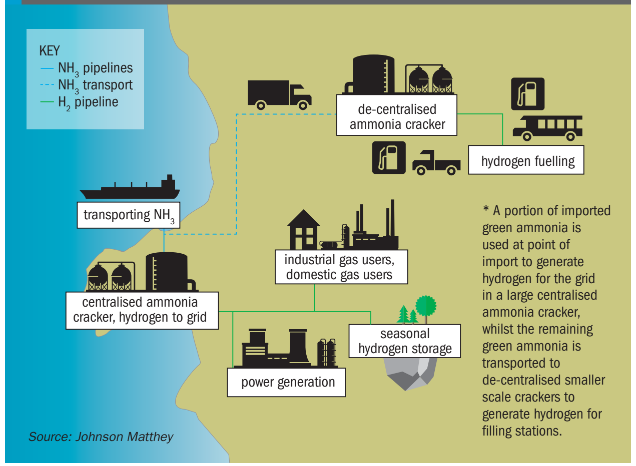
Fig. 2: **Green ammonia***



Source: Johnson Matthey

grid. The hydrogen purity specification for this application can be achieved using well-established separation technology, with pressure swing absorption able to deliver high recovery rates at the required purity.

In the decentralised scenario, ammonia is transported to point of use, and cracked onsite to produce hydrogen. Hydrogen generation at fuel stations for fuel cell electric vehicles and localised hydrogen generation for off-grid users would benefit from this type of application. The purity requirement for hydrogen within fuel cell applications is extremely high; ammonia levels over 0.1 ppmv and nitrogen levels over 300 ppmv are not acceptable. As a result, the purification stage for this application may need to utilise technologies such as palladium membrane separation, which while technically proven are not operating on a significant scale within any markets today.

The common features to both flowsheets are the requirement for efficient heat transfer and recovery from the system, in order to maximise the hydrogen recovery and energy efficiency of the process. Large-scale ammonia cracking may be similar to primary steam-methane reforming technologies, with management of heat transfer critical to successful operation of a large-scale ammonia cracking reactor. The design of the reactor and the catalyst plays a part in optimising performance. De-centralised cracking will be on a significantly smaller scale but will benefit when designed with knowledge of heat transfer and high temperature applications.

The separation stage within both large- and small-scale applications generates a waste gas stream containing mostly nitrogen, along with the residual ammonia and unrecovered hydrogen. Within ammonia cracking applications, energy efficiency must be maximised. Within large-scale applications, the waste gas can be used as a fuel source to drive the cracking reaction, increasing the energy efficiency of the process. For electrical crackers, this may not be feasible and other options must be considered, such as using the waste stream to drive a turbine and recover the energy as electricity. However, there are further losses associated with any multi-stage energy recovery system.

Endothermic reactions such as ammonia cracking benefit from being carried out within a multi-tubular reactor, with an external heat source providing radiant and convective heat to the tubes. Regardless of the energy source there will be heat loss across the tube wall and tube, however this can be minimised through selection of the optimal catalyst pellet. Formation of a gas film at the tube wall limits heat transfer, however this can be managed with the correct catalyst pellet shape and size. A catalyst with good packing characteristics can minimise this effect, causing the flow to be more turbulent with an associated smaller gas film at the tube wall. This increases the heat transfer into the catalyst to drive the endothermic reaction, which can result in lower tube wall temperatures and a more efficient process.

Table 1: **Centralised and de-centralised ammonia cracking options**

	Centralised ammonia cracking	De-centralised/point of use ammonia cracking
Application	Hydrogen generation for distribution into hydrogen grid	Local hydrogen generation to provide fuel for hydrogen filling stations or for remote users
Scale	Large scale production (>1,000 t/d NH_3)	Small scale production (~100 kg/hr NH_3)
Location	Industrial plant near port site using imported ammonia	Urban location, filling station forecourt; Remote location with accessibility challenges
Energy requirements	Can benefit from heat integration & efficiency of large-scale high temperature applications	Energy requirement will be minimised by low temperature operation; May favour electrical heating.
Product specification (separation)	Feeding H_2 into grid – purity requirements similar to current large scale hydrogen production	Stringent H_2 purity requirements requiring specialised separation step
Catalyst requirements	High temperature catalyst, scale requires high GHSV	Low temperature catalyst, scale can economically support low GHSV

Source: Johnson Matthey

Johnson Matthey has a long history and significant experience in the development and design of reforming processes and reactors, including pre-reforming, primary reforming and secondary reforming which all have different design requirements. Maximising performance from a reformer-style ammonia cracking reactor requires knowledge of both reactor design and catalyst design, which are both areas Johnson Matthey has significant experience and knowledge.

Ammonia cracking catalysts

Base-metal ammonia cracking catalysts have a long history within industry, with applications including the production of forming gas for welding and generation of nitrogen at chemical plants, through cracking of ammonia and combustion of hydrogen. These catalysts are active at high temperatures, and as a result achieve very low ammonia slip.

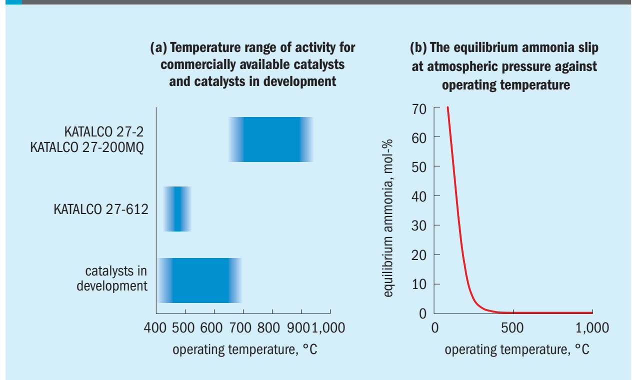
Johnson Matthey's KATALCO 27-2 is a nickel-based ammonia cracking catalyst that has been supplied for ammonia cracking applications for over 50 years. It is a highly active catalyst that typically operates in the range 700-950°C, giving high hydrogen recovery due to the low residual ammonia levels at this temperature range.

Nickel based catalysts are very suitable for use in high-temperature applications, providing a robust and stable product that combines good activity with a relatively high tolerance to poisons in the process feed.

For large-scale cracking processes Johnson Matthey proposes a high-temperature catalyst, KATALCO 27-200MQ, a nickel-based ammonia cracking catalyst, which combines high surface area with low pressure drop due to the QUADRALOBE™ pellet shape. This high-temperature ammonia cracking catalyst achieves high activity and near-equilibrium conversion when operated between 650 and 900°C. Due to the high activity of the catalyst, relatively high gas hourly space velocities (GHSV) can be used to achieve the required conversion, minimising catalyst volume requirements and, as a result, minimising the ammonia cracker size.

