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NITROGEN+SYNGAS
ISSUE 394
MARCH-APRIL 2025

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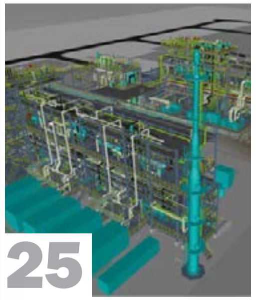

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Trump and fertilizer markets

President Trump's flurry of activity in his first month of office has not only upended the global political order that has existed, more or less, since the US rearranged it to its satisfaction in 1945, but has also had a seismic impact on world trade. How the various strands of US policy will play out remains highly uncertain, but some clear trends are beginning to emerge.

The first has been protectionist measures implemented by the US, in particular 25% tariffs on goods entering from Mexico and Canada. Mexico appeared to have negotiated another one month stay of execution on tariffs at time of writing, but in spite of being granted a similar stay until April 2nd, Canada has been less willing to play ball. Newly elected prime minister Mark Carney has been talking tough, and US industries face significant hikes on the price of many key raw materials from Canada, from potash to crude oil, as well as key minerals such as aluminium, nickel, zinc, cobalt and lithium.

The US has also imposed new tariffs on China, which has retaliated with tariffs of up to 15% on the US, mainly covering $22 billion worth of trade in cotton and agricultural goods including chicken, corn and soyabeans. The impact of this and US fertilizer prices may lead to a fall in farm demand for fertilizer this year. As well as potash, the US imports significant amounts of UAN, urea and some ammonia, as well as phosphates, though unlike potash there are a number of countries to source these from which are not – or perhaps not yet - subject to US tariffs. So far other countries have not yet been targeted, though Trump has indicated that Europe could be next in line for restrictive economic measures.

> **"A peace deal... could see US sanctions on Russia lifted rapidly..."**

Meanwhile, the diplomatic – and sometimes very undiplomatic – back and forth on Ukraine is also forcing many to recalibrate their expectations. A peace deal, albeit one that Ukraine is strongarmed into by the US, could see US sanctions on Russia lifted rapidly. A return of Russian gas flows into Europe would certainly damp down on high European natural gas costs, which reached $18/MMBtu in February (though lower since then), easing the pressure on European nitrogen producers, but equally a potential return of Russian exports of ammonia or flows of ammonium nitrate into Europe would make life correspondingly more difficult for them. In the meantime, Russia has yet to bring its 1.3 million t/a transhipment terminal at Taman on the Black Sea online, while the European Commission proposed import tariffs on 29 January on fertilizers arriving from Russia and Belarus in a drive to reduce dependence on imports from those countries and support domestic European production.

The collective impact of this has so far mainly been on the stock market. The Dow Jones index is down 5% from its February peak, while the three major US fertilizer producers; CF Industries, Nutrien and Mosaic all saw their stocks slide. There are indications the US economy may contract in 1Q 2025, and fears of a recession. Conversely, Chinese stocks are up, but prices are falling, with a 0.7% fall in consumer prices during February as the economy faces slack demand, likely to be worsened by US tariffs on Chinese exports.

In spite of all of this, the prospects for the global economy remain overall positive, with growth continuing in India and southeast Asia, though probably the global average may drop slightly below the 3.0-3.5% growth we have become used to, due to a range of structural issues, from demographics and ageing populations, the stalling of the Chinese economy, poor productivity growth and the retreat from globalisation that the current trade skirmishes will exacerbate. ■

Richard Hands, Editor

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Price Trends

Support for ammonia prices in markets east of Suez eroded during February. The ongoing bubble of support seen in NW Europe remained just about intact, though news of further declines at Tampa for March and slumping natural-gas prices should begin to eat away at any remaining support in the West. After declining $70/t during the first two months of 2025, the Tampa settlement between Yara and Mosaic was revised down a further $40/t for March, imposing further downward pressure on f.o.b. values in Trinidad and the US Gulf.

Across the Atlantic, while no new business was confirmed out of Algeria, supply appears still healthy, with Hexagon loading spot material for NW Europe, around which the majority of global spot activity of late has been centred. Spot material also arrived into Poland after Trammo agreed a prompt deal with fertilizer manufacturer Grupa Azoty.

East of Suez, markets were long in the Middle East with a healthy export line-up across the region. Prices continue to ease, with Ma'aden reporting considerably lower contract netbacks to India, where the market awaited the result of FACT's 28 February import tender for up to 15,000 tonnes. There was no change to healthy export availability seen in Malaysia and particularly Indonesia, where spot numbers could soon approach $300/t f.o.b. In the Far East, domestic prices in China gained further ground, though delivered values on the seaborne market appear to be headed in the opposite direction. Contract prices in both South Korea and Taiwan, China slipped again, with demand almost completely non-existent.

In urea markets, anticipation about forthcoming India tenders put some price benchmarks under pressure. India has an import requirement to build its inventory level back up to 6 million t/a but the Department of Fertilizers has some time on its side as India is now into the lower consumption months for urea, when production will exceed demand.

In the US, there has been considerable volatility in New Orleans markets. Prices dipped to $380/st f.o.b. during February before recovering to $403/st, then dropping back to $385/st f.o.b. for March imports. The volatility at NOLA is doing little to encourage fresh urea imports even though the market is still perceived to be short of urea. Brazilian prices also took a tumble during the month, with offers sliding to $420-425/t c.fr. Some sales are being made, but many buyers are preferring to take cargo on a formula basis. Overall demand is fairly thin, and is unlikely to pick up until much later in the year.

Europe has been quiet but trades are reported reflecting $440-450/t f.o.b. Egypt. There has been no f.o.b. trade in Egypt and the only sales reported from Algeria were formula based. Further south, Nigeria's Dangote came back to the market to place March tonnes but had yet to conclude a sale at time of writing. Reports suggest that the high bid is sub-$410/t f.o.b. Lekki, which has so far been rejected by the Nigerian producer. Indonesia also rejected a bid for 45,000 tonnes of granular. Ameropa was the high bidder at $411/t f.o.b. against the owner's estimate of $429/t f.o.b. and the tender was scrapped.

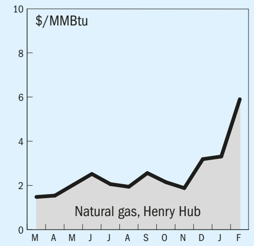
Table 1: **Price indications**

Cash equivalent	mid-Feb	mid-Dec	mid-Oct	mid-Aug
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	460	530	520	440-500
f.o.b. Arab Gulf	330-360	350-430	350-430	320-350
c.fr N.W. Europe	550-600	610-620	600-610	550-575
Urea ($/t)				
f.o.b. bulk Black Sea	385-395	305-320	320-330	305-325
f.o.b. bulk Arab Gulf*	402-445	319-358	350-370	290-335
f.o.b. NOLA barge (metric tonnes)	402-418	326-338	330-339	305-316
f.o.b. bagged China	n.m.	n.m.	253-261	n.m.
DAP ($/t)				
f.o.b. bulk US Gulf	588-595	n.m.	550-570	550-570
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	330	278-280	265-270	240-245

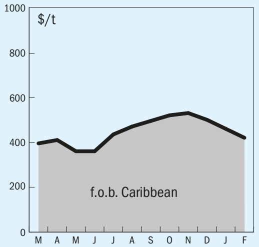
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

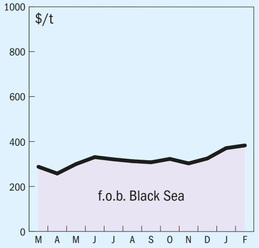
natural gas



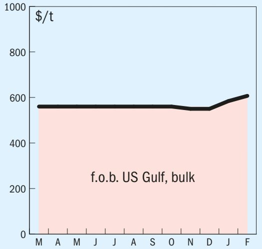
ammonia



urea

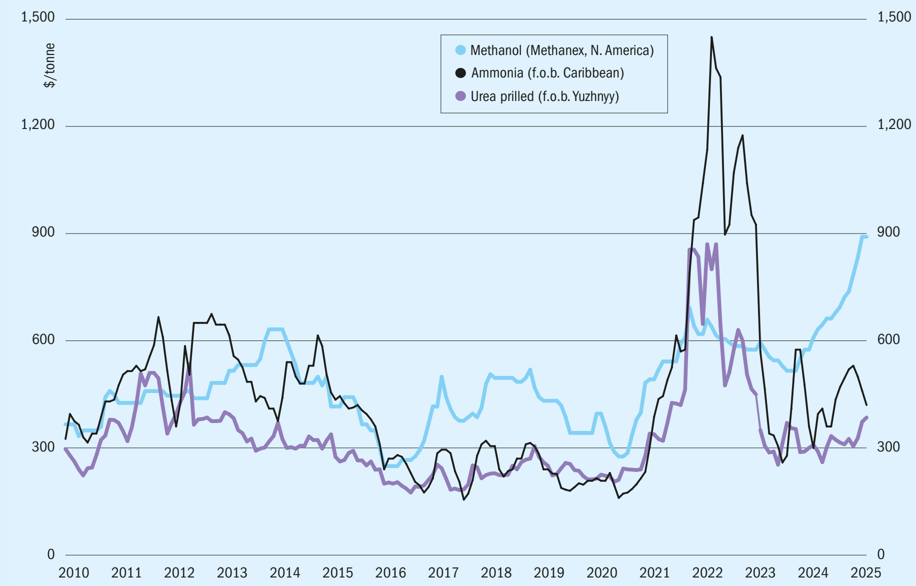


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Prices look set to come under further pressure moving into March, particularly east of Suez. Prices in the West – specifically in northwest Europe – have enjoyed a partial degree of support through February, though this appears unlikely to hold for much longer.
- In the US, there is pessimism in the market about exports from the 1.3 million t/a Gulf Coast Ammonia (GCA) facility in Texas, but there is confidence that Woodside Energy's 1.1 million t/a Beaumont New Ammonia project will come online on time in Q3 of this year.
- In Ukraine, prospects for a restart at one of the two 550,000 t/a units at Odesa Port Plant (OPZ) were dashed after Russian missile attacks on local infrastructure impacted gas supply to the complex.
- Global demand remains limited outside NW Europe, but renewed import appetite could also emerge from India in late March.

UREA

- Prospects for urea prices remain bearish. Every week that India delays coming to the market puts pressure on the market, although producers in many areas have yet to accept the lower bids. The question remains open on whether support from India can be found for March loading, though it seems certain that April tonnage will be required.
- Ice on upper reaches of the Mississippi River have also impacted on US internal demand, though stocks continue to build at New Orleans. Some February shipments have been pushed into March, shifting the import forecast to 585,000 tonnes for February and 529,000 tonners for March. Demand is expected to improve in the coming weeks, but in the meantime NOLA urea prices remain under pressure.
- Chinese prices have rallied due to downstream buying, but the downward pressure of significant supply still exists.

METHANOL

- Methanol demand remained strong in southeast Asia particularly among chemical end-users, while operating issues at some regional production plants helped to keep availability tight and prices higher than anticipated.
- China, conversely, has seen a dip in demand due to maintenance at major MTO plants, and weaker demand from other downstream industries at the same time that production rates remained relatively high, leading to increasing stockpiles, with storage closer to capacity. All of this had the effect of pushing domestic Chinese prices lower.
- European methanol prices had stabilised by the end of February after a decline in the first two months of the year, reaching $350/t after the restart of the 900,000 t/a Tjelbergodden plant. The European methanol market shrank by 2.3% during 2024. US prices were also stable, with loadings from Trinidad down.

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Nitrogen Industry News

INDIA

New urea plant for Assam

PHOTO: BVFCL

The existing BVFCL plant at Namrup.

In her Indian 2025-26 budget presentation on February 1st, finance minster Nirmala Sitharaman announced a $1.15 billion investment to build a new 1.27 million t/a ammonia-urea complex at Namrup in Assam province. The plant will be a brownfield development at the Brahmaputra Valley Fertiliser Corporation Ltd (BVFCL) site. Sitharaman said that it was part of the Indian government's commitment to strengthening agricultural infrastructure and self-sufficiency in fertilizer production. The gas-based ammonia-urea plant is expected to start up in 2028-29 and will supply farmers in northeast and eastern India.

India currently produces around 32 million t/a of urea, short of demand of around 40 million t/a. The new plant is intended to reduce India's dependence on imports as part of the government's long-term goal of self-reliance in agricultural inputs and ensuring a stable fertilizer supply to farmers at affordable prices. While BVFCL will operate the new plant, state-owned National Fertilizers Ltd (NFL) will own 18% of the facility, while Hindustan Urvarak & Rasayan Limited (HURL) is expected to take a 13% stake. ■

Casale to license renewable ammonia plant

Casale is partnering with Indian renewable energy company Avaada Group to develop a 1,500 t/d green ammonia plant in Gopalpur, Odisha. This represents India's largest grassroots green ammonia facility to date, and will be powered entirely by renewable energy. Casale will provide the ammonia process license, basic engineering package, proprietary equipment, and detailed engineering review, ensuring the facility operates at the highest levels of efficiency and sustainability. The plant will use Casale's FlexAMMONIA technology, part of the FLEXIGREEN® portfolio.

Federico Zardi, CEO of Casale, said: "Casale is honoured to partner with Avaada in delivering India's largest grassroots green ammonia plant. This marks a significant milestone in our commitment to supporting India's clean energy transition. With this project, Casale further strengthens its presence in India, where we have now licensed a total green ammonia capacity of 5,700 t/d. Our cutting-edge technologies will enable Avaada to produce green ammonia efficiently, contributing to India's decarbonisation goals and global leadership in sustainable industrial solutions. We look forward to playing a pivotal role in shaping the future of green chemistry in India and beyond."

EGYPT

MOPCO lines up thyssenkrupp to lower carbon intensity of production

thyssenkrupp Uhde says that it has been selected by MOPCO – the Misr Fertilizers Production Company – to supply advanced technology for three existing ammonia and urea plants in Damietta, Egypt, to improve the sustainability of production. Using an innovative carbon capture and usage (CCU) solution, the aim is to remove up to 145,000 t/a of CO_2 from the flue gas of the existing ammonia production and use them to boost urea production. At the same time, three 150 t/d axial-radial flow uhde® ammonia converter cartridges using JM's high performance KATALCOTM 74-1 catalyst will be installed in the existing converters to increase ammonia production capacity while lowering natural gas consumption in the synthesis loop by around 10%. To bring down CO_2 emissions further, additional green hydrogen feedstock will be sourced from new water electrolysis units powered by renewable energy. MOPCO plans to produce up to 150,000 t/a of green ammonia.

Ahmed Mahmoud El-Sayed, chairman and managing director of MOPCO said: "This collaboration with thyssenkrupp Uhde marks a significant step towards our sustainability strategic goals. Their world-leading technologies will not only increase our production capacity but also deliver proof for our commitment to provide more climate-friendly urea and produce green ammonia, where MOPCO will become one of the leaders to produce such products in MENA."

MOPCO is the largest nitrogen fertilizer complex in Egypt. The ammonia and urea plants (three plants each) were originally built by thyssenkrupp Uhde between 2006 and 2015, each with a capacity of approximately 1,200 t/d of ammonia and 2,000 t/d of urea.

CHINA

Stamicarbon to revamp Hulunbuir urea plant

NextChem subsidiary Stamicarbon has been selected to provide the process design package to upgrade the Hulunbuir New Gold Chemical Co., Ltd.'s urea plant in Hulunbuir, Inner Mongolia, using its proprietary NX STAMI UreaTM technology. The upgrade will integrate Stamicarbon's EVOLVE MELT MP flash design to enhance operational efficiency and reliability while minimizing process steam consumption. Following the upgrade, the plant's capacity will be increased by about 26% to 3,600 t/d, with an expected high-pressure steam reduction of 15%.

Alessandro Bernini, CEO of MAIRE, stated: "This project strengthens our technological presence in China, a major and rapidly growing market, and reinforces our position as the global leader in innovative solutions for the nitrogen fertilizer industry."

UNITED STATES

ExxonMobil and Trammo sign low carbon ammonia offtake agreement

Trammo, Inc. and ExxonMobil signed a heads of agreement to advance discussions for Trammo's long-term offtake of 300-500,000 t/a of low-carbon ammonia from ExxonMobil's Baytown, Texas facility. The facility is expected to produce virtually carbon-free 'blue' hydrogen with approximately 98% of CO_2 removed, and will use this low-carbon hydrogen to make low-carbon ammonia. Trammo, a leading international physical commodity trader, will leverage its market and logistical expertise to deliver and sell in Europe and worldwide this unique low-carbon ammonia for use as fertilizer feedstock and for other key industrial applications.

The facility is expected to be the world's largest of its kind, capable of producing up to 1 bcf/d of low-carbon hydrogen and more than 1 million t/a of low-carbon ammonia. A final investment decision by ExxonMobil is expected in 2025 with anticipated startup in 2029, subject to supportive government policy, regulatory permitting, and market conditions.

"Our Baytown project continues to make significant strides, attracting more and more customer interest," said Barry Engle, president of ExxonMobil Low Carbon Solutions. "We're looking forward to working with Trammo on this project, which would be a win for America's Gulf Coast, creating jobs and enhancing US energy exports."

Worley to provide FEED for green ammonia plant

Worley says that they have been selected by First Ammonia to provide front end engineering and design services for a new green ammonia facility in Victoria, Texas. This facility will have an initial anticipated production capacity of 300 t/d of green ammonia. First Ammonia also says that it will be the first in the US to use solid oxide electrolyser technology (SOEC) for hydrogen production, which are 30% more energy efficient compared to conventional electrolysers.

The plant's design will accommodate a fluctuating renewable energy supply, and will play a key role in stabilising the local grid and paving the way for scalable and cost-effective ammonia production. The FEED study has a target completion date of Q1 2025, with construction expected to begin later this year.

Marc Van Den Boom, Senior Vice President of Gulf Coast Operations, commented, "We're thrilled to partner with First Ammonia on this groundbreaking project. The plant is a pivotal step in delivering decarbonized energy solutions, and we look forward to supporting the project's success."

Joel Moser, CEO of First Ammonia, emphasized the significance of the collaboration: "We are excited to be partnering with Worley, whose strong relationship with Topsoe, our technology licensor, and proven Gulf Coast expertise will help us decarbonize heavy industry, transport fuels, and power generation. Clean ammonia is essential in reducing emissions across hard-to-abate sectors, and Worley's capabilities are vital for enabling decentralized, electric ammonia production."

MOROCCO

Green ammonia for Morocco

H2 Global Energy says that it has completed initial studies for the development of a green hydrogen and ammonia plant in southern Morocco. With an anticipated production capacity of 1.0 million t/a of green ammonia, the project aims to use Morocco's abundant solar and wind resources to produce green hydrogen, which will then be converted into green ammonia. Production is expected to be used in various sectors, including agriculture, transportation, and energy storage, supporting the global shift towards decarbonisation.

Mr. Waleed AlHallaj, Chief Commercial Officer of H_2 Global Energy, said: "The establishment of the green hydrogen and ammonia plant is a significant step towards realising Morocco's renewable energy ambitions. This facility will not only contribute to the country's sustainable development goals but also create jobs and stimulate economic growth. We are excited about the potential of this project to support Morocco's transition to a green economy and enhance its position in the global energy market."

UNITED ARAB EMIRATES

Fertiglobe expects FID on green ammonia projects soon

In its 4Q 2024 results presentation, Abu Dhabi-based Fertiglobe said that it expects to reach a final investment decision (FID) on two clean hydrogen and ammonia projects in the US and Egypt in 2025. Fertiglobe confirmed that FID on the ADNOC-ExxonMobil low-carbon hydrogen and ammonia project in Baytown, Texas, is expected in 2025, with operations anticipated to begin in 2029. ADNOC's 35% equity stake in the project will be transferred to Fertiglobe at cost once the project is operational.

An FID for the Egypt Green Hydrogen project is also expected in the first half of 2025, backed by demand and pricing support from H2Global, according to Fertiglobe. The project will feature a 100 MW electrolyser facility, producing renewable hydrogen as feedstock for approximately 74,000 t/a of renewable ammonia at Fertiglobe's existing ammonia facilities in Ain Sokhna, Egypt. Production is scheduled to commence in 2027.

Meanwhile, construction of a 1.0 million t/a blue ammonia facility in the UAE began in Q3 2024, with operations set to start in 2027. A preliminary life cycle assessment study estimates that Phase 1 of the plant will produce ammonia with 50% lower carbon intensity compared to conventional methods. In its second phase, the facility aims to further reduce carbon emissions through CO_2 capture and sequestration. Fertiglobe currently holds a 30% stake in the project and will consolidate ADNOC's share at cost upon start-up, increasing its ownership to 54%.

CANADA

New contracts for Stamicarbon

Maire Group says that its nitrogen fertilizer technology licensor Stamicarbon has been awarded new contracts related to its NX STAMI UreaTM technology in Canada. The first award is a process design package and the licensing of an integrated urea and diesel exhaust fluid (DEF) production plant currently being developed by Genesis Fertilizers, a farmer-owned consortium, at Belle Plaine, Saskatchewan. The plant will have a urea melt capacity of 2,500 t/d, with operations expected to begin by 2029. Also thanks to a carbon capture and sequestration unit, it will be the first proposed low-carbon nitrogen fertilizer plant in Canada. Stamicarbon will apply its proprietary flash urea melt technology to enhance operational efficiency and reliability while minimising process steam consumption. The plant will also include a DEF facility with a production capacity of 1,500 t/d.

The second award is for the supply of a replacement high-pressure urea stripper to Nutrien's Fort Saskatchewan Nitrogen Operations in Alberta, esigned to enhance operational efficiency while minimising downtime and ensuring long-term reliability.

AUSTRALIA

NH3 Clean Energy looking at clean ammonia exports

Australia's NH3 Clean Energy, formerly Hexagon Energy Materials, has signed a memorandum of understanding with the Pilbara Ports Authority to explore options for the loading and export of 600,000 tonnes per annum (TPA) of clean ammonia from its flagship WAH2 project. The MoU is intended to establish operational

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arrangements and binding agreements supporting ammonia export from the project, covering ship loading for both export and bunkering customers. Ammonia would be transported from the WAH2 plant to the port of Dampier by a new-build pipeline located in the existing infrastructure corridor and loaded onto ships at the port's bulk liquids berth, subject to availability and commercial agreements.

NH3's Chairman Charles Whitfield commented: "Pilbara Ports have demonstrated their support and enthusiasm for becoming a key hub for the handling of clean ammonia for the international market and marine fuel. As promised in the first gas supply announcement, the tempo of achieving milestones and development of the project will continue to increase as we drive for FID in H1 2026."

Construction ongoing on Perdaman urea plant

The Saipem Clough Joint Venture says that it has reached a major milestone on Perdaman's Project Ceres urea plant, with the completion of construction of the first modules. The batch has been successfully loaded out and shipped from the project's modular fabrication facility in India to its destination in Western Australia. Once completed, the 2.3 million t/a facility will be the largest urea plant in Australia. Clough and Saipem in a 50-50 joint venture, are delivering the engineering, procurement of equipment and materials, construction, pre-commissioning and commissioning for the urea project.

Orica saves 1 million tonnes of CO_2

Orica says it has achieved a decarbonisation milestone by eliminating 1.0 million tonnes of carbon dioxide equivalent (CO2-e) from its Kooragang Island site, the equivalent of taking 600,000 cars off the road. The emissions reduction is the result of deployment of tertiary abatement technology on three nitric acid plants, in a project co-financed by the New South Wales Government's Net Zero Industry and Innovation Program and the Federal Government's Clean Energy Finance Corporation. The Clean Energy Regulator also approved the project as eligible to generate Australian carbon credit units.

Orica Group Executive and President Australia Pacific and Sustainability, Germán Morales said: "This is another proud and critical milestone in Orica's decarbonisation journey and ambition to achieve net zero emissions by latest 2050. Sustainability is at the core of our purpose and this milestone highlights our ongoing commitment to supporting our customers in achieving their sustainability goals and our long-term support of the Hunter region while also supporting government decarbonisation ambitions. It also shows the power of partnership when private business and government work together."

INDONESIA

Pupuk Kujang trialling green ammonia

PT Pupuk Kujang, a subsidiary of state-owned fertilizer producer holding company PT Pupuk Indonesia, is conducting a trial production of green ammonia projected to replace coal in the power generation industry. In local press reports, Robert Sarjaka, Director of Operations and Production of Pupuk Kujang, said that the production of green ammonia is part of the company's efforts to contribute to realizing the energy transition in Indonesia, namely making Pupuk Kujang the first company to produce green ammonia in the country. Pupuk Kujang receives green hydrogen from renewable power supplied by PLN Indonesia Power (PLN IP), part of state power utility PT PLN. In the first trial phase, Pupuk Kujang will process 1 t/d of green hydrogen into 5 t/d of green ammonia.

ANGOLA

Toyo to license new large scale urea plant

Toyo Engineering Corporation (TEC) will license its ACES-21 urea technology to Angolan fertilizer producer Amufert for the Soyo urea plant in Angola. The plant will have a capacity of 4,000 t/d and will be the first of its kind in the country, based on abundant local natural gas supplies. Toyo Engineering will supply licensing, basic design, certain equipment procurement and technical services, while international engineering company Wuhuan Engineering will lead the engineering, procurement and construction of the plant. Production is expected to start in 2027. KBR was previously awarded the license for the 2,300 t/d ammonia plant in November 2024 (see *Nitrogen+Syngas* 393, Jan/Feb 2025, p6).

JAPAN

Time charter agreement for ammonia powered gas carrier

Yara Clean Ammonia has signed a time-charter contract with Nippon Yusen Kabushiki Kaisha (NYK) for an ammonia-fuelled medium gas carrier, to be delivered in November 2026. Medium gas carriers are the most popular type of vessel for international shipping of ammonia, and Yara and NYK have been studying the possibilities of running them off ammonia fuel since 2021. Yara Clean Ammonia operates the largest global ammonia network with 15 ships and has, through Yara, access to 18 ammonia terminals and multiple ammonia production and consumption sites across the world. Yara says that use of an AFMGC will contribute to reducing GHG emissions from marine transportation and developing an ammonia supply chain by providing a more environment-friendly means of ammonia transport as demand grows for ammonia use in the power sector, for marine fuel, and the like.

"Our successful collaboration with NYK enables us not only to comply with future regulations related to CO_2 emissions from sea-going vessels but also helps us to ensure that our customers can receive carbon-intensity compliant clean ammonia throughout our supply chain from well to wake," said Murali Srinivasan, Senior Vice President Commercial in Yara Clean Ammonia.

NORWAY

Fertiberia exits Barents Blue project

Horisont Energi says that Fertiberia's participation in the Barents Blue ammonia project will end on February 28th 2025. The two companies had been collaborating on the project since August 2023. Horisont Energi says that it is now looking for additional industrial partners to "further strengthen" the project, which aims to produce 1.0 million t/a of low carbon ammonia using 99% carbon capture at a plant at Markoppnes in northern Norway. Barents Blue has secured sufficient power supply for the first phase of the project, and is supported by a grant via the EU IPCEI hydrogen program, Hy2Use. The project is targeting a final investment decision in 2026 and estimated production start in 2029/2030. ■

Syngas News

UNITED ARAB EMIRATES

Samsung to build UAE's first methanol plant

UAE-based chemicals and transition fuels hub TA'ZIZ has awarded an engineering, procurement, and construction (EPC) contract worth $1.7 billion to engineering company Samsung E&A to build the UAE's first methanol plant. The facility will be located at the Al Ruwais Industrial City in the western part of the emirate of Abu Dhabi. It is projected to produce 1.8 million t/a green methanol, powered by clean energy from the grid, with the plant scheduled for completion in 2028.

Mashal Saoud Al-Kindi, CEO of TA'ZIZ, said: "This landmark EPC contract was a significant step in realising TA'ZIZ's vision to drive the UAE's industrial growth by creating a world-scale integrated chemicals ecosystem in Al Dhafra region. The plant will enhance the UAE's position as a leader in sustainable chemicals production and strengthen TA'ZIZ's role in enabling ADNOC's global ambition to lead the chemicals sector."

Hong Namkoong, President and CEO of Samsung E&A, added: "we are honoured to receive this recognition, highlighting TA'ZIZ's and our commitment to driving industrial innovation, diversifying the UAE's economy, and enabling sustainable growth. This milestone underscores the power of collaboration in creating world-scale facilities that will position the UAE as a global hub for advanced methanol production."

In its initial phase, the TA'ZIZ complex will produce 4.7 million t/a of chemicals by 2028, including methanol, low-carbon ammonia, polyvinyl chloride (PVC), ethylene dichloride, vinyl chloride monomer, and caustic soda. ■

FINLAND

Gasgrid awards Worley contract for hydrogen pipeline system

Gasgrid Finland Oy has awarded Worley a four-year framework agreement with an option for extension until 2032, to provide owners engineering services for Gasgrid's hydrogen pipeline system development in Finland. This 1,100 km long hydrogen pipeline system is expected to link major hydrogen production and offtake centres across Finland and enable the development of hydrogen export routes to neighbouring markets. Gasgrid says that the planned hydrogen pipeline system will support cost-efficient, reliable and secure renewable energy market development for the Nordic countries and elsewhere in Europe. Worley will provide the OE services primarily through Worley's offices in the Netherlands and Finland with support from the Global Integrated Delivery (GID) team in India.

ITALY

Waste to methanol plant development

Maire Group subsidiary MET Development, together with Eni and utility company Iren Ambiente, have started the permitting process for a renewable methanol and hydrogen plant at Eni's refinery in Sannazzaro de' Burgondi near Pavia. The plant will be developed using NextChem's NX Circular™ technology, which allows the plant to convert waste by generating syngas, which is subsequently used to produce high quality sustainable fuels and chemicals. Once completed, the plant will be able to convert approximately 200,000 t/a of non-recyclable waste supplied by Iren's waste management unit Iren Ambiente into synthesis gas. This will in turn be converted to produce up to 110,000 t/a of renewable methanol, as a potential fuel for decarbonisation of the maritime sector. It will also produce up to 1,500 t/a of hydrogen, which could be used in refinery processes, reducing CO_2 emissions compared to fossil-generated hydrogen, or, alternatively, for sustainable mobility in road and rail transport. The plant will also recover 33,000 t/a of inert granulate, which can be used for the cement industry. The plant will use infrastructure and services already available at the refinery to optimise costs.

Fabio Fritelli, NextChem managing director, commented: "This project is a unique opportunity to combine environmental sustainability and economic growth. Italian ports will be among the first in the world to be able to benefit from the new environmentally friendly fuel required by international regulations."

UNITED KINGDOM

JM releases data on reformer catalyst

Johnson Matthey (JM) has released new production performance data which shows the significant improvements in efficiency of existing steam methane reformer (SMR) based hydrogen plants with the use of its catalyst, *CATACEL SSR*™. The company says that the data show that the catalyst can increase hydrogen plant capacity by 15% and reduce reformer energy use per unit of hydrogen by 15%, with a 5% reduction in gas consumption per unit hydrogen, as well as ease of installation, and enhanced durability and heat transfer. The catalyst uses uniquely engineered structures of thin metal foils, or "fans," coated with catalysts through a proprietary process, which offer greater surface area, higher durability, and superior heat transfer, essential for high-temperature processes such as SMR.

Joachim von Hoyningen-Huene, Managing Director Catalysts at Johnson Matthey, said: "*CATACEL SSR* represents a step forward in optimising existing steam methane reforming processes, enabling producers to maximize hydrogen output while reducing energy consumption. By improving performance in a practical and scalable way, we are supporting the industry in making more efficient use of resources".

HyLion looking to produce renewable methanol in Scotland

The partners in the HyLion network are planning to produce low carbon hydrogen from renewable energy in Scotland and convert it into methanol for use as a low carbon fuel in the shipping, aviation, and motorsport sectors in the UK and Europe. The HyLion project partners include ARUP, McPhy Energy, Bosch, E.On, CO_2 Recovery Ltd, Mareneco Ltd, Cadeler A/S, and P1 Fuels. Management and IT consultancy MHP is providing strategic and operational advice on the development and digitalisation of an efficient supply chain. Around 9,000 t/a of hydrogen and around 45,000 t/a of green methanol are planned in the initial pilot plant, which will use 63,000 t/a of biogenic CO_2 from E.On's biomass power plant at Lockerbie and from local whisky distilleries for the production of methanol. Hydrogen will come from an 80

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MW electrolyser supplied by McPhy Energy, using local wind energy, with pure water being supplied using Bosch technology. P1 Fuels' technology will convert e-methanol into an e-fuel that fits seamlessly into the existing fuel infrastructure and offers a decarbonisation solution for the automotive industry, international and national racing series, and light aircraft, for example. Another customer for the e-methanol will be the shipping company Cadeler A/S. The plant is expected to start production at the beginning of 2028.

"CO2-reduced hydrogen plays an essential role in achieving the climate targets. The stricter CO2 reduction targets and the increasing political decisions to replace fossil fuels will significantly increase the demand for e-methanol in the future. The abundant wind resources in Northern Europe, especially in Scotland, provide an ideal basis for scalable production of CO2-reduced hydrogen and derivatives," explains Dr. Sylvia Trage, Partner at MHP and responsible for Supply Chain Excellence.

GERMANY

Collaboration on development of zero-emission hydrogen technology

Johnson Matthey (JM) has signed an agreement with Bosch, a leading supplier to the automotive industry, to develop and produce catalyst coated membranes (CCM) for use in fuel cell stacks. JM's high performance CCMs will be used in Bosch's integrated, compact and scalable fuel cell power module for commercial vehicles, designed for longer distances.

JM Hydrogen Technologies Chief Executive, Anish Taneja, and Bosch Mobility's Executive Vice President of Engineering Power Solutions, Beate Grota, marked the agreement at Bosch's fuel cell centre in Stuttgart-Feuerbach, Germany. Anish Taneja commented "JM is thrilled to be joining forces, exploring and developing future possibilities to accelerate cleaner mobility and energy generation ". Beate Grota added: "The fuel cell technology for mobile applications is technologically ready for widespread use. Our partnership aims to further increase the performance and efficiency of the fuel cell stacks."

Mabanaft converting tanks to methanol storage

Energy company Mabanaft says that it plans to convert four of its tanks at the Blumensand tank terminal in the Port of Hamburg over the next two years. The company's aim is to facilitate the import of low-carbon methanol to northern Germany. Mabanaft expects demand for low carbon methanol to grow in future, both in the shipping and other transport sectors, as well as in the chemical industry.

While the tanks are planned to be retrofitted from mid-2025, the methanol storage is scheduled to start in 2027. Mabanaft intends to import the methanol itself and then store and distribute it in Germany and possibly other locations. The four tanks that would be converted have a total capacity of approximately 20,000 m³. Subject to the necessary approvals their conversion is planned to be carried out in two stages: the first two tanks by the middle of 2026 and the remaining tanks in 2027.

"In the shipping industry, there is no single solution for sustainable fuels," explained Oleksandr Siromakha, Head of Sustainable Fuels at Mabanaft. "That's why we are committed to offering our customers a diverse range of options tailored to their needs, both now and in the future. Alongside conventional fuels, we currently offer bio-blends and want to provide more tailored solutions such as hydrogen, ammonia, and methanol." He added, "Our goal is to simplify the transition for our customers by making methanol and other alternative fuels more accessible."

MALAYSIA

Hydrogen plant for Pengerang refinery

KT-Kinetics technology has signed an $125 million engineering, procurement, construction and commissioning (EPCC) contract to build a hydrogen production unit at Petronas' Pengerang Biorefinery, Malaysia. The hydrogen plan is expected to be operational by the second half of 2028, and will supply up to 38,000 normal m³/h of hydrogen for the production of sustainable aviation fuel (SAF) and hydrogenated vegetable oil (HVO). NextChem will license its NX ReformTM technology for the unit. The new biorefinery will process approximately 650,000 t/a of raw materials such as used vegetable oils, animal fats and waste from the processing of vegetable oils to produce sustainable aviation fuel (SAF), hydrotreated vegetable oil (HVO) and bio-naphtha.