As the interest in ammonia as an energy vector supporting green hydrogen fuel has grown, there has been a focus on reducing the energy requirements demanded by the cracking process, and subsequent research on the feasibility of ammonia cracking at low temperatures.

Fig. 3: **Temperature range of catalyst activity and equilibrium ammonia slip**



Source: Johnson Matthey

KATALCO 27-612, a commercially available pgm-based ammonia cracking catalyst, was developed in response to this market need. This catalyst typically operates in the range 450-500°C, substantially extending the available operating range for ammonia cracking applications. The overall economics of a low temperature application will be a balance between the savings associated with lower temperature operation and the increased catalyst costs for pgm-based catalysts.

In addition to these commercially available catalysts, Johnson Matthey continues to develop and evaluate alternative ammonia cracking catalyst technologies, with a view to further extend the operating range to lower and intermediate temperatures. However, as the reaction is equilibrium limited, there is a limit on the lowest feasible operating temperature. For atmospheric pressure operation, ammonia equilibrium levels increase drastically below 250°C, and this minimum viable temperature increases with operating pressure, reaching 450°C at 35 bar g operation.

Hydrogen-fuelled power plants in South Korea

Johnson Matthey and Doosan Enerbility have signed an agreement to develop hydrogen-fuelled power plants in South Korea. The partnership supports the South Korean Government's plans to increase the share of clean hydrogen-based power generation from 0% in 2022 by 2.1% by 2030 and 7.1% by 2036.

JM will provide innovative ammonia cracking technology and catalyst, which converts clean ammonia into nitrogen and hydrogen. The clean hydrogen can then be used to power turbines, which are key components of hydrogen-fuelled or hydrogen-LNG fuelled combined cycle power plants.

Analysis from the Korea Institute of Machinery & Materials shows that using ammonia cracking technology to enable hydrogen-fuelled turbines could reduce carbon emissions by 10.4% when a gas turbine is fired up with 30% hydrogen. It can be lowered to 21.4% when there is 50% hydrogen present. According to data from IHS Markit, hydrogen demand in 2030 for power and heat generation is set to be 2.1 to 4.6 million tonnes globally.

Conclusion

Ammonia is expected to play a key role as a transport vector for green hydrogen, and as a result ammonia cracking is an area of increasing interest and development. Johnson Matthey has developed processes for highly efficient ammonia cracking which improve energy and feedstock efficiency, providing cost efficient conversion and a low emission process.

On-going development within Johnson Matthey has resulted in the development of KATALCO 27-612, a low temperature ammonia cracking catalyst, as well as high temperature catalysts such as KATALCO 27-200MQ which allows flexibility in the operating temperature range for cracking. ■

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DUIKER COMBUSTION ENGINEERS

Duiker ammonia cracking technology

Albert Lanser

Duiker Combustion Engineers is a Dutch process technology solution provider with a rich history dating back to 1919. Duiker has developed to become a world leader in providing process solutions for sulphur recovery and ammonia valorisation. Since the installation of the first Luynet Multipe Vortex (LMV) burners at Shell Godorf-Hafen in 1961, Duiker rapidly established a sound track record in the global energy industry and has built up more than a decade of experience in low NOx ammonia combustion. Driven by its mission to serve people and the planet, Duiker has developed an advanced, highly energy-efficient, innovative ammonia cracking technology.

Ammonia, in liquid form, can be utilised as an energy carrier. It can be produced from hydrogen in regions with abundant renewable energy sources such as sun, water, geothermal and wind. A global supply chain infrastructure is already in place for large-scale production, transportation and utilisation to serve various industries. This allows countries with abundant renewable energy sources to produce and export ammonia to end users across the globe, where it can be used as a direct fuel or converted back to hydrogen to enable the decarbonisation of industry, power generation, and mobility. A schematic overview of the ammonia-hydrogen supply chain is shown in Fig. 1.

Duiker offers solutions for direct utilisation in industrial steam boilers as well as in ammonia cracking. The Duiker developed ammonia cracking technical solution focuses on delivering highly efficient, economic and environmentally sustainable processes by combining state-of-the-art equipment with a high technology readiness level.

Hydrogen is a commodity product that is currently often labelled by the colours "grey", "blue" and "green" depending on the way it is produced. However, in Duiker's view these coloured labels will likely soon fade away and be replaced by a number that reflects the carbon footprint during its entire production and supply chain. As such, the only difference will be the levelised cost of hydrogen. For this reason, Duiker has focused on economies of scale during its cracker technology development, to achieve the lowest cost price for hydrogen from cracked ammonia. Duiker's cracking technology results in very low prices for the cracking itself, whilst offering extremely high reliability, availability and energy efficiency.

The novel Duiker Ammonia to Hydrogen Converter (AHC) converts green ammonia, the feedstock, into green hydrogen, the product.

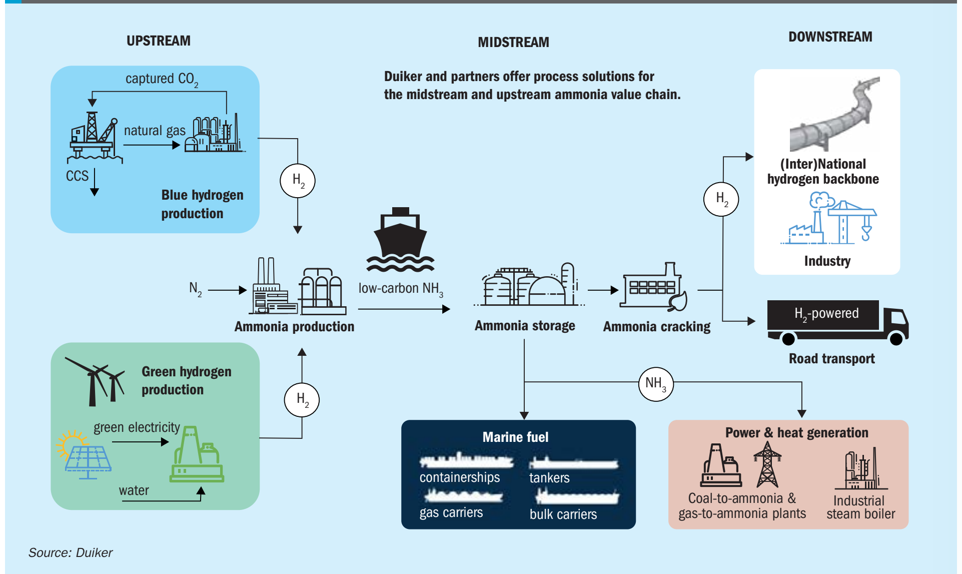
Proprietary SCO technology and nitrogen related emissions

The SCO technology has been developed for valorising ammonia-rich gases in refineries (Fig. 2). The first commercial-scale SCO unit was put into operation in 2009. Since then, Duiker has gained significant know-how and experience in low NOx ammonia combustion. The NOx levels from SCO installations are so low that they operate within existing permits for the refineries and without the necessity for additional DeNOx units.