Alessandro Bernini, Chief Executive Officer of Maire, parent company of both KT-Kinetics Technology and NextChem, commented: "This important achievement confirms Maire's pivotal role in the energy transition, and its ability to deliver advanced and integrated solutions that enable our clients to lead the way in producing renewable fuels, contributing to a more sustainable future."

FRANCE

TotalEnergies to decarbonise its refineries in Northern Europe

TotalEnergies has signed agreements with Air Liquide to develop two projects in the Netherlands for the production and delivery of some 45,000 t/a of green hydrogen produced using renewable power, generated mostly by the OranjeWind offshore wind farm, developed by TotalEnergies (50%) and RWE (50%). These projects will cut CO_2 emissions from TotalEnergies' refineries in Belgium and the Netherlands by up to 450,000 t/a and contribute to the European renewable energy targets in transport.

The two companies have signed an agreement to set up a 50-50 joint venture to build and operate a 250 MW electrolyser near the Zeeland refinery. This project will enable the production of up to 30,000 t/a of green hydrogen, most of which will be delivered to Zeeland's platform. The electrolyser will be commissioned in 2029 and will cut the site's CO_2 emissions by up to 300,000 t/a. This project represents a global investment of around €600 million for both partners and has made requests for support under European and national subsidy programs. Project funding will also be sought by the partners.

In addition, as part of Air Liquide's 200 MW ELYgator electrolyser project in Maasvlakte, TotalEnergies has signed a tolling agreement for 130 MW to be dedicated to the production of 15,000 t/a of green hydrogen for TotalEnergies in Antwerp. Under this agreement, TotalEnergies will supply the renewable electrons produced by the OranjeWind project to Air Liquide to be transformed into green hydrogen. The project is expected to be operational by the end of 2027 and will reduce CO_2 emissions at the Antwerp site by up to 150,000 t/a.

"Following the first partnership agreement with Air Liquide to supply the Normandy refinery with green hydrogen, and the agreements to supply the Grandpuits and La Mède biorefineries with renewable hydrogen, the partnership with Air Liquide… marks a new step in TotalEnergies' ambition to decarbonise the hydrogen consumed by its refineries in Europe by 2030", said Vincent Stoquart, President, Refining & Chemicals at TotalEnergies.

SPAIN

Repsol to invest in renewable methanol

Repsol has approved a historic €800 million investment in Ecoplanta, a pioneering project in Europe to transform urban waste into renewable fuels and circular products, adding a solution for reducing CO_2 emissions in the transport sector, while at the same time promoting the circular economy. Located in Tarragona, the facility will be the first in Europe to produce methanol from municipal waste via a gasification process developed by Enerkem - a technology company in which Repsol is a partner – using waste that would otherwise end up in landfills or be incinerated.

The new plant will have the capacity to process up to 400,000 t/a of municipal solid waste (MSW) and turn them into 240,000 t/a of renewable fuels and circular products. The renewable methanol originates from organic waste, while the circular products come from non-organic waste, such as non-recyclable plastics. The start-up of the plant is scheduled for 2029. Ecoplanta will be integrated into Repsol's industrial complex in Tarragona to take advantage of existing infrastructures and accelerate the transformation of the centre into a multi-energy hub that will continue to manufacture essential products for society, such as renewable fuels and circular materials. According to the European Commission, the Ecoplanta will reduce the equivalent of 3.4 million tons of CO_2 in greenhouse gas (GHG) emissions during the first ten years of operation.

SWEDEN

Liquid Wind to progress abandoned renewable methanol project

Liquid Wind has announced the development of a new 100,000 t/a green methanol project in Örnsköldsvik, Sweden, in collaboration with local energy company Övik Energi. Övik Energi's combined heat and power plant in Örnsköldsvik was due to be the site of Ørsted's FlagshipONE project, which was slated to produce 55,000 t/a of green methanol from 2025. A final investment decision (FID) was made in late 2022 when Ørsted bought out Liquid Wind's 55% stake in the project, but the Danish offshore wind company chose to discontinue FlagshipONE in August 2024.

Liquid Wind says it will be responsible for development of the new project from 1Q 2025. The 100,000 t/a output will involve the capture of 150,000 t/a of biogenic CO_2 from Övik Energi's combined heat and power plant as a feedstock for its e-methanol. Green hydrogen will be generated on-site by electrolysis using renewable energy. The plant announced last year that it had switched to using 100% renewable biofuels from forestry and paper industry residues, phasing out its use of peat products. The majority of its fuel comes from local sources, it claims.

Liquid Wind is developing several projects using captured carbon from combined heat and power plants in Sweden and Finland, including a 130,000 t/a green methanol plant in Umeå, Sweden, which was granted an environmental permit in late January, and is expected to begin production in 2027. ■

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People

Klaus Ohlig, CTO of thyssenkrupp nucera.

Dr. Werner Ponikwar and Dr. Stefan Hahn of thyssenkrupp nucera

thyssenkrupp nucera Management AG has appointed Klaus Ohlig as its new Chief Technology Officer (CTO), effective from July 1st, 2025. **Klaus Ohlig** will succeed Fulvio Federico, who has decided to not extend his contract for personal reasons. To ensure a smooth and seamless transition, Fulvio Federico will continue to support thyssenkrupp nucera on a consultancy basis for at least one year, providing strategic guidance and technical expertise to maintain continuity and stability.

"We are delighted to welcome Klaus Ohlig to thyssenkrupp nucera. With over 30 years of extensive experience in process engineering and a proven track record of leading diverse technology portfolios, his expertise will be instrumental in advancing thyssenkrupp nucera's commitment to technology leadership. Klaus Ohlig will play a key role in advancing technological and key components' capabilities and strengthen nucera's market position. We would also like to express our heartfelt thanks to Fulvio Federico for his significant contribution and dedication over the last decade", said Dr. Volkmar Dinstuhl, Chairman of the Supervisory Board.

Ohlig's career includes senior leadership roles at Linde, notably as Executive Director Research & Development at Linde Engineering in Pullach, where he managed global teams and was responsible for the development and expansion of Linde Engineering's technology portfolio. Before that, he was Managing Director of Linde Kryotechnik AG in Switzerland.

thyssenkrupp nucera previously agreed to extend the existing CEO contract with **Dr. Werner Ponikwar** by a further five years until July 2030. In addition, the board decided to appoint **Dr. Stefan Hahn** as new CFO starting from March 1st, 2025. Hahn will succeed Dr. Arno Pfannschmidt, who is retiring.

"Werner Ponikwar has been driving the development of thyssenkrupp nucera as a strong player in the hydrogen market in recent years. Under his leadership, the company successfully completed the IPO in July 2023, established itself in the dynamic and evolving hydrogen market and brought high-technology products to market. His strategic vision and commitment to innovation have been pivotal for thyssenkrupp nucera's growth journey and we are looking forward to continuing our trusting collaboration", says Dr. Volkmar Dinstuhl, Chairman of the Supervisory Board.

Stefan Hahn joins from thyssenkrupp AG, where he has held various senior positions in the Finance & Controlling department, most recently as interim CFO for the Business Unit Polysius and Head of Controlling, Accounting and Risk of the Business Segment Decarbon Technologies. He has also served as CFO of the Business Unit Automation Engineering.

Ostara has announced that **Tom Snipes** has been appointed as CEO. "Tom brings a valuable combination of agricultural experience and business expertise to Ostara. He has a track record of innovation and growth that will enable us to continue expanding our presence and product line," said Monty Bayer, executive chairman of Ostara's Board of Directors.

Calendar 2025

MARCH

12
Clean Ammonia Storage Conference, ROTTERDAM, Netherlands
Contact: Stichting NH3 event Europe
Tel: +31 6 10544501
Email: info@ndh3event.com

19-20
Gasification 2025, BOLOGNA, Italy
Contact: Mohammad Ahsan – Marketing & Delegate Sales, ACI
Tel: +44 (0) 203 141 0606
Email: mahsan@acieu.net

20-24
11th Annual Gasification Summit, GHENT, Belgium
Contact: Mohammed Ahsan, ACI
Tel: +44 203 141 0606
Email: mahsan@acieu.net

APRIL

1-3
Nitrogen+Syngas Expoconference USA, TULSA, Oklahoma, USA
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

MAY

12-14
IFA Annual Conference, MONTE CARLO, Monaco
Contact: IFA Conference Service, Paris, France
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

15-18
International Methanol Technology Operators Forum, LONDON, UK
Contact: Polly Murray, Johnson Matthey.
Email: polly.murray@matthey.com

SEPTEMBER

8-11
69th AIChE Ammonia Safety Symposium, ATLANTA, Georgia, USA
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363
Web: www.aiche.org/ammonia

OCTOBER

13-17
Ammonium Nitrate/Nitric Acid Conference, OMAHA, Nebraska, USA
Contact: Sam Correnti, DynoNobel, Karl Hohenwarter, Borealis.
Email: sam.correnti@am.dynonobel.com, karl.hohenwarter@borealisgroup.com, annaconferencehelp@gmail.com
Web: annawebsite.squarespace.com/

Plant Manager+

How to solve stripper efficiency issues (pt 5)

In part 5 of this series on stripper efficiency issues we conclude the discussion with a focus on fouling inside stripper tubes.

Fouling inside tubes

During operation solid iron oxides deposit as a scale in the bottom part of the stripper tubes. While corrosion rates are highest in the top part of the tubes, scaling in the stripper tubes takes place in the bottom half of the tubes.

What are the consequences of this scaling?

The scales lead to a lower stripper efficiency resulting in a larger recycle of ammonium carbamate via the recirculation section. This recycle via the recirculation section also contains water (some 35 wt-%), which negatively influences the urea conversion rate in the reactor. This leads to a higher load on the stripper, whose capacity is already limited due to the scaling leading to even lower stripper efficiency. This negative spiral leads to more steam consumption and possibly a lower plant load or more ammonia losses. 1% lower urea conversion leads to some 25 kg/t higher steam consumption or for a 2,000 t/d urea plant: €180k/year additional steam costs (2,000 t/d * 365 days/year * 25 kg/t * €10/t steam * 1/1000 t/kg).

A lower stripper efficiency leads to a higher load on the recirculation heater and in case that heater is also already limited due to scaling, more load will be put on the further downstream sections. This will lead to more ammonia emissions from, e.g., the urea solution tank, via the stack to atmosphere. For example, 50 kg/hour more ammonia emission will lead to €175k/year additional losses (50 kg/hr * 24 hr/day * 365 days/yr * €400/t NH_3 * 1/1000 t/kg).

The layer of scales has a negative influence on the heat transfer from the steam side (shell) to the process side (tubes). A larger steam pressure will be required to compensate for this influence. This leads to higher tube wall temperatures. The corrosion rate is exponentially related with the temperature (every 10°C higher temperature doubles the corrosion rate). A higher tube temperature thus increases the corrosion rate leading to a shorter lifetime of the stripper. One year shorter lifetime will cost the end user some €200k (assuming €4 million for a new stripper which has a typical lifetime of 20 years).

And finally, in case the scaling on the stripper tubes becomes too thick it will no longer be easy/possible to perform eddy current wall thickness measurements leading to a risk of unexpected tube ruptures. This leads to large ammonia emissions and an unexpected shutdown.

The scales in the stripper tubes are too hard to be removed by high pressure water flushing. Stamicarbon, together with VECOM in the Netherlands, has developed a chemical cleaning procedure to remove these scales.

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India's hunger for urea

India's push to replace its sizeable urea imports with home grown capacity continues, but may not keep pace with rising domestic demand.

India's urea buying has dominated urea markets for many years, but that has been changing as it attempts to replace imports with domestic urea capacity. India was until recently the largest global importer of urea, but that changed in 2024 when it lost that position to Brazil. India continues to be the world's second largest consumer of urea overall, with demand of 36.2 million t/a in 2024, considerably ahead of the US, but below China's huge total of 66 million t/a. Urea is the key nutrient for India's farmers, and consequently ensuring a secure supply of urea has been a major concern for every Indian government. But India's urea plant construction went through a hiatus from around 1995, when new building of capacity stopped as the government became concerned over spiralling subsidies to urea producers, and during the first decade of the 21st century the gap between demand and production began to widen until by the 2010s it had reached 10 million t/a, all of which had to be filled by imports(see Figure 1).

The Indian government has attempted to tackle this in two ways; by switching to slower release urea to try and reduce farmers' demand for urea, and a programme of new plant construction which began in the late 2010s. The latter however remains constrained by feedstock cost and availability.

Feedstock availability

Feedstock availability became the key constraint on developing new urea capacity during the 2000s and 2010s. India's first wave of urea capacity, which led to the 'Green Revolution' of the 1960s and 70s, had been based on naphtha feedstock, but high oil prices led to high naphtha prices and consequently a high subsidy bill to keep urea made from naphtha affordable. To keep bills lower, the government pressured plants to switch to using natural gas feedstock, and new plant construction during the 1980s and 90s was generally based on natural gas feedstock. This was cheaper, but India's shortage of domestic natural gas meant that the plants often suffered gas supply curtailments, especially as its electricity industry also built gas-fired power capacity. During winter when more power was needed for heating, gas was often preferentially given to gas-fired power stations and urea plant suffered outages.

Attempts to develop domestic gas reserves in the Bay of Bengal did not generate as much gas as hoped, while pipeline import projects from Iran or Turkmenistan foundered on political issues with neighbour Pakistan, which the pipelines would have had to cross.

One alternative seemed to be to build Indian-owned capacity in gas-rich regions and import urea from these areas at prices hopefully cheaper than prevailing market prices. However, in spite of several proposals as far afield as Iran, Canada and the US, only one was actually built; the Oman-India Fertilizer Company (OMIFCO), a joint venture between the government of Oman (50%) and Indian state-owned fertilizer collectives Kribhco and IFFCO (25% each). OMIFCO operates two 2,500 t/d urea plants at Sur on Oman's Indian Ocean coast, with the 1.65 million t/a offtake earmarked 100% for India.

Another potential solution for India's urea conundrum was to move to a Chinese model and use coal gasification to produce large volumes of urea. Two coal gasification plants had been built during the 1970s, but these had been plagued by technical difficulties, and this proved a major stumbling block to new coal-based capacity. One major issue was the high ash content of Indian coal as compared to Chinese, making gasifiers less efficient and leading to ash agglomeration, which can lead to poor syngas quality, and increased operational challenges due to the ash buildup within the gasifier, potentially blocking gas flow and requiring frequent cleaning or even causing equipment damage. Only one coal gasification projected ended up greenlit, at the Talcher site, and this ran into problems of its own, significantly delaying its start-up.

Eventually India turned wholeheartedly to liquefied natural gas (LNG) imports in the 2000s to make up for its domestic natural gas shortfall, and LNG capacity rapidly ramped up, producing enough gas for both power and urea production and providing sufficient surplus to build a new wave of urea capacity in the 2010s and 2020s.

New urea capacity

The construction hiatus from 1995-2015 meant that what urea capacity increase that did occur was provided via incremental debottlenecking and upgrades of existing plants. There was one exception to this rule; the 1.3 million t/a Matix Fertilizer plant in Bengal, which was built to exploit reserves of coalbed methane in the region. However, when this facility was completed in 2015, the volume of gas that was able to be supplied from coal seam gas was only about 35-40% of the plant's requirement, and the plant remained idle until 2021, when it could be connected to a pipeline from the LNG terminal at Dhamra.

The LNG boom of the 2010s meant that the Modi government was able to set urea self-sufficiency as a target, announcing its ambitious New Investment Policy in 2013, and in 2017 securing $8.7 billion of funding aiming to "end" imports of urea within five years. This would be achieved by reviving five mothballed urea plants and setting up two new facilities, bringing 7.5 million t/a of new urea capacity on-stream.

The five plants at existing sites included Ramagundam in Andhra Pradesh province; Gorakhpur in Uttar Pradesh; and Sindri in Jharkhand – all sites originally belonging to the Fertilizer Corporation of India Ltd (FCIL), and the fourth at the Hindustan Fertilizer Corporation Ltd Barauni site in Bihar province. All of these new plants were owned and operated by a new state

PHOTO: LARSEN & TOUBRO

The new HURL plant at Sindri, Jharkhand state.

venture, Hindustan Urvarak and Rasayan Ltd (HURL), a joint venture of Coal India (CIL), NTPC and the Indian Oil Corporation (IOCL), in cooperation with Fertilizer Corporation of India (FCIL) and Hindustan Fertilizer Corporation (HFCL). All four are fed from LNG via pipeline. The fifth was the Talcher coal gasification plant mentioned earlier, which will use a mix of petroleum coke as feedstock to avoid the ash content problems. The four LNG-fed plants were completed and started up from 2021-2023, with production ramping up during 2024. Talcher remains behind schedule however, and is not expected to start up until 2027.

In addition to the five government-backed projects, two privately funded projects have been approved. The first was the revival by Chambal Fertilizers and Chemicals of its old urea plant at Kota near Gadepan in Rajasthan state, which closed in 2015 due to unfavourable economics. A new 1.27 million t/a replacement plant began operation in 2019. However, in spite of government approval of a new brownfield 1.27 million t/a ammonia/urea complex at the Brahmaputra Valley Fertilizer Corp (BVFCL) site at Namrup in Assam, development remains stalled, with BVFCL now looking at 2029 for a possible startup.