Duiker can maintain the NOx level of the ammonia cracking plant at 60 ppm (v) @ 3% O_2 dry without a DeNOx unit. Duiker can also limit these emissions to practically a few ppm in case of lower NOx requirements.

If ammonia cracking is to be ubiquitous, the emissions from these plants must be strictly managed. Uncontrolled combustion of ammonia or hydrogen can lead to high NOx levels in the 1,000s of ppm. These emissions will require large DeNOx units and the addition of ammonia (NH_3). However, the production of N_2O, a potent greenhouse gas, NH_3 slip are inherent to NOx removal where starting NOx levels are high. The SCO technology will safeguard its users from NH_3 slippage, greatly facilitating the environmental permitting process.

Fig. 1: **Duiker's vision of an ammonia-based economy**



Source: Duiker

Fig. 2: SCO unit in a refinery in Asia.

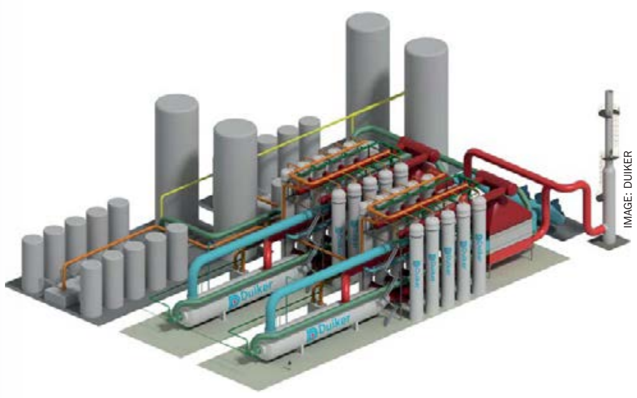


Fig. 3: Large-scale ammonia cracker with a hydrogen output of 500 t/d.

Key parameters

Important features of the Duiker AHC technology are listed below:

- **Efficiency:** The overall efficiency of the process based on the lower heating values (LHV) of ammonia and hydrogen, electricity consumption and counting for heat losses is 90% on an end-of-run basis.
- **Utilities:**
  - The only required utility of the AHC is considered to be electricity.
  - No cooling water or demi water is required.
- **Plot space:** Duiker's design for the ammonia to hydrogen converter is compact and can be flexibly adapted to customer requirements. An initial indication for the total plot footprint of the plant consisting of all necessary equipment can be quickly estimated for different sizes. For instance, a total plot footprint of 3,000 m² for a 180 t/d H_2 (@ 99.97% H_2) plant.
- **Emissions and effluents:**
  - During regular operations the only effluent of the AHC is flue gas that exits the system via the stack.
  - NOx emissions are below 5 ppm.
  - NH_3 emissions are below 1 ppm.
  - Zero CO_2 Scope 1 emission.
  - Zero liquid waste streams are produced in this process.
- **Output H_2:**
  - Purity in accordance with the ISO 14687:2019
- **Technology readiness level:**
  - Based on the equipment that the AHC comprises, the technology readiness level (TRL) is 8.

Large scale

The Duiker ammonia cracking technology can be scaled up to world-scale needs (Fig. 3). The plot space of the large-scale plant is highly flexible and can be further reduced according to customer requirements. ■

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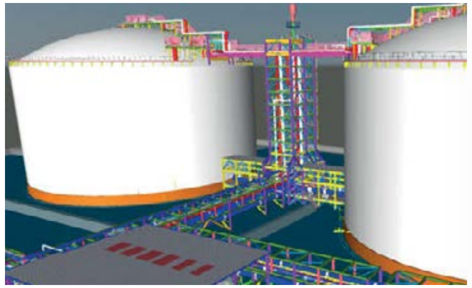
PROTON VENTURES

Ammonia cracking as part of the ammonia value chain

Kevin Rouwenhorst

Fig. 1: High-pressure ammonia cracking facilities at the high-pressure laboratory at the University of Twente, the Netherlands.



3D image of an ammonia storage facility (FEED+ engineering package) in the United Arab Emirates.

IMAGES: PROTON VENTURES B.V.

Proton Ventures is an engineering solutions provider in the (green) ammonia industry. The company was founded in 2001 by former CEO Hans Vrijenhoef, who had previously been the plant manager of a now defunct ammonia plant in Rozenburg, The Netherlands. Even in the early days, Hans already had the vision to use ammonia as a zero-carbon fuel and hydrogen carrier. Some 20 years later, this vision is taking shape with weekly announcements of green ammonia production plants.

Proton Ventures has its fair share of projects in this emerging landscape. These range from scoping studies, feasibility studies, FEEDs (front end engineering designs), and EPC (engineering, procurement & construction) projects. One of the distinguishing strengths of Proton Ventures is its technology agnostic approach as system integrator, which allows Proton Ventures to select the most suitable licensors and original equipment suppliers (OEMs) for the specific project.

Ammonia cracking for large-scale sustainable hydrogen production

Ammonia is increasingly considered as a zero-carbon fuel and hydrogen carrier in a decarbonised energy and food landscape. As ammonia will become more abundant as an energy vector, its use as a hydrogen carrier is set to increase. Ammonia cracker facilities for hydrogen production are currently being considered in various northern European ports, such as Rotterdam and Wilhelmshaven. Proton Ventures has performed various studies on ammonia cracking for clients and remains active within various research consortia. Such centralised ammonia cracker solutions are currently being developed, which do not always require full conversion and purification of the hydrogen, thereby improving the energy efficiency of the system and the cost.

To consolidate Proton Ventures' solutions for ammonia cracking, the company is currently operating a high-pressure ammonia cracking testing facility at the high-pressure laboratory at the University of Twente, the Netherlands (Fig. 1). This is critical to validate operational performance under industrially relevant conditions, while also allowing the testing of novel cracker concepts.

The next aim is to build a commercial pilot for ammonia cracking, which is an essential intermediate step for the industry to move toward world-scale hydrogen production facilities. A pilot plant is necessary, as performance in terms of ammonia feedstock utilisation is key for the cost of produced hydrogen. The ammonia feedstock cost can account for over 90% of the total levelised cost of hydrogen from ammonia cracking. Thus, ensuring minimal ammonia feedstock utilisation is paramount. At Proton Ventures, efficient process integrations in the developed processes allow for the lowest cost of hydrogen.

Ammonia storage and handling

Every ammonia cracker needs ammonia storage and handling. Some of the largest projects executed by Proton Ventures are its refrigerated storage tanks in Estonia (BCT & Eurochem) and Bulgaria (Agropolychim), which are among the largest operating ammonia storage tanks in Europe. For example, the tanks in Estonia each have a capacity for 30 kilotonnes of refrigerated ammonia at -33°C. The tanks are double containment storage tanks complying with modern safety standards. The facilities in Estonia also consist of railcar loading and unloading systems, a marine loading arm facility, and four UAN tanks of 20 kilotonnes each. Full containment storage tanks can also be realised with Proton Ventures.

The global trade of ammonia is set to expand over the coming decade, as the use of ammonia as shipping fuel, as stationary fuel, and as hydrogen carrier is taking off. In light of these developments, Proton Ventures and consortium partners have been awarded a turnkey contract by OCP Group for two refrigerated ammonia storage tanks in Jorf Lasfar, Morocco. Also, Proton Ventures is currently investigating the revamping of two storage tanks operated by Vesta Terminals in Vlissingen, The Netherlands.

Railcar loading and unloading facility in Sillamäe, Estonia.

IMAGES: PROTON VENTURES B.V.

Proton Ventures complies with state-of-the-art requirements for new ammonia storage tanks, even when these are located in desert areas with temperatures sometimes measured in excess of 50°C. Recently, a FEED+ engineering package was completed for a new ammonia export terminal in the United Arab Emirates. Intermittent flaring and an interconnecting bridge between the two storage tanks with a combined staircase optimises the capital investment, spatial utilisation and simplicity. Furthermore, the refrigeration system design is optimised for hot climate operations and a low operational cost.

Project development for large-scale green ammonia production

Large-scale ammonia crackers also require large-scale green ammonia production. This is most economical in locations with optimal solar PV and wind electricity. These renewables are coupled with electrolysis for hydrogen production, air separation for nitrogen purification, and a Haber-Bosch plant for ammonia production.

Proton Ventures is active within the TransHydrogen Alliance (THA), which aims to produce ammonia in areas with abundant solar and wind resources, such as Brazil and Morocco, with subsequent transport and cracking of ammonia to hydrogen in Rotterdam, the Netherlands. Herein, the aim is to produce ammonia at world scale, e.g., producing up to several millions of tonnes/annum. The benefit of the TransHydrogen Alliance is that production and utilisation are coupled, ensuring supply, while keeping the overall system cost low.

In February 2023, Casa dos Ventos and Comerc Eficiência, an energy efficiency company of the Comerc Energia Group, signed a partnership with the TransHydrogen Alliance. The purpose of the agreement is to enable the export of green ammonia produced in the Industrial and Port Complex of Pecém (CIPP), in Ceará. The plant is to be built on a 60-hectare site with a capacity of up to 2.4 GW of electrolysis, producing 960 t/d of hydrogen, and with all phases implemented, will enable the production of 2.2 million t/a of ammonia. The parties signed a memorandum of understanding to jointly develop a viable partnership targeting production of the first phase for export to Europe through the Port of Rotterdam, in the Netherlands in the year 2026.

Leading by example

The ammonia economy will likely become a reality soon. Various decarbonisation projects for existing ammonia plants have already been realised, with new build green ammonia plants under construction. Various consortia are commercialising ammonia energy solutions.

Proton Ventures has been at the forefront of these discussion with the initiation of the NH3 Event Europe in 2017, which was the first European conference focused on low carbon ammonia production, as well as its utilisation as a low carbon fertilizer, zero-carbon fuel, and hydrogen carrier. The conference boasts a strong industrial presence, as well as various excellent academic speakers. On the 8th and 9th of June 2023, the NH3 Event Europe will be held for the sixth time, returning to its iconic venue: Diergaarde Blijdorp in Rotterdam, the Netherlands.

Twenty years ago, even five years ago, very few believed in ammonia as an energy carrier. Over the last two decades Proton Ventures has established itself as an engineering solutions expert in the green ammonia landscape. ■

CASALE

A pathway to large-scale sustainable hydrogen production

Aurelia Pipino

Casale is highly committed to supporting and accelerating the energy transition through innovation and advanced technology, offering its customers decarbonised and cost-effective solutions for ammonia and hydrogen production.

Ammonia for generating CO_2-free energy

Ammonia cracking technology represents a fundamental path towards sustainability as it enables green ammonia produced in regions where renewable energy resources are available to be converted back to green hydrogen in places where renewable energy resources are not available to produce it.

While ammonia cracking technology for generating CO_2-free energy is new to the market, industrially the concept of an ammonia cracker is not new. Many plants were developed in the past where a so-called "ammonia dissociator" was installed to provide small amount of hydrogen for start-up activities.

Nowadays this operation is commonly achieved through the steam methane reformer which is actually used as an ammonia cracker during the start-up operation in several ammonia plants for this purpose.

However, despite being a well-known technology, today there are no available or known processes to decompose ammonia at large scale quantities.

Most commercially available solutions offer an electric-based furnace solution with a production capacity ranging from 1 to 2 t/d and rarely include any additional steps to produce hydrogen at high purities.

To meet the new challenges of the green revolution, Casale has developed a new process for converting ammonia synthesised from renewable resources into pure hydrogen via the Casale ammonia cracking technology. The Casale ammonia cracker design is applicable for a wide range of hydrogen plant capacities. All single components of the Casale process scheme are proven technologies with the ammonia cracker at the heart of the process.

Casale ammonia cracking technology is based on a simple, highly efficient and reliable scheme able to produce high purity hydrogen (up to Grade 5 hydrogen purity). It belongs to the Casale Flexigreen® family which includes a wide range of innovative products and technologies within the Casale portfolio dedicated to "Green" production (Fig. 1).