Subsidies

India's demand for urea is predicated on its popularity with Indian farmers. India subsidises fertilizer costs to farmers to ensure that the country's population is fed – India is now the most populous country on earth, overtaking China in 2023 with an estimated 1.44 billion people. Urea has always been the cheapest nitrogen fertilizer per unit N, which is why such a large proportion of Indian nitrogen consumption has been as urea. When the government changed the way it calculated fertilizer subsidies in 2010, urea was exempted from the move and continued to be subsidised

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at the old rate. This special treatment for urea has largely continued since then. In the most recent government budget, in which the government reduced fertilizer subsidies by 2.6% to $22.1 billion, urea subsidies remained largely unchanged at $14.3 billion, keeping the government set maximum retail price (MRP) for urea at the same level. This tends to skew fertilizer consumption towards urea and away from phosphate and potassium. While this leads to an imbalance in nutrient application, India's reliance on imported phosphate and potash means that these fertilizers are often expensive and securing raw materials for P and K fertilizers remains a challenge for the government.

In an attempt to make existing supplies of urea go further, the government instead mandated in 2015 that all domestically produced urea must be coated with neem tree seed oil. The neem coating slows the conversion of urea to ammonium in the soil, making it available to plants for a longer period during the growth cycle, reducing volatilisation to ammonia and soil leaching of nitrates and meaning less urea is required for the same effect. The move effectively extends urea capacity by around 10%.

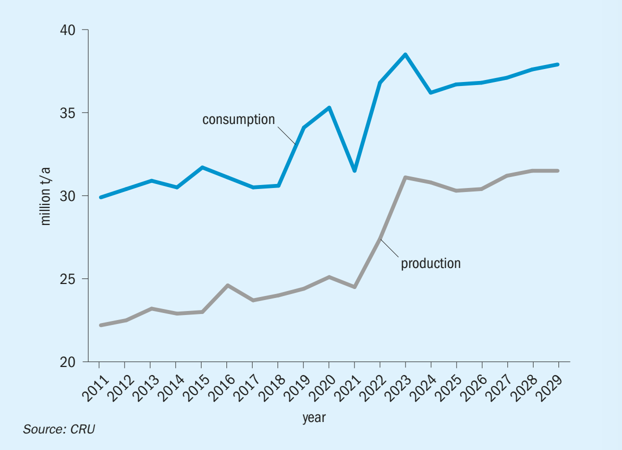
Import substitution

As Figure 1 shows, the spate of new capacity completed in the early 202s has closed the gap between Indian urea production and demand to around 5.4 million t/a in 2024, its lowest level in decades. However, with only the Talcher coal/coke based urea plant due to come onstream over the next few years, last year looks to be a minimum for Indian urea imports, and the gap is projected to widen again as demand continues to increase, with imports forecast to be around 6.4 million t/a by 2029. While India is likely to run second to Brazil in terms of imports going forward, it will continue to be a major urea importer in spite of all government attempts otherwise. India remains at the top of the global cost curve and is likely to be a major price setter.

Low carbon production

India is of course – like most of the nitrogen industry – looking towards low carbon hydrogen and ammonia production. The Indian government has established funding and policy initiatives via its National Green Hydrogen Mission, which aims to establish India as a major global hub for green hydrogen and ammonia, with a target of producing 5 million t/a of green hydrogen annually by 2030. A major plank of this is the Strategic Interventions for Green Hydrogen Transition (SIGHT) program, which is looking to identify and develop green hydrogen hubs – regions capable of supporting large-scale production and utilisation of green hydrogen in special economic zones (SEZs) or export oriented units (EOUs). An electricity transmission system is being planned to deliver power to green hydrogen/green ammonia manufacturing hubs in the states of Odisha, Gujarat, West Bengal, Andhra Pradesh, Tamil Nadu and Karnataka. However, given the high levelised cost of green hydrogen for domestic consumption in India, the plan anticipates that exports will play a crucial role in scaling up green hydrogen/ammonia production in India, with plants on the east coast at e.g. Paradip targeting customers in east Asia such as Japan, Singapore, and South Korea, where the governments are looking at using green ammonia as an extender for coal fired power plants.

Fig. 1: **Indian urea production and consumption, 2011-2029, million t/a**



Source: CRU

Green ammonia projects

With this target in mind, a number of firms have been developing projects to meet the government mandate. Recent project announcements have included the conversion by AM Green of the Kakinada urea plants to renewable production. AM Green bought the Kakinada ammonia-urea complex from Nagarjuna Fertilizers and Chemicals Limited (NFCL) last year and is in the process of converting them to two 500,000 t/a green ammonia plants, in cooperation with Casale, Technip Energies and John Cockerill. AM Green is also looking at developing green hydrogen and ammonia production at other sites in India, including Tuticorin in Tamil Nadu, Kandla in Gujarat, and UNA in Himachal Pradesh.

Hygenco is licensing Topsoe technology for a 750 t/d green ammonia plant at Tata Steel's Special Economic Zone Industrial Park (GIP) in Gopalpur, Odisha, India. The plant is expected to be operational by 2027.

ACME Group has also secured land in the Gopalpur Industrial Park for a new hydrogen and ammonia project. The new facility will be powered by renewable energy, producing up to 1.3 million t/a of renewable. Japan-based IHI will partner with ACME to develop the project.

In addition to these which have secured a final investment decision, there have been a flurry of other announcements as companies rush to fulfil the 5 million t/a government mandate by 2030. However, as ever with India the devil remains in the details and the financing, and how many come to fruition remains to be seen. Nevertheless, it seems likely that India will be switching a significant proportion of its existing ammonia production to renewables over the coming decade. ■

US nitrogen capacity

New carbon capture-based plants could see US nitrogen capacity jump over the next few years, but Trump attacks on IRA tax credits may scupper some ongoing projects.

The establishment of the US Inflation Reduction Act (IRA) and the Infrastructure Investment and Jobs Act (IIJA) and their tax credits for producing low carbon hydrogen has galvanised low carbon ammonia development in the US, with a number of large scale blue ammonia projects aiming to produce low carbon ammonia for export. The IRA and the IIJA have driven over $300 billion in clean energy investments, including battery production, electric vehicles (EV), hydrogen and carbon capture projects

Major projects

While a number of blue ammonia projects have been proposed, fewer have made it to a final investment decision. Two are so far under construction. The first is the Woodside project at Beaumont, Texas, previously owned by OCI. An additional 1.1 million t/a ammonia plant is being constructed next to 300,000 t/a of ammonia and 1.4 million t/a of existing 'grey' methanol capacity. Hydrogen supply will come from Linde, already a major supplier of hydrogen to a network of refineries and other industrial customers in the US Gulf Coast, who will supplying blue hydrogen 'over the fence' from a new clean hydrogen facility. The ammonia plant is nearing completion and due to start up this year, with carbon capture beginning in 2026.

In Indiana, Wabash Resources is developing a 550,000 t/a blue ammonia project, using an existing petroleum coke gasification plant as a front end to the ammonia synthesis unit. A $1.6 billion loan guarantee was extended last year by the US Department of Energy which will cover two thirds of project costs. The plant is currently planning to start up in 2026.

Many other projects are at the development stage. CF Industries and Mitsui are looking to a 1.4 million t/a blue ammonia plant in the US Gulf Coast to supply Europe with lower carbon ammonia (although carbon capture rates are put at 60%), and a final investment decision is expected imminently. BASF and Yara are looking at a similar sized plant in the Gulf Coast with 95% carbon capture, but have also not made a final investment decision, and LSB Industries and Japan's Inpex are also performing front end engineering and design on a 1.1 million t/a blue ammonia project in the Houston Ship Channel.

Policy shift

However, the Trump administration has taken a diametrically opposite view to the Biden administration and made an effort to reverse many of its environmental policies. The US has announced its intention to withdraw from the Paris climate agreement, and halted financial contributions to several climate mitigation and adaptation efforts, revoking the US international climate finance plan. The Trump administration has also suspended new funding under the IRA and IIJA under a new 'Unleashing American Energy' executive order, putting grants, loans and tax incentives for clean technologies at risk. Approximately 60% of funding for the IRA comes from tax credits. However, Trump would require legislation to be passed through Congress to completely eliminate or change the tax credits. That being said, he will likely be able to narrow the credits, with the new tariffs also potentially raising project costs, adding uncertainty to the projects already under way.

Trump's administration is also expected to make regulatory changes and legislative amendments to the IRA, including potentially tightening eligibility for clean energy tax credits, making it harder for projects to qualify, accelerating expiration dates for key tax incentives, reducing long-term investment certainty.

Conversely, expanding fossil fuel production to "drill, baby, drill" has been the centre of Trump's energy policy. One possible driver for blue ammonia exports from America had been the potential for restrictions to US LNG exports and a desire to monetise US natural gas. President Biden paused new approvals for US LNG export projects, and seemed to be seeking to restrict LNG outflows, but the Trump administration has restarted approvals for liquefied natural gas (LNG) exports.

Investor uncertainty

Even with IRA credits, Nutrien had backed out of a 1.2 million t/a blue ammonia project for Geismar, and ExxonMobil withdrew from the Baytown project. Air Products is looking to sell its own stake in another US Gulf blue ammonia project. Carbon capture and storage for blue ammonia production increases the cost by around $120/t ammonia, while autothermal reforming credits producers with only $76/t under IRA 45Q assuming 95% of emissions are directed to enhanced oil recovery, or $129/t for geological storage. Enhanced oil recovery can also recover some cost – around $40/t CO_2, or about $60/t ammonia. This means that in theory the process breaks even, but it can depend on variables such as the distance that the CO_2 must travel to be pumped, the nature of the underground field and expected rates of oil recovery etc. Uncertainties about tax credits will make investors even more nervous.

There is also a question of demand. There are three major sources; power plant operators in east Asia looking to reduce the carbon impact of operations; ship owners seeking to comply with IMO low carbon fuel mandates; and the European Union, whose Carbon Border Adjustment Mechanism will see steadily increasing additional taxes on grey ammonia entering the EU from next year.

Of course, not all projects need be 'blue' The 1.3 million t/a Gulf Coast Ammonia plant is currently in start up, and may begin exports this month. But at the moment the fate of the IRA and its tax credits looks like it will determine how much additional ammonia is coming out of the US Gulf in the next few years. ■

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Nitrogen+Syngas Expoconference 2025

A review of papers presented at CRU's Nitrogen+Syngas 2025 Expoconference, held in Barcelona from February 10th-12th 2025.

With the nitrogen and syngas industries facing perhaps their greatest transition since the move from coal to natural gas as feedstock, CRU's 38th Nitrogen+Syngas meeting once again attracted large numbers of delegates from around the world to discuss the latest developments in markets and technology. An innovation on the first morning was a session on business development, which ran in parallel to an operator training seminar organised by UreaKnowHow.com in cooperation with the University of Twente and the Fertilizer Academy which covered case studies for analysing hazards associated with green ammonia production. There was also a separate series of technical showcases covering biogas for sustainable fuel production, steel alloys for high pressure equipment, high temperature pressure measurement, sustainable nitric acid production, mist elimination and steam reformer efficiency improvements.

Nina Fahy delivers the keynote address.

Business development

Heading up the business development session, Marti Leppälä, Secretary General of PensionsEurope, gave an investor's eye view of the climate for investment in sustainable technologies. While acknowledging the uncertain financial climate, particularly as regards the new government in the USA, Marti argued that a "net zero ambition is no longer optional but increasingly mandatory, especially in Europe." The US pension funds of course dominate the sector, with up to 65% of assets held, but even so, 35% of all global investments are into sustainable projects, and much more will need to be invested to reach 2050 targets. While Marti touched on the forest of EU regulations and reporting requirements, recent EU reports appear to belatedly acknowledge that the continent's welfare model is unsustainable without increased competitiveness, and there is a new focus on innovation and digital transformation, and reducing some of the onerous green reporting commitments.

Key takeaways from the subsequent investment panel discussion, chaired by CRU's Head of Fertilizers Chris Lawson, and including representatives from ING, Rabobank and Société Generale, as well as the Oxford Institute for Energy Studies and Germany's Nitric Acid Climate Action Group, were:

- the hype for the low carbon hydrogen and ammonia sectors is passing, but 2025 will be a "crunch year" for final investment decisions into green and blue ammonia projects, with Chile, Morocco, India and the Middle East all seeing projects coming up to key milestones.
- certainty is required in regulation to reassure investors – the US IRA has generated few green ammonia projects because of lack of clarity in the subsidy regime, whereas the US Gulf Coast, already used to large scale carbon capture, utilisation and storage projects, and with a more robust subsidy programme, has generated some important blue ammonia projects such as OCI/Woodside at Beaumont and Air Products in Louisiana. In Europe, the EU has taken a more puritanical approach that has tried to favour green projects, while the UK has been more relaxed in encouraging blue investments such as at Teesside.
- there is still plenty of room for investment in N_2O reduction, with up to 100 million t/a of CO_2e still to be abated. Companies who sell into the EU are aware of the upcoming Carbon Border Adjustment Mechanism which is encouraging producers to make N_2O abatement investments, but regulation is not a level playing field worldwide.
- low capex is important, but the key driver of investment in low carbon ammonia is guaranteed offtake agreements; everything else can be worked out once that is in place. There is little concern about technical risk, but more so about scale up. Mandated consumption of low carbon ammonia has a place to play in creating certainty in demand to kickstart developments – infrastructure will follow naturally from that.

But where will this supply come from? An optimistic answer came from Bernd Haveresch, KBR's Chief Technical Advisor for Business Development, Clean Ammonia and Hydrogen. Europe's current ammonia capacity is around 20 million t/a, but demand for 2040 is forecast to be as high as 47 million t/a, with demand rising rapidly in the 2030s for clean ammonia and hydrogen to feed energy and industrial sectors, and towards the end of that period strong demand as a bunker fuel, representing perhaps 50% of maritime consumption by that time. Current low carbon ammonia projects worldwide that have reached a final investment decision total perhaps only 5 million t/a, leading to a gap of up to 20 million t/a, perhaps more if more grey ammonia capacity closes in Europe. KBR puts production cost at anything from \$440/t for blue ammonia in the US (\$330/t with IRA incentives) to \$670/t for blue ammonia in Europe and \$700/t for green ammonia in Chile. The recent announcement by H2Global and Fertiglobe for delivered low carbon ammonia from Egypt to Rotterdam at \$1,000/t leaves plenty of headroom for investors.

Delegates in the exhibition hall.

Nitrogen markets

The main conference programme began on Monday afternoon with the commercial sessions, introduced by Lisa Connock, *Nitrogen+Syngas magazine's* Publisher and Technical Editor, who remarked that it had been a year now since the magazines were brought back into the CRU fold, and showcasing our new website.

Keynote speaker Nina Fahy of Rabobank noted that investment into clean energy projects had dipped in 2024, presumably due to political uncertainty. Nevertheless, the US IRA has generated \$500 billion of new spending in the US on green projects. Going forward, she said, there needs to be a balance of risks between producers and consumers, which may require a role for government.

Charlie Stephen, CRU senior analyst for fertilizer costs and emissions, presented the nitrogen market outlook. The EU has pivoted from Russian gas to LNG, a move made easier by large new incremental supplies from the US. High gas prices and falling ammonia prices will make 2025 a difficult year for European producers, who may have to switch to ammonia imports, but gas prices will ease over the decade as more LNG comes onstream, and European producers may be assisted by new tariffs on Russian fertilizers, especially after 2028-29 when they will push Russian product out of the market.

There was much discussion of the EU Carbon Border Adjustment Mechanism, including a paper on its economics by Halima Abu Ali of CRU. January 1st 2026 is the first time that EU importers will have to pay a capped carbon price of around \$50/t ammonia (on an average grey ammonia energy basis), but this will rise to as high as \$350/tonne of ammonia by 2034. By 2029, it should have reached a break even point where EU low carbon producers will be advantaged, especially for downstream nitrate production, which has better margins than urea.

Nevertheless, CRU's Chris Lawson and Charlie Stephen gave delegates "a dose of realism" on the market potential for low carbon ammonia and hydrogen. Carbon capture and storage requires a carbon price of \$150/t to incentivise in Europe, ranging up to \$400/t for ammonia as a transportation fuel and \$500 to make green hydrogen gas grid injection worthwhile. Enabling policy frameworks are at risk due to the new US administration, and possible opt-outs and delays for the CBAM. Policies to support the development of market demand will be required. Nevertheless, if we are now in the 'trough' of the Gartner 'hype cycle', at least that means that the only way is up.

Technical sessions

Days 2 and 3 of the CRU's 38th Nitrogen+Syngas 2025 Expoconference turned to the technical sessions, organised in three parallel streams covering: green ammonia technology, nitric acid and ammonium nitrate, plant operations and reliability, urea technology, digitalisation, carbon capture, emissions reduction and sustainable fertilizer production, and fertilizer finishing. As always the conference and exhibition provided a great forum for those involved in the industry to catch up on the latest developments, with thought-provoking papers and good audience participation.

Renewable ammonia

Several licensors looked at ways of tuning plant operations to cope with fluctuating power from renewable sources, including modelling and plant control programs. thyssenkrupp acknowledged that market development has been slow for green ammonia, with technical risks and high costs of production, as well as variability in definitions of 'clean hydrogen' and a slow roll out of policy seeding incentives. They have developed RHAMFS – the Renewable Hydrogen and AMmonia Feasibility Simulation – for modelling projects, whether using grid electricity, renewables and battery storage, or a hybrid of the two. Turndown capacity has the highest impact on the storage size of the key parameters of the synthesis loop, while the levelised cost of ammonia is primarily determined by power cost (52% of cost). Construction costs can be lowered

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by modularisation, while operating and maintenance costs can be lowered by digitalisation. In their designs, a proprietary master control can vary the loop pressure in the ammonia converter to increase efficiency of operation.

Casale considered the impact of varying pressure and temperature on mechanical stresses in the plant. After using screening criteria to assess if a design for cyclic loads is needed (ie there is more than around 15% variation in load), their design aimed at minimising temperature and pressure variations and ensuing mechanical stress using computer modelling for ammonia converter stresses with fluid dynamic finite element analysis. Current code methods do not address the effect of nitriding on crack formation, so Casale developed their own proprietary method to cover this.