In the Casale ammonia cracking scheme, liquid ammonia from storage is evaporated and preheated before being

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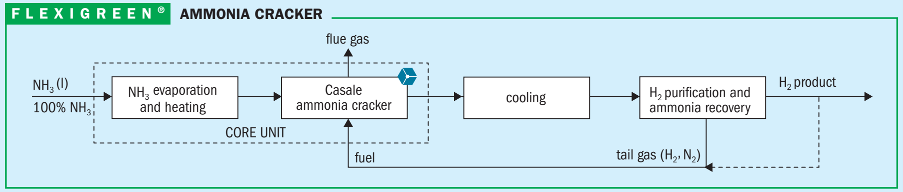
Fig. 1: Casale ammonia cracking conceptual scheme



Source: Casale

Table 1: Casale ammonia cracking process technology readiness levels (TRL) according to EU definition

Units	Technical description	TRL	Remarks
Ammonia storage and pumping	Actual system proven in operational environment	9	Well-proven system: Casale has already designed several units, in operation in different ammonia plants.
Ammonia vaporiser and preheater	Actual system proven in operational environment	9	Well-proven system: Casale has already designed several units, in operation in different ammonia plants.
Ammonia cracker	System prototype demonstration in operational environment	7	Proven in similar service: Similar units (based on SMR and fixed-bed reactors) have been designed by Casale, in operation in several syngas generation plants. Catalyst proven at small scale in commercial units. Optimised and improved for large-scale application validated and tested by major catalyst manufacturers.
Hydrogen Purification	Actual system proven in operational environment	9	Well-proven system (PSA based): Commonly used for a wide range of applications and capacities in syngas generation plants.
Ammonia Recovery	Actual system proven in operational environment	9	Well-proven system: Casale has already several ammonia recovery units designed and in operation in different ammonia plants.
Burners, high H_2 content fuel	Actual system proven in operational environment	9	Well-proven system: Casale experience with burner operation and test with 82% H_2 fuel gas content.
DeNOx System	Actual system proven in operational environment	9	Well-proven system: Commonly used for a wide range of applications and capacities.
Hydrogen Compression (if present)	Actual system proven in operational environment	9	Well-proven system: Hydrogen compressor commonly used in syngas generation plants for a wide range of applications and capacities.

Source: Casale

Table 2: Large-scale Casale ammonia cracking process key performance indicators

	Unit of measure	Unit Performance	
		Small/medium scale	Large scale
Hydrogen capacity (for one single train configuration)	t/d Nm_3/h	From 5 up to 325 From 2,300 up to 150,000	From 15 up to 1,300 From 6,900 up to 600,000
H_2 specific production	Nm_3 H_2/t NH_3 fed	Up to 1,530	
H_2 production efficiency from NH_3*	%	Up to 78 **	
H_2 pressure	barg	As required. 40 max w/o H_2 compressor	
H_2 purity	%	Up to grade 5 (99.999% H_2) **	
CO_2 emission	t/h	0	
Max NOx emission	ppm	According to local regulation or even lower	
Turndown	%	40	
On-stream factor	hours	As required (depending on the ammonia cracker catalyst life)	

**Defined as the % of NH_3 effectively converted into H_2 at battery limits; the balance ammonia is used as fuel.*
***PSA performances are affected by the H_2 purity required.*

Source: Casale

fed to the Casale ammonia cracker, where the ammonia decomposition reaction takes place. The ammonia decomposition reaction is an endothermic reaction promoted by high temperature and low pressure. To achieve the desired efficiency, it is performed in the presence of a catalyst while the heat is provided by the combustion of clean fuel (the tail gas coming from the hydrogen purification unit). The product from the ammonia cracking reactor is then cooled and purified in the separation unit where high purity hydrogen is recovered.

The hydrogen purification units consist of well-know and proven technologies commonly used in different industrial processes:

- hydrogen PSA unit;
- ammonia recovery unit: based on H_2O/NH_3 absorption and distillation technologies where ammonia is recovered and recycled back to reduce ammonia consumption.

The by-product coming from the separation unit is recovered as the main fuel providing the heat required for the reaction; a limited quantity of hydrogen is used as make-up fuel.

Casale can offer different ammonia cracking reactor design concepts depending on the size of the hydrogen production plant. Proposed solutions are tailored according to specific users' needs.

Ammonia cracking technology main features

The main features of the new process are:

- totally carbon-free operation;
- high efficiency;
- high reliability;
- simple and flexible;
- very high H_2 purity;
- completely self sustainable;
- highest single train capacity on the market;
- continuous operation;
- NOx emission controlled according to local regulations;
- no steam export;
- high pressure H_2 production without the need of a compressor;
- high modularisation grade approach;
- solution immediately available;
- wide range of hydrogen capacities in a single train configuration.

The process scheme selection is a function of the specific client requirements in terms of performance and investment cost.

Ammonia cracker furnace main features

The Casale ammonia cracker furnace design duplicates concepts from proven reaction furnaces designs, like the steam methane reformer, wherever practical, coupled with Casale's know-how of material behaviour exposed to an ammonia environment (nitriding).

Casale has the longest, successful experience in material selection for processes operated in an NH_3 environment at high pressure and temperature. This will likely be one of the most critical factors to be considered for a reliable and steady operation of an ammonia cracker process.

The similarity principles used are:

- physical similarity for process variables;
- duty similarity for endothermicity of the reaction;
- geometric similarity for shape considerations and flow symmetry (large size);
- metallurgy similarity: creep, hydrogen environment, nitriding.

Large-scale ammonia cracker furnace

The Casale large-scale ammonia cracking furnace is comprises multi parallel catalyst-filled tubes located inside a radiant section (multi shape design). The nickel-based catalyst is the current benchmark for non PGM catalyst used for ammonia cracking. The Casale ammonia cracker design has been developed in close cooperation with a major catalyst manufacturer.

The radiant chamber is provided with a combustion system able to operate with a wide range of free carbon fuels. The flue gases from the radiant section are collected in the convection section where all the available heat is recovered, and all pollutants are treated to achieve the required environmental limits. A further recovery step with a combustion air preheating facility is added to improve the overall furnace efficiency before the flue gases are sent to the atmosphere.

This scheme is suitable for a hydrogen plant capacity from 6,900 Nm³/h (15 t/d) up to 600,000 Nm³/h (1,500 t/d).

Small/medium-scale ammonia cracker furnace

The Casale small/medium-scale ammonia cracking furnace comprises a radiant section and a convective section in which different steps for preheating of the ammonia vapour are foreseen to supply the required heat for the ammonia dissociation reaction.

This scheme is suitable for a hydrogen plant capacity from 2,300 Nm³/h (5 t/d) up to 150,000 Nm³/h (about 325 t/d).

A similar approach to the previous large-scale cracker concept has been applied for the combustion system.

The main advantage of this scheme is a lower operating temperature allowing a reduction in the investment cost, but is limited in the maximum hydrogen capacity achievable.

Process technology readiness levels (TRL)

The technology readiness level (TRL) for the Casale ammonia cracker process is 7, mainly due to the catalytic furnace for medium/large scale applications (see Table 1).

The TRL assigned to the other ammonia cracking scheme components is 9 as they are all well-proven technologies commonly used in a wide range of applications and in which Casale already has experience.

Regarding the ammonia cracker, Casale has designed many steam reformers for both ammonia and methanol plant production with similar capacity/duty or higher, whose technology can be totally applied to the Casale ammonia cracking furnace.

Scalability of the plant is mainly limited by the size of the catalytic furnace unit and the performance of current catalysts available on the market.