Linde and Yara gave an overview of their work on adding a green hydrogen feed to Yara's Porsgrunn ammonia plant in Norway, providing some real world experience of the challenges involved. They admitted that Porsgrunn is fortunate in having hydroelectric power available, removing the fluctuating input of solar or wind, and also in having an ammonia plant already in site. PEM electrolysers were chosen for the project, as they are compact, with a small footprint, produce high purity hydrogen at the correct pressure (30bar), removing the need for a compressor, and can ramp output up and down quickly. The electrolysers produce 10.4 t/d of hydrogen, which is converted into 20,000 t/a of ammonia, and saves 41,000 tonnes of CO_2 equivalent. High purity water is essential, as well as a buffer to prevent hydrogen/oxygen mixing and consequent explosive risk. Linda say that they can now supply prefabricated PEM modules as a 10MW core unit. Scaling up to GW capacity is still a work in progress, but two 100 MW projects are under construction. They acknowledged the need to reduce capital costs, however.

Great interest was generated by Technip Energie's solutions for low-carbon hydrogen which includes ROX, a cutting edge solution for clean hydrogen production, achieving up to 99% CO_2 with maximum efficiency.

On the methanol side, Kei Fukuzawa of TEC showcased his companies digital solutions for next generation methanol plants, aimed at the projected increase in use of renewable methanol as a marine fuel, using captured CO_2 and electrolytically generated hydrogen. Their design uses a conventional MRF-Z adiabatic methanol reactor, assisted by a design program, *Methamaster*, which aims to mitigate the variability of renewable electricity via additional facilities (e.g. battery, hydrogen storage), and an operating program, *Methadynamics*, which monitors and alters plant parameters to cope with a fluctuating input of renewables.

Blue ammonia

Klemens Wawrzinek of Linde presented an interesting case study which showed that the optimum carbon capture rate for large scale ammonia plants based on ATR is not 99+% but may be closer to 95% if plant design is focused on carbon intensity rather than carbon capture. Maximising carbon capture only may lead to over-engineered flow sheets, which will not bring benefits with respect to the carbon intensity of the final product.

Ammonia cracking

Ammonia cracking continued to be a topic of interest, with a good turnout for Unicat's presentation on its new ACTS catalyst based on its established *Magcat* spherical support base, designed for a tubular fired reactor, with 75-96% hydrogen efficiency, depending on the main cracker heating source. Michael Lutz and Laurent Prost of Air Liquide also presented their company's low risk approach to developing an ammonia cracking technology, now at the pilot plant stage, and examined the issue of nitriding of construction materials due to high temperature hydrogen attack.

On the supply side, Andrea Zambiano of Saipem discussed the potential issues with large scale ammonia storage worldwide, once the use of low carbon ammonia becomes more widespread, particularly as a hydrogen carrier, and presented Saipem's own gravity-based terminalling solution, based on their own experience in designing large LNG tanks.

Catalysts

BASF has developed a new methanol catalyst specially optimised for the synthesis of e-methanol from CO_2-rich feedstocks under dynamic operating conditions.

Another new catalyst development by BASF presented at the conference was its 3D printed catalyst X3D® secondary N_2O abatement catalyst for nitric acid plants, which has demonstrated significant economic and environmental savings by reducing blower energy requirements and improving operational efficiency.

Other highlights

Stamicarbon in collaboration with Curtiss-Wright has developed a special mechanical plug made of Safurex® for urea applications which has been successfully installed in a pool condenser for the first time.

Manuel Prohaska of MPC2 provided an update on the latest improvements to non-destructive test methods enabling quick and reliable on-site assessment of critical process equipment at the manufacturer's workshop and the end-user's plant.

Operator experiences

As usual several operators shared their real world experiences of plant operation, issues encountered and how they were tackled. Winandyo Mangkoto of PT Pupuk Sriwidjaja Palembang (Pusri) in Indonesia described issues with a vacuum pressure increase at the Pusri IIB ammonia plant which was leading to increased steam import. The issue was traced to the cooling water system, with increased dissolved oxygen content due to air ingress into the vacuum system, but the root cause was fouling. Chemical injection of scale inhibitors and slime control agents improved operating efficiency, leading to a reduced consumption of steam by 4-5 t/h and savings of $150,000/month.

Muhammad Imran Idris and Muayad Qatan of Oman's OQ looked at plans for decarbonising production from their 3,000 t/d methanol plant and 1,000 t/d ammonia plant fed on purge gas from the methanol plant. The aim is to reduce carbon intensity of production by 25% in 2030 from a 2021 baseline, using flare recovery, reducing steam venting, increased process integration, electrification of heating and other services, and carbon capture, utilisation and storage. Better integration of the methanol and ammonia plants is the most significant step to boost efficiency. Other operators presenting their experiences included Engro Fertilizers, Indorama Eleme, MOPCO, Fauji Fertilizers, Helwan, Yara and PT Petrokemija Gresik. ■

Next year the Expoconference will be held in Barcelona once again, on 10-12 February 2026. See you there!

Nitrogen project listing 2025

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
ANGOLA							
Wuhuan Engineering	KBR	Amufert	Soyo	Ammonia	2,300	CA	2027
Wuhuan Engineering	TOYO	Amufert	Soyo	Urea	4,000	CA	2027
AUSTRALIA							
Daelim	KBR	NeuRizer	Leigh Creek, WA	Ammonia	1,600	DE	On Hold
Daelim	Stamicarbon	NeuRizer	Leigh Creek, WA	Urea	2,850	DE	On Hold
Saipem, Clough	Topsoe	Perdaman	Karratha, WA	Ammonia	3,500	UC	2027
Saipem, Clough	Saipem, TKFT	Perdaman	Karratha, WA	Urea	2 x 3,100	UC	2027
n.a.	KBR	H2Perth	Kwinana, WA	Ammonia	1,800	DE	n.a.
n.a.	n.a.	CSBP	Kwinana, WA	Ammonia	900	P	n.a.
Tecnicas Reunidas	Topsoe	Allied Green Ammonia	Gove, NT	Ammonia	2,500	DE	2029
n.a.	n.a.	AFC	Gladstone, QLD	Ammonia	1,000	FS	n.a.
n.a.	n.a.	AFC	Gladstone, QLD	Urea	1,500	FS	n.a.
BULGARIA							
Casale	Casale	Agropolychim	Devnya	Nitric acid	n.a.	DE	2027
Casale	Casale	Agropolychim	Devnya	Ammonium nitrate	n.a.	DE	2027
CANADA							
DL E&C	thyssenkrupp IS	Genesis Fertilizer	Belle Plaine, SK	Ammonia+CCS	1,500	DE	2029
DL E&C	Stamicarbon	Genesis Fertilizer	Belle Plaine, SK	Urea	2,500	DE	2029
DL E&C	thyssenkrupp IS	Genesis Fertilizer	Belle Plaine, SK	Nitric acid	n.a.	DE	2029
DL E&C	thyssenkrupp IS	Genesis Fertilizer	Belle Plaine, SK	Ammonium nitrate	n.a.	DE	2029
CHILE							
TOYO	KBR	HyEx	Tocopilla	Ammonia	55	UC	2025
Wood Group	n.a.	Total Energies	San Gregorio	Ammonia	2,600	FS	2030
CHINA							
n.a.	Casale	Henan Jindadi	Luohe, Henan	Ammonia	1,800	C	2024
n.a.	Casale	Jiangsu Huachang	Zhangjiagang	Ammonia	1,800	C	2024
n.a.	Casale	Henan Shenma Nylon	Pingdingshan	Ammonia	1,200	C	2024
n.a.	Stamicarbon	Henan Xinlianxin	Jiangxi	Urea	2,330	C	2024
n.a.	Topsoe	Mintal HET	Baotou, Mongolia	Ammonia	1,800	CA	2025
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	Jiangsu Huachang	Zhangjiagang	Urea	1,860	DE	n.a.
n.a.	Stamicarbon	Xinjiang Xinji	Xinjiang	Urea	3,800	DE	2026
n.a.	Stamcarbon	Shaanxi Shanhua	Weinan	Urea	n.a.	RE	n.a.
n.a.	Stamicarbon	Jiangxi Xinlianxin	Jiujuang, Jiangxi	Urea	3,850	DE	2027
n.a.	Stamicarbon	Qinghai Yuntianhua	Qinghai	Urea	2 x 1,200	RE	2026
n.a.	Stamicarbon	Linggu Chemical Co	Yixing	Urea	3,100	RE	2025
n.a.	n.a.	Jizhong New Energy	Duerbot, Mongolia	Ammonia	1,500	UC	2028
n.a.	Stamicarbon	Hulunbier New Gold	Hulunbier, Mongolia	Urea	3,600	RE	2025
DENMARK							
n.a.	n.a.	CIP	Esbjerg	Ammonia	1,810	FS	2030
EGYPT							
n.a.	thyssenkrupp IS	MOPCO	Damietta	Ammonia	450	UC	2027
Bilfinger	n.a.	Kima	Aswan	Nitric acid	600	UC	2027
Bilfinger	n.a.	Kima	Aswan	Ammonium nitrate	800	UC	2027

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n.a.	Topsoe	Egypt Green Hydrogen	Ain Sokhna	Ammonia	210	DE	2027
n.a.	n.a.	AMEA Power	Ain Sokhna	Ammonia	910	DE	n.a.
n.a.	Stamicarbon	Delta	Talkha	Urea	2,250	RE	n.a.
FRANCE							
n.a.	n.a.	FertigHy	Hauts de France	Ammonia	1,500	P	2030
HUNGARY							
Casale	Casale	BorsodChem	Kazincbarcika	Nitric acid	1360	UC	2026
INDIA							
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Nitric acid	900	UC	2025
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Ammonium nitrate	970	UC	2025
Tata	Casale	Deepak Fert & Chem	Dahej	Nitric acid	1,450	UC	2025
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.
Larsen & Toubro	Casale	Chambal Fert & Chem	Gadepan	Nitric acid	600	RE	2025
Larsen & Toubro	Casale	Chambal Fert & Chem	Gadepan	Ammonium nitrate	700	RE	2025
n.a.	Topsoe	Hygenco	Gopalpur	Ammonia	750	DE	2027
n.a.	Casale	Avada	Gopalpur	Ammonia	1,500	BE	n.a.
n.a.	n.a.	BVFCL	Namrup	Ammonia	2,100	P	2029
n.a.	n.a.	BVFCL	Namrup	Urea	3,800	P	2029
IRAN							
PIDEC	Topsoe	Hengam Petrochemical	Assaluyeh	Ammonia	2,050	C	2025
PIDEC	Saipem, TKFT	Hengam Petrochemical	Assalyueh	Urea	3,500	C	2025
Namvaran	KBR	Kermanshah Petchem	Kermanshah	Ammonia	2,400	UC	2025
Namvaran	Stamicarbon	Kermanshah Petchem	Kermanshah	Urea	2,000	UC	2025
Hampa	Casale	Zanjan Petrochemical	Zanjan	Ammonia	2,050	UC	2025
Hampa	Stamicarbon	Zanjan Petrochemical	Zanjan	Urea	3,600	UC	2025
INDONESIA							
n.a.	Casale	PT Pupuk Kalimantan	Bontang	Ammonia	1,800	RE	2025
Wuhuan Engineering	KBR	PT Pupuk Sriwidjaja	Palembang	Ammonia	1,350	BE	2027
Wuhuan Engineering	TOYO	PT Pupuk Sriwidjaja	Palembang	Urea	2,750	BE	2027
ISRAEL							
Saipem	Topsoe	Haifa Chemicals	Mishor Rotem	Ammonia	300	UC	2025
KAZAKHSTAN							
Wuhuan Engineering	KBR	KazAzot	Aktau	Ammonia	2,000	CA	2028
Wuhuan Engineering	TOYO	KazAzot	Aktau	Urea	1,750	CA	2028
Wuhuan Engineering	Espindesa	KazAzot	Aktau	Nitric acid	1,200	CA	2028
Wuhuan Engineering	Espindesa	KazAzot	Aktau	Ammonium nitrate	1,500	CA	2028
MEXICO							
thyssenkrupp IS	thyssenkrupp IS	Proman	Topolobampo	Ammonia	2,200	UC	2027
n.a.	Casale	Pemex	Escolin, Vera Cruz	Ammonia	1,200	FS	2029
n.a.	Casale	Pemex	Escolin, Vera Cruz	Urea	2,125	FS	2029
NIGERIA							
Worley	n.a.	OCP	Tarfaya	Ammonia	2,300	DE	2027
NORWAY							
Casale	Casale	Skipavika Green Ammonia	Skipavika	Ammonia	300	UC	2027
n.a.	n.a.	North Ammonia AS	Eydehavn	Ammonia	440	DE	2029
n.a.	Topsoe	Barents Blue	Markoppneset	Ammonia	3,000	DE	2029
n.a.	Technip	Iverson eFuels	Sauda	Ammonia	600	P	2029
OMAN							
n.a.	n.a.	Hyport Duqm	Duqm	Ammonia	900	DE	2030
Wood	KBR	Blue Horizons	Duqm	Ammonia	3,000	CA	2030

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
PARAGUAY							
Casale	Casale	ATOME	Villeta	Ammonia	300	DE	2027
Casale	Casale	ATOME	Villeta	Nitric acid	n.a.	DE	2027
Casale	Casale	ATOME	Villeta	CAN	800	DE	2027
QAFCO							
thyssenkrupp IS	thyssenkrupp IS	Qafco	Mesaieed	Ammonia+CCS	3,500	UC	2027
n.a.	n.a.	QatarEnergy	Mesaieed	Ammonia	3 x 3,500	P	n.a.
n.a.	n.a.	QatarEnergy	Mesaieed	Urea	4 x 4,500	P	n.a.
RUSSIA							
CNCCC	Topsoe	ShchekinoAzot	Pervomayskyy, Tula	Ammonia	1,500	UC	2025
CNCCC	Stamicarbon	ShchekinoAzot	Pervomayskyy, Tula	Urea	2,000	UC	2025
Tecnimont	KBR	EuroChem	Kingisepp	Ammonia	3,000	UC	2026
Tecnimont	Stamicarbon	EuroChem	Kingisepp	Urea	4,000	UC	2026
n.a.	n.a.	Lukoil	Budyonnovsk	Ammonia	3,600	P	2030
n.a.	n.a.	Lukoil	Budyonnovsk	Urea	5,300	P	2030
n.a.	Azot	AEON/VEB	Vorkuta, Komi	Ammonia	3,600	P	2030
n.a.	Azot	AEON/VEB	Vorkuta, Komi	Urea	5,300	P	2030
SAUDI ARABIA							
Larsen & Toubro	Topsoe	Neom	Neom	Ammonia	3,500	UC	2027
SENEGAL							
n.a.	n.a.	SEFCO	n.a.	Ammonia	n.a.	FS	2029
n.a.	n.a.	SEFCO	n.a.	Urea	300	FS	2029
SOUTH KOREA							
n.a.	KBR	Hanwha	Yeosu	Nitric acid	1,200	UC	2025
SPAIN							
n.a.	n.a.	Iberdrola	Puertollano	Ammonia	330	BE	2026
TANZANIA							
n.a.	n.a.	ESSA	Mtwara	Ammonia	1,800	P	2029
n.a.	n.a.	ESSA	Mtwara	Urea	3,000	P	2029
UNITED STATES							
n.a.	Stamicarbon	Confidential	n.a.	Urea	+1180	RE	2025
n.a.	KBR	Monolith Materials	Hallam, Nebraska	Ammonia	830	DE	n.a.
Tecnimont	KBR/Linde	Woodside	Beaumont	Ammonia+CCS	3,300	UC	2025
n.a.	n.a.	CF Industries	Donaldsonville	Nitric acid	n.a.	RE	2025
Worley	Topsoe	First Ammonia	Victoria, TX	Ammonia	300	UC	2026
thyssenkrupp IS	thyssenkrupp IS	CF Industries	Blue Point, LA	Ammonia+CCS	3,300	DE	2027
KT-Kinetics Tech	Stamicarbon	Confidential	n.a.	Ammonia	450	CA	2026
n.a.	Topsoe	Air Products	Ascension, LA	Ammonia+CCS	1,700	UC	2027
n.a.	Topsoe	CF Industries	Louisiana	Ammonia	n.a.	FS	n.a.
n.a.	n.a.	ExxonMobil	Baytown, TX	Ammonia+CCS	3,000	P	2029
n.a.	thyssenkrupp IS	Cronus	Tuscola, IL	Ammonia	2,600	P	n.a.
UNITED ARAB EMIRATES							
n.a.	n.a.	Ta'ziz	Ruwais	Ammonia+CCS	3,000	P	2027
UZBEKISTAN							
n.a.	Casale	Ferkensco	Karakul	Ammonia	1,500	UC	2026
n.a.	Casale	Ferkensco	Karakul	Urea	1,800	UC	2026
ZAMBIA							
n.a.	n.a.	United Capital Fert	Chilanga	Ammonia	550	UC	2028
n.a.	n.a.	United Capital Fert	Chilanga	Urea	900	UC	2028

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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HAZID techniques for green ammonia plants

Risk analysis tools such as hazard identification (HAZID), is often a first step in broader risk management and is especially valuable for green ammonia, where new technologies and processes introduce novel risks. This article explores various aspects of HAZID, from the basics of hazard identification to unique considerations specific to green ammonia facilities.

Hazard identification (HAZID) is a risk analysis tool used for early identification of potential hazards and threats to provide input to project development decisions. This leads to a safer and more cost-effective design with less chance of later design changes and cost penalties. HAZID predominantly addresses the hazards outside the envelope of the process equipment, whereas hazard operability (HAZOP) studies are concerned with deviations arising within process equipment and is used to identify abnormalities in the working environment and pinpoint the root causes of the abnormalities.

In the context of green ammonia production, thorough HAZID studies can be used to recognise unique risks associated with green ammonia, and implement best practices and safety standards to mitigate these risks.