Key performance indicators

Key performance indicators for Casale ammonia cracking are provided in Table 2.

Summary

Thanks to its background and experience, Casale can provide a simple, flexible and customised technology which can be tailored to specific plant needs with a well proven solution that is immediately available.

Covered by two different patent pending applications, Casale ammonia cracking technology covers a wide range of hydrogen plant capacities ranging from 5 t/d of pure hydrogen to 1,300 t/d of pure hydrogen, currently the highest single train plant capacity available on the market.

Casale is ready to support possible partners in various way starting from the engineering and design to product scale up for commercialisation of the first industrial-scale unit. ■

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Improving the lifetime of AN pipe reactors

Pipe reactors in ammonium nitrate plants suffer from short lifetimes due to serious corrosion and erosion issues. A new solution from NobelClad could provide a unique opportunity to address the problem faced by licensors and end-users in the pipe reactors of ammonium nitrate plants. The NobelClad solution provides higher safety and reliability standards and less downtime and maintenance leading to an attractive payback time.

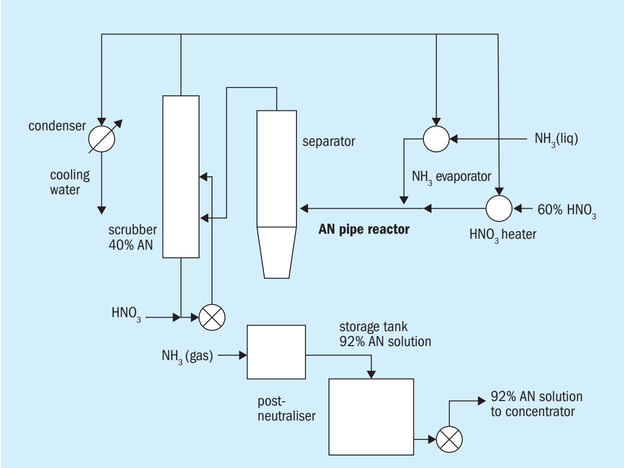
Mark Brouwer (UreaKnowHow.com) and Mukesh Ahlavadi (NobelClad)

Often seen in the production of inorganic fertilizers, a pipe reactor is an acid-base reaction vessel that uses reaction heat as the primary method of drying. This process reduces the burden on the dryer and can significantly decrease plant energy costs.

The pipe reactor accepts phosphoric acid, sulphuric acid or nitric acid in one side of the pipe, and gaseous or liquid ammonia is sparged into the reaction chamber. This results in either ammoniated phosphate, sulphate or nitrate, a hot "melt" of superheated product[1]. The contained heat of the reaction contributes to the heat requirement for moisture removal of the granulated material. This reduces the dryer fuel requirements for the plant.

Pipe reactors are popular equipment items in several ammonium nitrate (AN) process technologies. Ammonia gas reacts with heated nitric acid releasing heat which evaporates a significant part of the water fraction leading to a concentrated ammonium nitrate solution. Fig. 1 shows the flow scheme of the Grande Paroisse (now Casale) AN process.

Fig. 1: **Grande Paroisse ammonium nitrate process scheme**



Source: NobelClad

The ammonia flow rate is measured in the liquid phase and then the ammonia is vaporised and superheated up to 90°C. Heat is provided by the condensation from process steam generated by the neutralisation reaction. Hot gaseous ammonia is fed into the pipe reactor.

The nitric acid flow rate is measured and controlled through ratio control related to the ammonia flow. Nitric acid is heated in a heat exchanger fed with process steam to increase the ammonium nitrate concentration.

The instantaneous reaction starts as soon as nitric acid and ammonia are mixed and goes on all along the pipe reactor. Pressure decreases from the reactor head (4~7 abs. bar) to the separator tank (~1 abs. bar). At the pipe reactor outlet, the ammonium nitrate solution (ANS) and process steam are split in a separator.

The ANS flows by gravity from the separator tank into the buffer tank where a small flow of gaseous ammonia is fed to automatically adjust the pH of the solution.

Pipe reactor issues

A main advantage of a pipe reactor is its operating flexibility, it can be operated over a wide capacity range. For example, the pipe reactor in Fig. 2 was designed for a capacity of 1,650 t/d and has been operating within a range of 700 and 2,000 t/d. This range is achieved by one single pipe reactor (DN 200 mm – length 9 m).

However, in the stainless steel 304L pipe reactor, corrosion at a rate of approx. 12 mm/year takes place in a zone of

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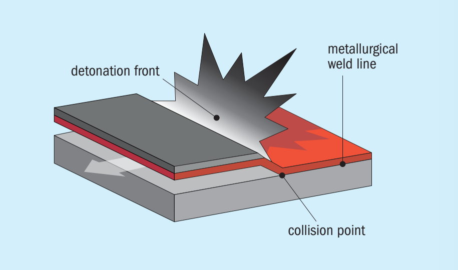
Fig. 2: Grande Paroisse pipe reactor at DSM Geleen (now OCI).

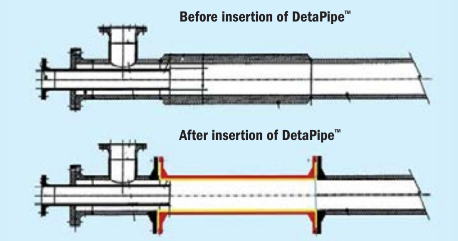
Fig. 3: **Arrangement of plates during the welding process**



Source: NobelClad

Fig. 4: DetaPipe™ Zr, a pipe spool clad with zirconium.

Fig. 5: **NobelClad solution for pipe reactors in ammonium nitrate plants**



Source: NobelClad

approximately one metre in length, close to the nitric acid inlet.

Besides possible erosion phenomena, the following corrosion mechanism is likely to happen in this turbulent environment: The already heated nitric acid plus the exothermic heat developed from the reaction between ammonia and nitric acid creates alternating wet-dry zones (condensation and re-evaporation).

The anodic reaction is:

$$Me \rightleftharpoons Me^{n+} + ne^-$$

While the cathodic reaction is:

$$NO_3^- + 4H^+ + 3e^- \rightleftharpoons NO + 2H_2O \quad (Eo = +940\ mV)$$

In these alternating wet-dry zones, dichromic acid will be formed and the above cathodic nitrate reduction reaction will be overruled by:

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O \quad (Eo = +1{,}330\ mV)$$

The higher equilibrium potential of this redox reaction will shift the corrosion potential further in the trans-passive area of the polarisation curve leading to high corrosion rates of stainless steels.

With the target of better corrosion resistance, titanium has been used for these pipe reactors. A passive layer of titanium oxide provides corrosion resistance. However, if this protective layer is broken, the exposed metal surface will oxidise, and the resulting combustion process can be highly exothermic. Therefore, care is needed when considering titanium for this application. To establish the safety of using titanium for nitric acid spargers, appropriate testing or assessment has been carried out by several companies, but details of such work do not seem to be available in the open literature for nitric acid reactions. Special care is advisable when urea off gases are used as a source of ammonia. The presence of contamination with incompatible substances such as iron should be avoided[2]. Besides the above-mentioned safety risks, titanium pipe reactors also show a limited lifetime of six months maximum as the corrosion resistance of

Fig. 6: Tantalum test spool.

titanium in nitric acid concentrations is limited to 40-60%[3].

Solutions

Grande Paroisse has operating experience of more than five years in two of its own plants (now owned by Agrofert, earlier Borealis). In these plants, the corrosion zone of the pipe reactor is made of SS 304L, but is also fitted with an internal lining. Those pipe reactors can operate for

more than two years without any corrosion issues.

In the DSM-Agro (now OCI) plant, it is preferred to maintain the equipment as simply as possible, and every six months the pipe reactor is changed and repaired.

NobelClad, a DMC Global Company, headquartered in Colorado, has been approached by some end-users looking for a better solution. NobelClad is an industry leader in explosion welding (EXW), commonly called explosion cladding, which is a solid-state welding technology for the manufacture of large clad metal plates, which are sold under its trademark DetaClad™. The technology was discovered around 1960. Explosion clad products are used extensively, worldwide in the manufacture of corrosion-resistant process equipment as well as other bi-metallic applications. The cladding metal alloy can be selected for optimum corrosion performance. The base metal alloy can be specified to optimise strength, fabricability, and cost. The high strength, durable explosion weld allows for the construction of chemical process industry equipment exhibiting the beneficial features of both[4].

Fig. 3 shows the general arrangement of the plates during the welding process. The distance of the gap is one of the crucial elements in explosion welding, helping to determine the angle of impact, the velocity of impact, and the consistency of the jet[5]. DetaClad™ has been extensively used in fertilizer and chemical plants (such as urea, nitric acid, purified terephthalic acid, acetic acid, polycarbonate, and chlor-alkali to name a few), as well as refinery, LNG, geothermal, and nuclear applications.

NobelClad has recently launched a revolutionary reactive clad metal product known as DetaPipe™. It is a mechanically clad pipe product. DetaPipe™ will be manufactured to B31.3 specifications which will assist the piping engineer when designing a piping system. Considering this is mechanically clad, NobelClad performs gripping force tests, like oil and gas industry standard API 5L. In addition, test spools have been tested at 200 bar and 225°C.

Fig. 4 shows DetaPipe™ Zr, a pipe spool clad with zirconium. The pipe spool, from flange face to flange face, is fully clad with zirconium inside carbon steel. This pipe spool can also be clad with titanium. DetaPipe™ can be fabricated with either ANSI flanges, compact flanges, or seal ring hubs. DetaPipe™ is currently being offered in straight lengths up to 9 m and elbows.

NobelClad can produce pipe spools currently from 6 inch to 30 inch NPS, however flexibility exists to downsize or upsize these dimensions by a few inches depending on the application and business viability.

To solve the corrosion issues in the earlier discussed pipe reactor, NobelClad proposed using a DetaPipe™ Zr spool along with flange faces made with DetaClad™ Zr. NobelClad can produce the entire length of the pipe reactor with Zr mechanical cladding, however, considering the cost benefits, the solution proposed included replacing only the section subject to maximum corrosion and erosion. Of all the corrosion-resistant metals, zirconium or tantalum are highly resistant to all forms of corrosion which include crevice corrosion[6]. The NobelClad solution for pipe reactors in AN plants reduces flange connections by providing a single construction piece (Fig. 5).

Recently, NobelClad installed a tantalum test spool for a chlor-alkali application (Fig. 6) and is further working to develop tees and reducers.

Conclusions

Pipe reactors in ammonium nitrate plants suffer from short lifetimes due to serious corrosion and erosion issues. NobelClad's DetaPipe™ coupled with its highly used and recommended DetaClad™ solution could provide a unique opportunity to address the problem faced by licensors and end-users in the pipe-reactors of ammonium-nitrate plants.

NobelClad's DetaPipe™ provides new opportunities for mining, fertilizer and other chemical applications. End users and licensors are encouraged to contact NobleClad to jointly test sample spools for critical applications. ■

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Modularisation, front and centre

With the market for green ammonia set to grow significantly in the coming years, modularisation of ammonia plants can bring many benefits to new projects, including optimised cost, speed of delivery and reducing overall risks. thyssenkrupp Uhde is committed to further develop standardised, modular solutions for its clients. **Tobias Birwe** and **Dustin Mayor** explain the company's modularisation concept.

Even in times of a slowing global economy with several countries on the brink of a recession, labour markets are persistently tight in most parts of the world – this is true for many branches from leisure and hospitality to engineering and especially so for the construction industry. For example, the total unemployment rate in the US has remained almost unchanged from its very low levels of 3.6% in March 2022 down to 3.5% in March this year.

Furthermore, there has been a significant shift of investments from conventional, grey, fossil fuelled technologies to blue and green alternatives, especially in the US, Europe, Middle East and Australia.

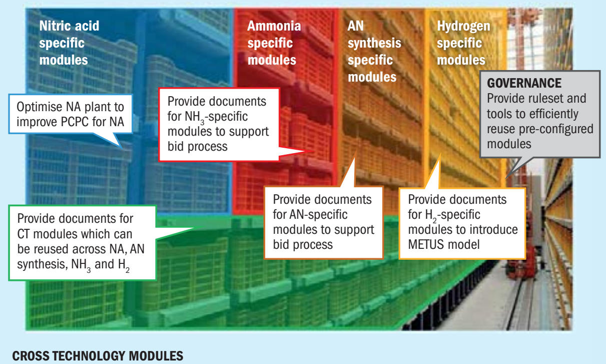
thyssenkrupp Uhde expects the market for green ammonia to outperform traditional ammonia markets as early as 2026, followed by a very dynamic market growth afterwards. For Australia alone, this could lead to a clean ammonia capacity of approximately five million tonnes per annum by 2030.

Green solutions have even higher demands in terms of optimised cost, speed of delivery, higher predictability especially in terms of supply chain security and therefore reduced overall execution risks. This is why, despite the already known benefits like better safety performance, potential cost savings and higher price and schedule accuracy, modularisation is becoming front and centre in the development phase of many capital projects. thyssenkrupp Uhde is therefore committed to further develop standardised, modular solutions for its clients, supporting the decision process for the application of modularisation and to increase its modular footprint.