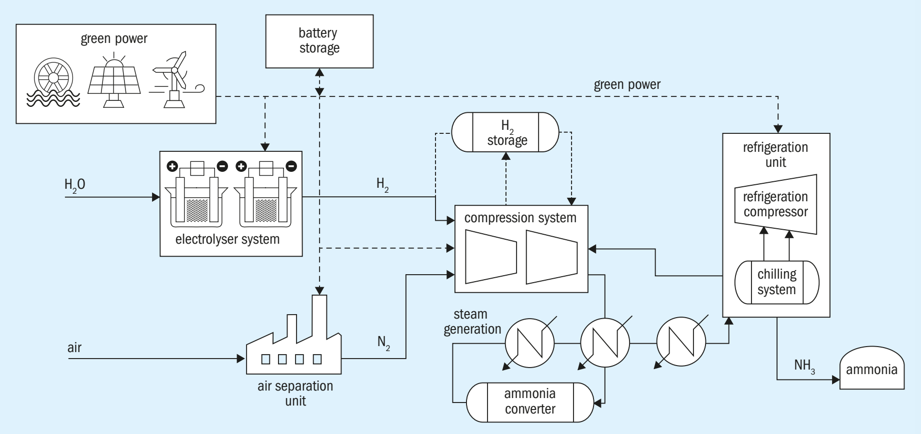
The key objectives of HAZID studies in green ammonia plants are:

- **Identify potential hazards**: Recognise sources of risk related to ammonia synthesis, renewable energy integration, and storage.
- **Assess likelihood and consequence**: Evaluate how likely each hazard is to occur and the potential impact it could have on safety, operations, and the environment.
- **Propose mitigation measures**: Recommend preliminary actions or design modifications to minimise risks before proceeding with detailed engineering.
- **Facilitate regulatory compliance**: Support adherence to safety regulations, industry standards, and best practices by identifying all potential hazards and addressing them early.

Unique considerations in green ammonia HAZID studies include:

- **Variable power supply**: Renewable energy sources are inherently variable. This variability can create instability in energy supply, impacting ammonia synthesis and potentially leading to operational hazards.
- **Electrolyser risks**: The electrolysis process, critical in green ammonia production to produce hydrogen from water, introduces risks such as high voltages, high-pressure hydrogen, and potential leaks. Hydrogen, as a flammable and small molecule, is more challenging to contain.
- **Water supply and quality**: Green ammonia requires significant amounts of purified water for hydrogen production, and interruptions or contamination in water supply can impact operations and introduce risks.
- **Battery storage**: If battery systems are used to manage energy storage and distribution, they introduce specific hazards, including fire risks, toxic emissions, and thermal runaway events.
- **Integration challenges**: The integration of renewable energy systems with ammonia production must be carefully managed to prevent failures due to synchronisation issues or control system mismatches.

Fig. 1: **Unique HAZID studies in green ammonia plants**



Source: Fertilizer Academy

HAZID study for green ammonia plants

There are several steps to conducting a HAZID study for green ammonia plants.

Define the scope and objectives: Define the scope of the HAZID study to include all areas and systems in the green ammonia plant, from renewable energy input to ammonia synthesis and storage. Establish clear objectives to address unique risks associated with green ammonia production, considering both conventional ammonia hazards and new risks from renewable energy integration.

Assemble a multidisciplinary team: A successful HAZID study requires a team with diverse expertise, including process engineers, renewable energy specialists, control systems engineers, and safety professionals. In green ammonia projects, involving personnel experienced in renewable energy and hydrogen safety is essential.

Systematic Hazard Identification: Using checklists, brainstorming sessions, and structured techniques like "What-If" analysis, the team identifies potential hazards for each part of the plant.

Energy supply and management: Analyse hazards associated with energy variability, storage, and distribution systems.

Table 1: **Selection of industry standards and guidelines relevant for ammonia and hydrogen safety**

Industry standards and guidelines

- NFPA 2: Hydrogen Technologies Code
- ISO 22734: Hydrogen Generators Using Water Electrolysis
- CSA/ANSI B22734: Hydrogen Generators Using Water Electrolysis (adopted with Canadian and US deviations of ISO 22734) / AS 22734 (adopted with Australia deviations of ISO 22734)
- NFPA 70: National Electric Code
- NFPA 497: Recommended Practices of the Classification of Flammable Liquids, Gases, or Vapors
- IEC 60079-10-1: Explosive Atmospheres – Part 10-1: Classification of Areas – Explosive Gas Atmospheres
- NFPA 69: Standard on Explosion Prevention Systems
- CGA G-5.5: Hydrogen Vent Systems
- CGA S.1: Pressure Relief Device Standards
- ASME B31.3: Process Piping or ASME B31.12 Hydrogen Piping and Pipelines
- CGA G5.4: Standard for Hydrogen Piping Systems at User Locations
- HGV 4.10: Standard for Fittings for Compressed Hydrogen Gas and Hydrogen Rich Gas Mixtures
- Oxygen Safety Standards: (CGA G-4.4, ASTM G63, G94, G93, NFPA 53)

Source: Fertilizer Academy

Electrolysis units: Examine potential hydrogen leaks, high-pressure system failures, and risks associated with electrolysis operations.

Ammonia synthesis loop: Identify hazards in the ammonia synthesis loop, including temperature, pressure, and catalyst-related issues.

Storage and handling: Consider hazards related to ammonia storage, transport, and handling, especially concerning emergency shutdowns and potential leaks.

Risk assessment and ranking: Each identified hazard is assessed based on its likelihood and consequence. This ranking helps prioritise high-risk areas, allowing for a focused approach on mitigating the most critical risks. The aim is to determine if risks can be reduced to ALARP (As Low As Reasonably Practicable).

Develop mitigation strategies: For each high-priority hazard, propose mitigation measures to either eliminate or reduce the risk.

Documentation and review: Document the findings, mitigation measures, and any recommendations for further risk assessment or design review. Conduct a review of the HAZID findings to ensure all hazards have been addressed and that mitigation measures are reasonable and effective.

Best practices for HAZID studies

It is important to conduct HAZID early in the design phase to allow enough time to incorporate necessary changes. As green ammonia technology evolves, continuous hazard reviews ensure that new risks or process changes are effectively managed. Regular training should be provided to the HAZID team, focusing on new technologies and evolving safety standards in renewable energy and ammonia production. Lessons learned from similar projects and case studies can be used to understand what has worked well and what has posed challenges. Adhere to industry standards and guidelines for ammonia and hydrogen safety, including updates for renewable energy integration.

Synthesis gas compressor fires due to gas leaks

Synthesis gas compressor fires due to gas leaks pose significant safety and operational risks in ammonia plants. Based on the incidents reported by the conventional ammonia industry, several key conclusions can be drawn.

Gas leaks leading to fires often result from mechanical failures, such as

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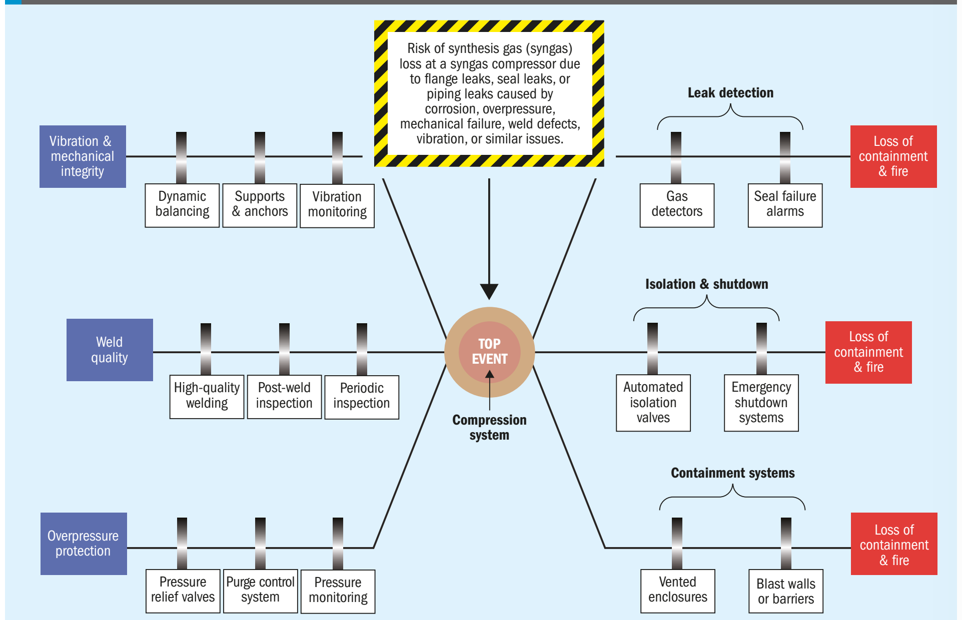
Fig. 2: **HAZID study bowtie diagram: Risk of syngas loss at a syngas compressor**



Source: Fertilizer Academy

disconnected instrument tubes, failed valve components, or compromised oil seals. Even small components like a missing rivet can lead to catastrophic events. Once a leak occurs, fires can spread quickly, causing extensive damage to compressors, buildings, and auxiliary equipment. The high-pressure, hydrogen-rich gas creates intense jet fires that are challenging to extinguish.

Early detection of gas leaks is crucial. Implementing comprehensive gas detection systems, regular inspections, and proper maintenance procedures can help prevent incidents or mitigate their severity. Having well-trained personnel and proper emergency response procedures is essential. This includes rapid plant shutdown protocols, effective firefighting strategies, and clear evacuation plans.

Compressor room fires can result in significant costs, including equipment damage, production losses, and implementation of additional safety measures. Proper design of compressor rooms, including adequate ventilation, fire suppression systems, and strategic placement of critical equipment, can help limit fire spread and damage.

Careful attention to start-up and shut-down procedures, as well as maintaining proper oil sealing systems, is critical to prevent gas leaks during transient operations. Regular inspections of all gas-carrying components, including small-bore piping and manual valves, are necessary to identify potential failure points before they lead to incidents.

Each incident provides valuable lessons for improving safety measures, operational procedures, and equipment design across the industry. Sharing these experiences is crucial for preventing similar occurrences in other facilities.

By addressing these aspects comprehensively, ammonia plant operators can significantly reduce the risk of synthesis gas compressor fires and improve overall plant safety and reliability.

By integrating preventive, mitigation, and administrative safeguards, the risk of syngas loss at the compressor can be effectively minimised. Gas detectors, automated isolation systems, and robust maintenance programs enhance safety and operational reliability. These measures work together to ensure early detection, containment, and controlled response to hazardous events.

Conclusion

HAZID studies remain a cornerstone of safety management in ammonia plants, regardless of whether the ammonia is green, grey, or brown. The hazards associated with ammonia production are constant, and comprehensive HAZID frameworks ensure that causes, consequences, and safeguards are systematically addressed. By fostering a culture of safety and leveraging lessons learned, organisations can enhance risk management, ensuring a safer and more sustainable production environment. ■

This article is based on the certified operator training programme by Fertilizer Academy, presented at the Nitrogen+Syngas 2025 Expoconference, Barcelona, 10 February 2025.

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Safety aspects of green ammonia production

Esben Sørensen and **Glenn Rexwinkel** of Plug Power review the safety aspects of integrating hydrogen production by electrolysis into existing ammonia processes. Novel safety risks associated with such changes are surmountable and the analysis presented shows that green ammonia production can be no more hazardous than traditional ammonia production.

Introducing hydrogen produced by electrolysis as an element to the ammonia process configuration requires not only that the electrolysis process itself should be completely safe but also that sections in the ammonia process where process conditions change because of this novel concept are analysed to understand how such change can be made without increasing the overall process risk compared to traditional process configurations.

Feeding pure hydrogen to a specific part of the ammonia process naturally means that the risks associated with higher hydrogen partial pressure in that part of the process increases compared to what it was in the original configuration. From a safety point of view, two main aspects of increasing the partial pressure of hydrogen in a given process section should be given focus:

- increased risk of explosion (or detonation) as the rate of flame propagation for a combustible gas generally increases with the partial pressure of hydrogen in the gas;
- increased risk of high-temperature hydrogen attack (HTHA) as mapped by the Nelson curve.

Fig. 1 shows the flammability range and ignition energy of hydrogen compared to other fuels.

A third safety aspect that should also be borne in mind is the risk of attaining unexpected, explosive conditions during abnormal operation due to the targeted increase of hydrogen partial pressure during normal operation. Incomplete purging in connection with equipment inspection or venting of hydrogen-containing gas at an unsafe location can create conditions where explosive mixtures of oxygen and hydrogen could be formed. The risk of attaining explosive conditions is naturally higher in the process sections with high hydrogen concentrations.

There are, of course, other safety aspects to be considered as well however, not all of them are negative. In cases where the increased hydrogen partial pressure has been attained at the expense of a reduced CO partial pressure, there may in fact, be certain safety aspects that are improved, for example, lower risk of personnel poisoning by CO or carbonyls.

PHOTO: PLUG POWER

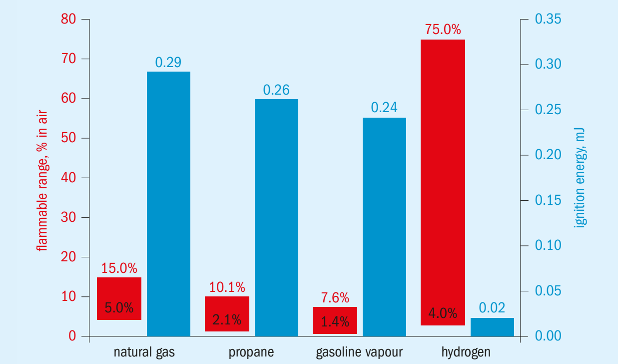
First of a network of liquid green hydrogen plants built, owned, and operated by Plug across the USA.

Hazards related to green ammonia processes

Production of ammonia by reacting hydrogen with nitrogen is not a new concept and hence does not require any specific analysis to identify hazards related to green ammonia production. On the contrary, there are certain operational and safety benefits to introducing pure hydrogen rather than producing it through the normal reforming process. There are however certain new safety aspects associated with the hydrogen production by electrolysis and novel aspects also result if there is an aim to vary the load of the ammonia plant as a function of power price as such dynamic green ammonia processes typically are controlled in a different manner than traditional processes. The safety aspects related to such novelties should of course also be considered.

Within the context of analysing novel risks related to green ammonia production, the most pertinent safety aspects to be discussed in the following sections can hence be divided into:

Fig. 1: Flammability range and ignition energy of hydrogen compared to other fuels



Source: Plug Power

- safety aspects related to revised design result from requirements of enhanced process dynamics or other new design requirements;
- safety aspects related to green ammonia revamps – i.e. sending hydrogen as supplementary feedstock to an already existing ammonia plant and;
- safety aspects related to the production of hydrogen by electrolysis.

Safety aspects related to process dynamics

Efforts to optimise plant performance towards purely green operation typically lead to changes in process control[1] and/or reactor design[2, 3]. Implications of such novel concepts on the plant safety should, of course, be carefully considered and addressed. These considerations will typically be made on a case-to-case basis and will, therefore, not be discussed further here.

Safety aspects related to green ammonia revamps

Most commercial-scale ammonia processes where a green revamp would be an option[4] have an overall process configuration as shown in Fig. 2. Various versions of this generic process configuration exist[5].

KBR developed a concept where the syngas purification takes place before introduction to the synloop in a so-called Purifier™. This adjusts the N_2/H_2-ratio in the syngas and thereby enables the reduction of the steam reformer size[6]. Others have discussed in some detail the implications of adding hydrogen to a conventional process based on two-step reforming[7].

Implications of adding hydrogen to a traditional two-step ammonia process

Adding hydrogen to an existing ammonia plant naturally means that the ratio between reactants (H_2/N_2) is increased above the optimal value, and some other design or operational change is required to restore that balance. The obvious way to achieve that in a traditional two-step ammonia process is to shift the load from the primary reformer to the secondary reformer. Increasing the load in the secondary reformer means that a more significant fraction of the hydrogen and CO in the syngas is burned, and at the same time, the amount of nitrogen added to the syngas is increased. For small disturbances (up to say 5-7% excess hydrogen) there hence exists a certain shift in load, which will restore the balance between H_2 and N_2 to the desired value.

Fig. 2: Overall process configuration for commercial scale ammonia plants

natural gas → HDS → primary reformer → secondary reformer → water gas shift section → acid gas removal → purification → ammonia loop → ammonia refrigeration → ammonia

Source: Plug Power

There are certain intrinsic safety considerations that must be made in connection with such a change in plant operation. In the first place, the temperature rise across the secondary reformer increases. This is a safety concern, and it will typically require that the inlet temperature to the secondary reformer is lowered so that the exit temperature from the secondary reformer does not exceed the mechanical design temperature of its outlet system. Excessive reduction in the primary reformer load, however, reduces the overall steam production from the unit. Hence, an appropriate balance has to be found, which both secures sufficient steam generation and avoids excessive temperatures exiting the secondary reformer. Addressing these issues simultaneously typically defines the limit for how much (green) hydrogen can be added to the plant and, hence, how much the plant capacity can be boosted if there is capacity available in downstream units.

An important implication of the above-mentioned modifications is that the process air compressor (PAC) will operate at an increased load. For plants where this is impossible, an alternative to increasing capacity is to add oxygen co-produced in the electrolyser unit, which produces green hydrogen for the unit and sends it to the PAC. Thereby, the load can be shifted from the primary reformer to the secondary reformer without increasing the load on the PAC, but such a change requires verification that the increased oxygen partial pressure in the PAC is acceptable from a design and safety perspective. Adding oxygen to the PAC could be attractive for plants where the primary reformer is the bottleneck or for feedstock-constrained plants. The overall result of such a modification is not an increase in production but merely a partial shift from grey to green production. At green ammonia prices[8] of ~700 \$/t and projected prices[9] for 2030 exceeding 1,100 \$/t, such modification could be quite attractive for many plants. Importing nitrogen to the process is another way to reestablish the stoichiometric ratio and can in principle be used to the extent required as long as there is still capacity available for compression to loop conditions.

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Implications of adding hydrogen to a Purifier™ based ammonia process

At first glance, adding hydrogen to an ammonia plant with a purifier seems to entail less plant modifications than what was presented above. Maintaining process conditions (pressure and temperature) in the purifier will, in principle, ensure that the desired H_2/N_2 ratio is maintained even if the inlet stream to the purifier has an increased hydrogen content. This mode of operation requires that hydrogen is added upstream of the purifier and hence entails the safety implications related to an increase in hydrogen partial pressure as described previously. An alternative modification is to operate the purifier at a slightly elevated temperature, evaporating more nitrogen into the process stream and then adding the hydrogen downstream of the purifier. Both cases have to account for potential bottlenecks on liquid nitrogen supply and evaporation capacity in the purifier but adding hydrogen downstream the purified naturally increases the requirement for the purity of the hydrogen imported. A detailed analysis must be conducted on a case-to-case basis to determine the best configuration. Overall, the safety precautions related to adding green hydrogen to a purifier-based ammonia process seem relatively minor.

Hazards related to hydrogen production by electrolysis

The previous section addressed the implications of feeding pure hydrogen to the ammonia process. This section focuses on the safety aspects of the electrolysis unit itself.

There are several types of electrolysis units commercially available, but the dominating technologies can be grouped as:

- PEM (Proton Exchange Membrane)
- AWE (Alkaline Water Electrolysis)
- SOEC (Solid Oxide Electrolysis Cells).

Of these, only PEM and AWE are available on a large scale to enable commercial-scale ammonia production.

While certain of the safety aspects are different for the different technologies, there are also many safety aspects that are similar[10]. To facilitate an in-depth analysis of these, a thorough analysis will be made on PEM technology as offered by Plug Power – simply because this is the electrolysis technology for which the author has the best insight. Most, if not all, of the safety aspects discussed below are equally relevant for all types of electrolysis but there are, on the other hand, certain risks associated with the SOEC and AWE technologies which must be taken into consideration and are not covered here as such risks don't exist in the case of PEM. For SOEC, such considerations relate particularly to the safety aspects of producing pure hydrogen in partially ceramic structures being heated up to 750-800°C (1,400-1,500°F) while in the case of AWE, the high concentrations and amounts of KOH in AWE systems demand additional safety measures.

The predominant risk associated with electrolysis is that a partition separating the anode side (with a high concentration of oxygen) from the cathode side (with a high concentration of hydrogen) ruptures and creates an explosive mixture of hydrogen and oxygen. This risk is intrinsic in all types of electrolysis technologies. There is a huge pressure on the development of electrolysis technology to reduce power consumption and make the technology more compact. The way to increase efficiency is to reduce the electrical and molecular resistance of the membrane or diaphragm between the anode and cathode sides by applying thinner membranes or diaphragms, but this naturally also leads to an increased risk of uncontrolled migration of hydrogen to the oxygen side or vice versa. Similarly, the push towards more compact layouts leads to geometries where oxygen and hydrogen in high concentrations are present in locations very close to each other.

This scenario and how to rectify its associated dangers will be the main focus of the subsequent part of this section. The analysis is relevant for all electrolysis manufacturers, irrespective of the type of technology.

There are essentially three types of pressure configurations available on the market:

- atmospheric electrolysis;
- pressurised alkaline electrolysis;
- PEM configurations with a pressure gradient across the membrane.

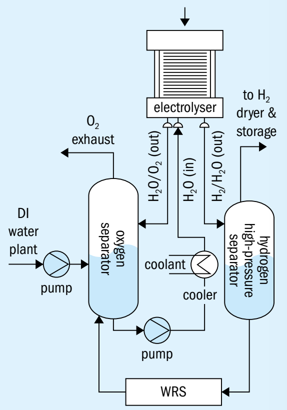
Plug Power's configuration is of the latter type, where the anode side operates close to atmospheric conditions while the cathode side operates at 40 bar g (580 psig).

Safe design of PEM units

The process used by Plug Power to produce hydrogen by PEM is shown conceptually in Fig. 3. The stack (marked electrolyser on the sketch) is the core of the process where water is split into hydrogen and oxygen. Protons formed within the stack permeate to the downstream cathode side of the stack, where they recombine with electrons to form a mixture of hydrogen and water, which is then separated into its constituents in the downstream hydrogen high-pressure separator. Hydroxyl ions, conversely, are constrained to the upstream anode side where they donate electrons to the stack and recombine to oxygen and water separated in the oxygen separator. The anode side operates at close to atmospheric conditions, whereas the cathode side operates at a pressure exceeding 40 bar g (580 psig). Water is recovered from the cathode side and recycled to the anode side via the water recycle system (WRS), which reduces the amount of hydrogen transferred to the anode side. The process configuration indicated in Fig. 3 has many benefits from a safety point of view, as described below.

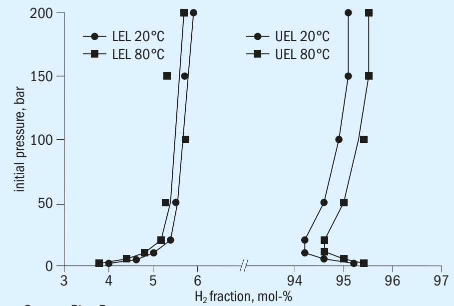
In the first place, the fact that the cathode side is operating at a much higher pressure than the anode side eliminates the risk that oxygen in relevant quantities should flow to the cathode side. This eliminates ~50% of the risk scenarios during normal operation (during which only the anode system can attain a flammable composition) whereas both the anode and cathode systems could achieve explosive conditions if both were

Fig. 3: **Plug Power's PEM process configuration**



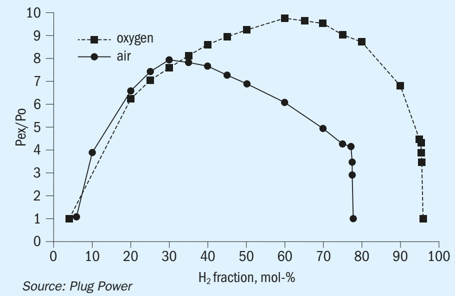
Source: Plug Power

Fig. 4: **Pressure dependence of the explosion limits of hydrogen-oxygen gas mixture**



Source: Plug Power

Fig. 5: **Deflagration pressure of hydrogen-air and hydrogen-oxygen mixtures in a closed vessel at room temperature**



Source: Plug Power

operating at the same pressure. The high pressure on the cathode side is generated electrochemically, i.e. without any use of compression, so any safety aspects related to compression of hydrogen up to the supply pressure are also avoided.

Moreover, the worst-case explosive scenario is now governed by the maximum operating pressure of the low-pressure side (i.e. the slight overpressure at the anode side) instead of the hydrogen supply pressure, which governs the max pressure of an explosive mixture in a system with a balanced pressurised configuration.

Hydrogen, in small concentrations, will always be present in the oxygen section. There are two main mechanisms for hydrogen to end up in the oxygen section: hydrogen carryunder and hydrogen crossover.

Carryunder is the transport of hydrogen dissolved in return water from the cathode separator to the anode separator. Crossover is hydrogen diffusion from the high-pressure cathode side through the proton exchange membrane to the low-pressure oxygen side. These mechanisms are well understood and accepted.

Plug ELX systems are equipped with safeguards that shut down the system to a safe state when elevated hydrogen concentrations are measured in oxygen or when elevated oxygen concentrations are measured in the hydrogen. These safeguards are adequate if the concentration changes are slow and take five minutes or more. However, if concentration changes are faster than five minutes, a potentially dangerous gas composition can be created before the safeguards can detect the condition. This potential safety issue has been addressed in Plug Power's design as described below.

The most common failure mode for a PEM electrolyser is the development of a pinhole leak between the cathode and anode compartments. These leaks do not pose a risk since they can be detected in time, and the system can be shut down safely. In very rare cases, a membrane can rupture, forming a much larger hole. Though very rare, it must be considered.

Since the hole size of a pinhole or even a larger rupture is impossible to quantify, Plug Power assumes for the design of the safety system the worst-case situation that a rare crossover event can cause a hydrogen-oxygen mixture to occur in the oxygen-water separator that will explode.

For hydrogen and oxygen gas mixtures, the explosive limit range is very wide and gets wider as the temperature increases. The lower flammability limit (LEL) of hydrogen in oxygen is 4 vol-% at 20°C (45°F) and 1 bara (14.5 psia), while the upper flammability limit (UEL) is 95.2 vol-%. Measured LEL and UEL values for hydrogen-oxygen mixtures as a function of temperature and pressure have been measured by others[11]. The results are shown in Fig. 4

Between the LEL and the UEL the gas mixture is flammable, and an ignition may result in a deflagration or detonation. Deflagration propagates with the velocity below the speed of sound (sub-sonic) in the unburned mixture. A detonation propagates with the velocity above the speed of sound (super-sonic).

Deflagration events in enclosures or confined spaces lead to significant overpressures. The pressure peak is nearly ten times higher than the initial pressure in oxygen-hydrogen mixtures. During deflagration, the pressure grows almost uniformly within the enclosed space. Deflagration in an enclosure can be mitigated by venting. This is the most cost-effective and wide-spread explosion mitigation technique.

Detonation is the worst-case scenario for a hydrogen incident. Detonation propagates 2-3 orders of magnitude faster than deflagration, resulting in pressures at the detonation front more than 15-20 times higher than the initial pressure. The venting technique used to mitigate deflagration events does not apply to detonation events, as there is insufficient time to release the pressure. Where deflagration events produce a uniform increase in pressure inside a closed vessel, detonations tend to show an oscillatory pressure response where very high but short pressure peaks are produced.

For hydrogen-air and hydrogen-oxygen mixtures, the highest deflagration pressure peak is obtained at a stoichiometric composition - see Fig. 5. The pressure behaviour of detonations looks similar but with much higher and shorter pressure peaks. Consequently, the worst-case scenario for a hydrogen-oxygen explosion is at a stoichiometric composition of 66.6 vol-% hydrogen and 33.3 vol-% oxygen.

Attaining ExPSR certification through experiments

The safe operating limits were determined experimentally to be sure that the oxygen-water separators could handle a stoichiometric detonation. Currently, Plug Power supplies two different size electrolyser systems: a 5 and a 10 MW system. These systems use oxygen-water separators of various sizes, and consequently, these need to be explosion tested separately. All

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systems use the Allagash stack depicted on Fig. 6 for the electrolysis process. The pressure vessels and the Allagash stack have been subjected to explosion testing based on European norm NEN-EN 14460:2018 for explosion pressure shock-resistant equipment where permanent deformation is allowed.

NEN-EN 14460 specifies requirements for explosion-resistant equipment that will withstand an internal explosion without rupturing and not give rise to hazardous effects on the surroundings. It applies to equipment (vessels and systems) where explosions are an exceptional load case. There are two types of explosion-resistant equipment: explosion pressure resistant and explosion pressure shock resistant. Explosion pressure-resistant equipment is designed to withstand the explosion pressure without permanent deformation and will not harm the surroundings. For explosion pressure shock-resistant equipment, permanent deformation is allowed, provided the equipment will not give rise to hazardous impacts on the surroundings.

IBExU conducted the explosion tests in Freiberg, Germany. The IBExU Institut für Sicherheitstechnik GmbH, IBExU for short, is a technical engineering service company in the field of explosion protection with a tradition going back to 1928. IBExU is an accredited test laboratory and accredited certification centre for the testing/certification of equipment, protective systems and components intended for use in potentially explosive areas in addition to safety, control and control equipment for use inside of potentially explosive regions in accordance with Directive 2014/34/EU.

To assess the vessels in terms of explosion pressure shock resistance, static ignition tests with stoichiometric H_2/O_2 mixtures were performed at various initial pressures. The gas volume inside each vessel was flushed at least three times with the stoichiometric gas mixture and then pressurised to the desired test pressure. This gas volume in the vessels was then ignited.

The tests started at a low ignition pressure, and the pressure gradually increased after every successful test. A test was successful when only ductile failure was observed, and no significant pressure peaks appeared 1 m (3ft) from the vessel. The fact that the vessel could be pressurised for the next test is proof that the previous test did not compromise the vessel integrity. The highest initial vessel pressure where no failure was observed is called the safe explosion pressure (SEP).

In total, 21 experiments were performed. where the conditions were gradually worsened until point of rupture. Each test was initiated at ambient temperature – approximately 20°C. The measured maximum pressure peaks were at least 7.3 times the vessel's design pressure and peaks up to 90 times the design pressure were observed. Because the duration of these high-pressure peaks is extremely short (in the order of several microseconds), the vessels can withstand these detonation events without brittle failure. When the test pressure was less than 52% of the design pressure of the vessel (absolute pressures), the vessel passed the test. Only when the test pressures exceeded 52% of the vessel's design pressure, did the detonation cause not only permanent deformation but also the ejection of the full content of the vessel.

Explosion experiments with the electrolyser stack showed it has a better explosion shock resistance than the separator vessels. Based on these results, it was decided to operate at 65% of the safe explosion pressure of the vessels, with the pressure safety valves set at 75% of the safe explosion pressure. The Plug ELX systems are equipped with SIL safeguards to ensure operation within a safe window.

Conclusion

All electrolysis processes are inherently challenged by the fact that pure oxygen and hydrogen are co-produced in the process systems and typically only separated by a thin partition. The safety aspects of a potential rupture of this partition have to be considered. This paper hence also explains how a dedicated effort resulted in achieving extraordinary safety features without adding substantially to the cost of the electrolysis.

It is believed that the standards to which Plug Power has designed their system could leverage further development of good industrial practice within the space of green ammonia technology. They have certainly proved their worth in the dozens of plants Plug Power have delivered electrolysis equipment to until now. ■

Fig. 6: **The Allagash stack utilised in Plug Power products**

Source: Plug Power

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New boilers enhance performance and reliability

A European ammonia plant, has successfully restarted following a revamp of the process gas cooling section, executed by Casale. Casale replaced the outdated boilers located downstream of the secondary reformer with three new double-tube type boilers supplied by Arvos. The new boilers were installed in the same location as the previous ones, minimising investment costs and plant modifications. The more robust and reliable design of the Casale-Arvos boilers has resulted in enhanced overall performance and reliability of the ammonia plant.

M. M. Carlucci (Casale), F. R. Fernandez Latorre (GrupoFertiberia) H. Ormann (Arvos GmbH | Schmidtsche Schack)

In Kellogg-designed ammonia plants, the traditional arrangement includes two parallel process gas coolers (PGC), a bayonet water tube type and a vertical fire tube type. Process gas enters these units at temperatures exceeding 1,000°C, and boiler feed water (BFW) is used to cool the gas. However, several inherent design flaws in these PGCs lead to reliability issues:

Primary PGCs (bayonet water tube design)

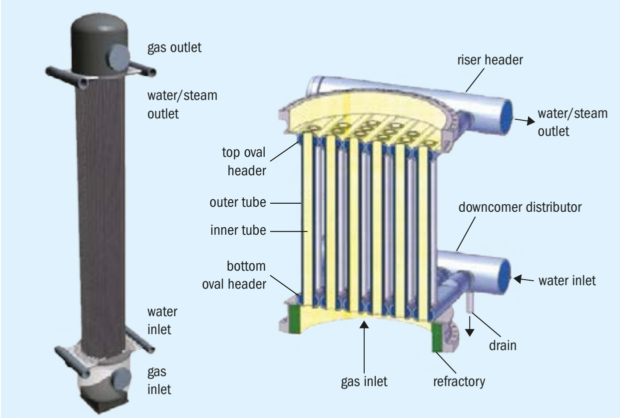
- Sludge deposition: BFW deposits accumulate in the bayonet end cap, causing blockages and local overheating.
- Tube vibration: Flow-induced vibrations from gas movement increase the risk of tube damage.
- Frequent failures: Tube bundle replacements are common, requiring spare parts and high maintenance costs.

Secondary PGCs (fire tube design)

- Lower tube sheet issues: Sludge deposition reduces cooling and leads to overheating and welding failures.
- Steam blanketing: Inadequate riser nozzle placement leads to steam bubbles accumulating, reducing cooling efficiency and causing welding failures.

These reliability challenges necessitated frequent shutdowns, higher capital costs for spare parts, and increased maintenance.

Fig. 1: **Sketch of double pipe system**



Source: Casale

The Schmidt'sche® Double Tube System

The Schmidt'sche® double tube system, established for over 50 years in ethylene and gasification plants, has been adapted for ammonia applications (see Fig. 1). Its key features include:

Design principles:

- Combines fire and water tube designs.
- Utilises coaxial double tubes welded to oval headers, ensuring robust construction and flexibility to accommodate thermal stresses.
- Natural circulation of BFW prevents sludge deposition and steam blanketing.

Operational advantages:

- Enhanced cooling: water flows between the inner and outer tubes, converting into steam and optimising heat exchange.

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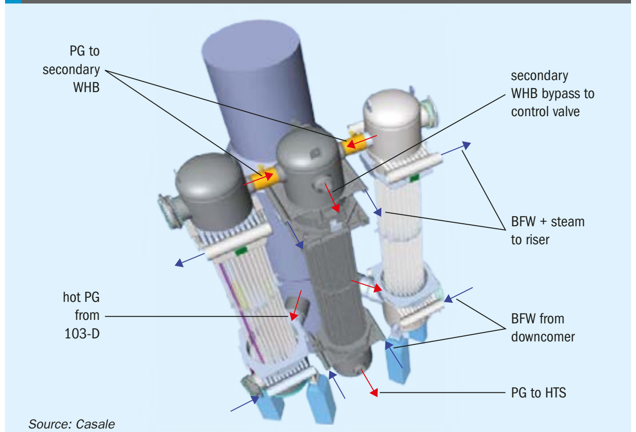
Fig. 2: **Streamlined flow path**



Source: Casale

- No flow-induced vibrations due to defined gas and water flow paths.
- Lower wall and material temperatures reduce thermal stresses, increasing reliability and lifespan.

Maintenance benefits:

- Full penetration, crevice-free welds prevent corrosion and ensure durability.
- Modular construction allows for the replacement of individual tube elements, reducing downtime and costs.