For more than 100 years, thyssenkrupp Uhde has been successfully serving its clients with its ammonia plants. Together with its competence centre for modularisation in Thailand, the concepts of prefabrication, preassembly, modularisation and offsite fabrication (PPMOF) are also increasingly applied to its core technologies, offering a range of modularisation services from project management, concept planning, preliminary engineering, detailed design, procurement up to construction management and commissioning.

thyssenkrupp Uhde differentiates its modularisation efforts into geometrical and functional modularisation. While geometrical modularisation describes the planning, engineering and fabrication of a physical module, functional modularisation defines the plant process from a predefined standard plant as per the relevant, specific requirements of the project.

Fig. 1: **Process should be defined through a standardised "plant warehouse"**



Source: thyssenkrupp Uhde

Functional modularisation

Functional modularisation is done through thyssenkrupp Uhde's self-developed pre-configured plant concept (PCPC). As briefly outlined already, it looks at modularisation from another angle. Plants configured by PCPC are adapted to the specific project requirements starting from a well defined standard plant. These standard plants divided into functional modules have been developed not only for ammonia plants, but also other technologies including nitric acid, ammonium nitrate and hydrogen. thyssenkrupp Uhde illustrates these functional modules as standards which can be taken from a "plant warehouse" (see Fig. 1). Deviations from specific project requirements to the standard plants are identified and can be linked directly to the functional modules using so-called variant drivers.

While functional modularisation is already the standard for certain technologies at thyssenkrupp Uhde, the extent of application of geometrical modularisation on a specific project must be determined individually for each project. This is done by an analysis of the value-add in terms of reduction of risks and cost advantages versus conventional stick-built solutions. Geometrical modularisation is applied so that the overall benefits to the project outweigh the additional challenges and cost imposed to the project, which result among others from the addition of material (especially steel), logistic complexity and transportation cost and higher engineering costs.

In addition, thyssenkrupp Uhde's approach for functional modularisation increases the quality of its early engineering deliverables through its standardised and pre-defined approach. Further, it shortens the time required for their development. Therefore, this concept enables the fast and early development of a clear set of engineering documents as a starting point which allows the customer to evaluate the impact of their project requirements on the plant design at an earlier stage. In this way, different project scenarios can be evaluated efficiently together with customers.

Geometric modularisation

geometric modularisation instead is defined as "the method of plant design which enables fabrication and assembly of a large proportion of the plant to take place in a location remote from the project site", typically consisting of four categories:

- PAU/PAM (pre-assembled units/modules);
- PAR (pre-assembled racks);
- VAU (vendor assembled unit);
- VPU (vendor packaged unit).

Other aspects of PPMOF include precast concrete, dressed columns and prefabricated buildings.

Modules generally consist of equipment items arranged in modular steel structures and buildings that can be assembled off-site, transported to site and lifted into place. The equipment is connected with piping to the fullest practical extent, instrumentation is installed and cabled to junction boxes, lighting and cabling is installed, steelwork is fireproofed up to the connection points, tracing and insulation on equipment and piping, and painting is completed as far as is practical, as illustrated also in Fig. 2.

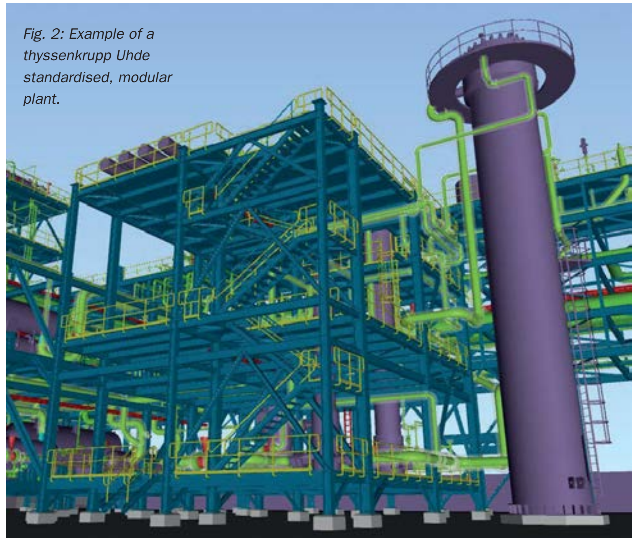


Fig. 2: Example of a thyssenkrupp Uhde standardised, modular plant.

IMAGE: THYSSENKRUPP UHDE

The size and scope of modules are only limited by the physical constraints of the transportation route to the site location and the available capacity of heavy lift and transportation equipment. Therefore, a preliminary transportation study, undertaken during the feasibility stage, is essential for any modular project. However, in case of the development of a standardised, modular plant, it is recommended to target smaller, truckable modules to be applicable for most site locations.

For standardised, modular plants, these modularisation concepts should be applied in a way that the plant process is split system-wise into physical modules (and submodules). The final module allocation of each component is shown in all relevant execution documentation. It is further understood as good engineering practice to arrange and connect such resulting process modules alongside and to a central pipe rack and avoid any inter-module piping connections. A constructability study finally assures the proper consideration of construction knowledge already in the early project phases especially related to erection sequencing on site and planning of heavy lifts.

For many applications, this value-add is given since geometric modularisation is a very effective way to improve quality by fabricating modules in more controlled environments off-site. It also increases productivity, enables cost savings from shifting site costs to workshop costs, increases reliability of schedules and mitigates site risks. Another significant lever for cost reduction results from the potentially smaller footprint required for a modular plant compared to a stick-built arrangement. Past engineering studies carried out by thyssenkrupp Uhde resulted in a reduction of land requirements of up to 30% – an achievement thyssenkrupp Uhde also seeks to increasingly apply to its ammonia plants. Further, it increases HSE and industrial relations performance. Finally, geometrical modularisation enables more sustainable project delivery through the reduction of impacts on local communities and infrastructure.

Conclusion

thyssenkrupp Uhde and many of its customers recognise that both concepts combined, functional and geometrical modularisation, yield a powerful basis for efficient project development and execution, with a significant value-add for many project applications. Especially within the last two years there has been a rapid increase in modularisation applications, in order to increase project predictability, mitigate labour shortages and reduce overall risks – a trend which is expected to continue. ■

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Editor:
RICHARD HANDS
richard.hands@bcinsight.com

Technical Editor:
LISA CONNOCK
lisa.connock@bcinsight.com

Publishing Director:
TINA FIRMAN
tina.firman@bcinsight.com

Subscription rates:
GBP 425; USD 850; EUR 655

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ISSN: 1750-6891

Design and production:
JOHN CREEK, DANI HART

Printed in England by:
Buxton Press Ltd
Palace Road, Buxton, Derbyshire,
SK17 6AE

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Published by: BCInsight Ltd
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