Proven reliability in ethylene and gasification plants

The Schmidt'sche® double tube system has proven its robustness in severe environments. The design has demonstrated success in over 7,000 units in ethylene and gasification industries, operating in harsh conditions with high temperatures, pressures, and corrosive environments.

Ethylene plants

- Operates cyclically with process gas temperatures of ~900°C and pressures up to 10 bar.
- Water-steam systems handle pressures of 100-120 bar.

Gasification plants

- Handles gas at up to 900°C and 27-50 bar with water-steam pressures of 50-115 bar.
- Successfully operates under high fouling, metal dusting, and hydrogen attack conditions.

Adaptation for ammonia plants

- The conditions in ammonia plants are less severe, making the design highly reliable.
- The double tube system's experience in harsher environments ensures confidence in ammonia applications.

Fertiberia Palos case study

The transition of the Schmidt'sche® double tube system into ammonia plants is a story of innovation meeting necessity. Traditional process gas coolers in ammonia facilities, particularly those in older Kellogg-designed plants, have long been a source of problems for plant operators. The opportunity to upgrade these systems with proven technology from the ethylene and gasification industries offered a promising solution.

The first ammonia plant to benefit from this breakthrough is a typical MW Kellogg plant located in Palos (Spain), with a production capacity of 1,175 t/d. This facility, built decades ago, relied on the older vertical PGC designs downstream of the secondary reformer. Like many plants of its era, it faced ongoing reliability issues with the bayonet water tube and fire tube systems. When Casale and Schmidtsche Schack joined forces, they took a comprehensive approach to address these challenges.

Design and engineering

Schmidtsche Schack supplied the new double tube PGCs and redesigned risers and downcomers.

Casale performed the detail engineering, including piping, civil, and instrumentation modifications and was responsible for the suitability assessment for existing plant (structures, foundations etc.).

A laser scan of the existing plant ensured precise integration.

One of the most pressing considerations was space. The area around the secondary reformer is notoriously cramped in most Kellogg plants, making it challenging to introduce new boilers without substantial modifications. The team tackled this issue head-on by designing the replacement PGCs to fit onto the existing positions of the outdated units. This clever adaptation not only saved on capital costs but also preserved the plant's thermal efficiency by avoiding the need for long transfer lines that could lead to heat losses.

The retrofit involved installing three new double tube PGCs, carefully tailored to the plant's requirements. The first two units (1101-CA and CB) were placed on newly constructed plinths, while the third unit (1102-C) was supported by the existing steel structure of the secondary reformer. This hybrid approach minimised construction time and costs while maintaining the integrity of the overall setup.

The installation also introduced several modern features. Unlike the original design, which included an external water jacket prone to hidden cracks and maintenance issues, the new 1101-CA and CB units were designed only with lined refractory in the hot channels. This improvement made it easier to detect refractory failures through sensitive paint systems, ensuring early intervention and reducing the risk of extensive damage. To connect the new boilers seamlessly to the existing system, a transition piece was added downstream of the secondary reformer outlet.

The hot gas from the secondary reformer now follows a streamlined flow path (Fig. 2). It enters the hot channels of the 1101-CA and CB boiler units, where it is cooled as it rises, before being directed into the top channel of 1102-C for further cooling as it descends. A bypass line was incorporated into the design of 1102-C to provide greater flexibility in controlling the downstream high-temperature shift (HTS) inlet temperature, which plays a crucial role in optimising reactor management throughout the life of the catalyst.

Fig. 3: Item 1101-C positioned vertically.

Fig. 4: Lifting 1101-C into place.

Fig. 5: Placing 1101-C onto foundation.

Fig. 6: Nozzle alignment.

Fig. 7: Reinforcing frame dismantling.

Fig. 8: Lifting 1102-C.

Fig. 9: 1102-C on temporary support.

Fig. 10: 1102-C hanging on spring supports.

Fig. 11: Prefabricated spools.

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Fig. 12: Insulation in progress.

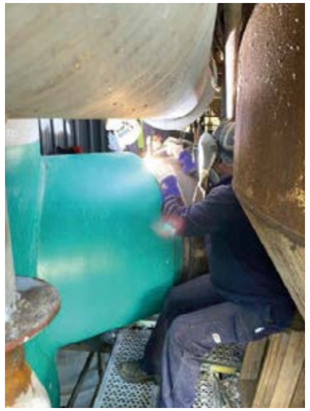

Fig. 13: Welding the transfer line spool.

The installation plan

The installation of the new boiler was carried out during an extended turnaround in late spring 2024, which also included other activities, such as the replacement of the refractory lining inside the secondary reformer. Fertiberia was responsible for dismantling old boilers, installation of the new ones and subsequent commissioning and start-up.

In the absence of other activities, the WHB replacement could be completed in less than four weeks, with around-the-clock work facilitated by effective project planning and monitoring.

The installation sequence involves lifting and positioning 1101-CA/CB vertically (Fig. 3). They are initially supported at the base with wooden logs and secured by suspending them from the crane. Once this is done, the reinforcing frame is dismantled, and the exchanger is lifted, inserted into the plant structure, and placed on its pillar foundation (Figs 4-6).

The installation of item 1102-C was carried out as follows: first, the spring supports were hung from the beams of the steel structure, and a temporary steel support was constructed on the ground. Next, item 1102-C was lifted and positioned vertically, placed on the ground on its skirt, and secured while hanging from the crane. Subsequently, its reinforcing frame was dismantled. Following this, item 1102-C was lifted again, inserted into the plant structure, and placed on the temporary steel support with its skirt, while remaining secured by the crane. The spring hangers were then connected to the exchanger lugs, and their lengths were adjusted to achieve the correct elevation. Finally, the lower temporary support was removed (Figs 7-10).

The spools were prefabricated prior to installation in accordance with the applicable isometric drawings. They were then lifted, fitted, welded, and subjected to NDT testing (Figs 11-13). Spring hooks and supports were installed progressively as the work advanced. Insulation for both the equipment and the piping was carried out concurrently with the piping installation.

Once the welding of the transfer line joints was completed, PWHT and NDT were performed.

Pre-comissioning - dry-out & boil-out

Prior to proceeding with the dry-out and boiling-out processes, the entire circuit was filled with water, and the spring hangers were unlocked.

The dry-out and boiling-out processes were performed simultaneously to allow for the drying of the secondary reformer at the same time. The boiling-out process lasted a total of 74 hours, after which the chemical solution was drained, and the circuit was rinsed twice with clean water.

Fertiberia requested an inspection of the steam drum, necessitating 6-7 additional flushes to cool it down. Once the steam drum was sufficiently cool, it was opened for inspection. The internal surfaces were found to be clean, with no debris, scales, or other residues. The steam drum was then closed and prepared for startup.

Next, another procedure, recommended by Solarca (the chemical cleaning subcontractor), was carried out. This procedure, called magnetite accelerated formation, involved re-boiling the circuit at approximately 40 bar and 250°C for a specific period.

Finally, the dry-out process continued until the operating temperature of 1,050°C was reached, at which point the plant was started directly.

Start-up

After completing boil-out process, Fertiberia prepared the waste heat boilers for operation and started the ammonia plant up. In parallel with the startup activities, Fertiberia performed the steam blowing of high-pressure steam line to syngas compressor turbine.

After three days, on July 29th 2024, the plant started to produce ammonia at 85% load, without any issue. Performance of the boilers is very satisfactory, with a final temperature downstream of 1102-C of 345°C and a bypass 27% open.

Futureproofing the plant

One of the most exciting aspects of this retrofit is its preparation for future technological advancements. The new PGCs were designed to handle a potential stream of green hydrogen, enabling the plant to be hybridised by up to 40%. This forward-thinking feature reflects the growing trend toward decarbonisation in the ammonia industry, where green hydrogen is increasingly being viewed as the key to reducing greenhouse gas emissions. As green hydrogen becomes more accessible and cost-effective, the upgraded plant will be able to integrate it seamlessly, supporting a cleaner and more sustainable ammonia production process.

Conclusion

The replacement of traditional vertical PGCs with the Schmidt'sche® double tube system represents a major advancement in ammonia plant reliability and efficiency. By leveraging proven technology from ethylene and gasification industries, Casale and SCHMIDTSCHE SCHACK have introduced a robust solution tailored to ammonia applications. The first installation in an ammonia plant marks a significant milestone, with broader implications for modernising aging industrial infrastructure. ■

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Revolutionising reformer tubes

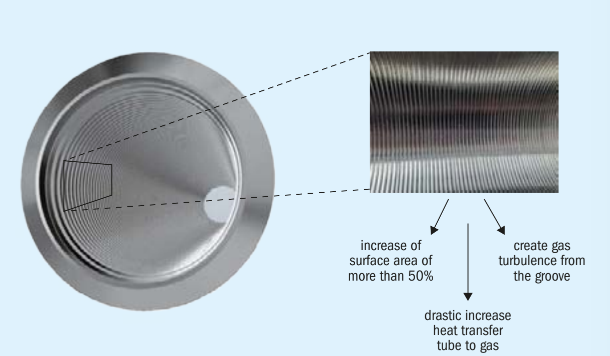
As the global demand for hydrogen, syngas, and ammonia production grows, efficiency improvements in steam reformer furnaces have become a priority. To address these challenges, Paralloy has developed Omega technology, an advanced reformer tube design that enhances heat transfer, gas turbulence, and process efficiency. **Dr Dominique Flahaut** of Paralloy explores the real-world implications of Omega reformer tubes.

Steam reforming is the dominant industrial process for hydrogen and syngas production, where hydrocarbons (typically methane) react with steam over a catalyst to produce hydrogen (H_2). This reaction occurs inside high-temperature reformer tubes, where efficient heat transfer is critical to maintaining optimal reaction kinetics.

However, traditional reformer tubes suffer from:

- **Inefficient heat transfer**: The heat transfer within the reformer tube is related to the tube surface area, which is smooth, limiting the overall heat transfer from the tube to the gas. As a result, the heat transferred to sustain the reaction is not optimal. The energy efficiency is not maximised.
- **High fuel consumption**: Due to the limited heat transfer efficiency, more fuel is required to maintain the necessary temperatures for the reforming process. This leads to substantial fuel consumption, keeping operation costly.
- **Increased carbon footprint**: The high energy requirements and reliance on fossil fuels contribute to a larger carbon footprint. Excessive CO_2 emissions from the process contribute to environmental concerns, especially as industries strive for greener alternatives.
- **Catalyst performance limitations**: The effectiveness of catalysts in the reforming process is influenced by the gas temperature, which in turn relies on the efficiency of heat transfer. While recent advancements in catalyst development have focused on enhancing performance within the catalyst itself, a significant limitation remains in the heat transfer from the tube to the gas. Addressing this issue is crucial for unlocking the full potential of catalysts

Fig.1: **Omega internal reformer tube surface**



Source: Paralloy

To address these challenges, Paralloy has applied an innovative approach to tube design that enhances heat transfer, gas turbulence, and process efficiency (see Fig. 1).

Omega technology

Internal surface profiling for superior heat transfer

The Omega reformer tube features a profiled internal surface, increasing the internal surface area by more than 50%. This expanded surface area allows for:

- **Greater heat absorption**: By enhancing the catalyst's ability to absorb heat with Omega, the thermal efficiency can be significantly improved. This means that the catalyst can operate more effectively at elevated temperatures, leading to faster reaction rates and higher yields in the reforming process. Improved heat absorption also contributes to better energy utilisation, making the overall system more efficient.
- **More effective heat transfer**: Optimising the heat transfer from the tube wall to the process gas is crucial for maximising the reforming performance. By employing Omega innovative design, we can enhance thermal conductivity and ensure that heat is efficiently transferred to the gas. This improvement not

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only reduces the amount of fuel needed to maintain optimal temperatures but also lowers operational costs and minimises environmental impact.

Gas turbulence for improved reaction kinetics

Traditional smooth-walled tubes create a more laminar gas flow, limiting contact between gas molecules and tube walls. Omega tubes introduce internal grooves, which generate gas turbulence, leading to:

- **Better heat penetration toward the tube centre**: By improving the heat penetration capabilities within the tube with Omega, temperature gradients can be significantly reduced. This ensures that heat is distributed more evenly throughout the entire cross-section of the tube, preventing hot spots and cold zones that can negatively impact the reforming process and tube reliability. As a result, the overall thermal stability of the system is enhanced, leading to more consistent performance, and longer tube life.
- **More uniform catalyst bed temperature**: Achieving a more uniform temperature across the catalyst bed is crucial for enhancing reaction efficiency. When the temperature is consistent, the catalyst can operate optimally, facilitating more effective chemical reactions. This uniformity helps to maximise the conversion rates of process gas and ensures that the catalyst is utilised to its full potential, ultimately improving the overall yield of hydrogen and syngas
- **Faster gas heating**: By optimising the heat transfer mechanisms, faster heating of the process gas can be achieved. This acceleration in heating not only shortens the time required to reach optimal reaction temperatures but also boosts reaction rates. As a result, the production of hydrogen is increased, making the process more efficient and economically viable. Faster gas heating contributes to a more dynamic and responsive system, allowing for better control over the reforming process.

Laboratory reforming test results

Laboratory tests using 300 mm-length reformer tubes consistently demonstrate a minimum of 10% improvement (double the initial expectations) in heat transfer coefficient with Omega tubes compare to usual reformer tubes, for all catalyst shapes and sizes. This higher heat transfer efficiency confirms the potential to increase process gas temperatures, to improve reformer performance and catalyst utilisation (see Fig. 2).

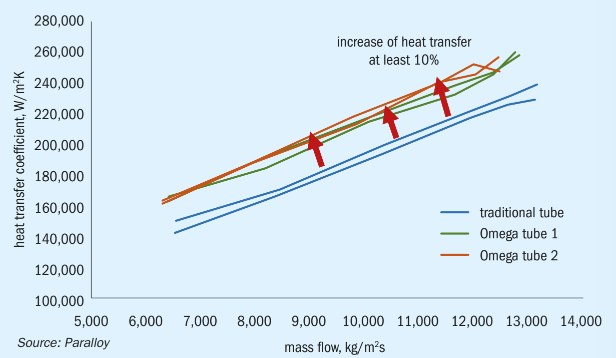
Performance benefits of Omega technology

Increased reformer tube efficiency

The improved heat transfer properties of Omega tubes lead to several key operational benefits:

- **Lower tube wall temperatures**: The improved heat transfer capabilities result in reduced temperatures at the tube walls. This not only extends the lifespan of the tubes by minimising thermal stress and wear but also leads to lower maintenance costs. With less frequent repairs and replacements needed, overall operational efficiency is improved.
- **Higher process gas flow rates**: With better heat transfer, the system can accommodate higher flow rates of process gas. This increase in flow rates directly contributes to greater production of syngas and hydrogen, enhancing the overall output of the reforming process. The ability to process larger volumes efficiently can significantly boost productivity and profitability.
- **Increased compatibility with high performance catalysts**: The optimised heat transfer environment allows for better integration with high-performance catalysts. This compatibility leads to more efficient reforming reactions, as the catalysts can operate at their optimal conditions. The result is improved reaction rates and higher yields of desired products, making the process more effective and economically advantageous.

Fig. 2: **Heat transfer coefficient increase with Omega**



Source: Paralloy

Economic benefits: Fuel savings and cost reduction

The enhanced heat transfer efficiency of Omega tubes allows reformer furnaces to operate at lower firing rates while maintaining the same level of hydrogen or syngas output. This results in direct fuel savings, leading to substantial cost reductions.

Case study: Fuel savings in a large-scale reforming operation

In this case study, the impact of improved heat transfer properties in a large-scale reforming operation, focusing on fuel savings achieved through enhanced efficiency is examined.

Fuel consumption reduction: The operation experienced a conservative estimate of a 2% reduction in fuel consumption. This seemingly modest improvement can lead to significant savings over time, particularly in large-scale operations where fuel costs are a major expense.

Annual fuel savings: The reduction in fuel consumption translates to an impressive savings of 128,000 per year. This substantial figure highlights the effectiveness of the implemented changes in optimising the reforming process.

Cost reduction: With the annual savings of 128,000 million Btu, the operation realised a natural gas cost reduction of $537,600, based on an assumed price of $4.2 per million Btu. This financial benefit underscores the economic advantages of improving heat transfer efficiency, demonstrating how operational enhancements can lead to significant cost savings.

In conclusion, this case study illustrates that even a small percentage reduction in fuel consumption can yield substantial savings in both energy usage and operational costs. The findings emphasise the importance Omega technologies that enhance heat transfer properties, ultimately leading to more efficient and cost-effective reforming operations.

Environmental impact: CO_2 emissions reduction

With lower fuel consumption, Omega tubes contribute to a significant reduction in CO_2 emissions, aligning with global decarbonisation efforts.

Case study: Reduction of CO_2 emission

In this case study, the significant environmental and economic benefits achieved through enhanced operational efficiencies in a reforming operation, focusing on the reduction of CO_2 emissions is explored.

Annual CO_2 emissions reduction: The operation successfully reduced its annual CO_2 emissions by 7,060 tonnes. This substantial decrease not only contributes to a lower carbon footprint but also aligns with global efforts to combat climate change and meet regulatory requirements.

Cost savings from CO_2 reduction: The reduction in CO_2 emissions translates to total cost savings of €706,000 per year, based on an assumed CO_2 price of €100 per ton. This financial benefit highlights the economic advantages of implementing strategies that lower emissions, demonstrating that environmental responsibility can also lead to significant cost reductions.

In conclusion, this case study illustrates the dual benefits of reducing CO_2 emissions in a large-scale reforming operation. The substantial decrease in emissions not only supports sustainability goals but also results in significant financial savings.

These environmental benefits make Omega tubes an ideal solution for companies pursuing sustainability and ESG (Environmental, Social, and Governance) goals.

Conclusion

The Omega technology by Paralloy represents a significant leap forward in reformer tube design, offering:

- at least 10% improved heat transfer coefficient;
- lower fuel consumption (-2%);
- reduced CO_2 emissions (-2%);
- longer reformer tube lifespan and improved catalyst efficiency;
- potential for new reactor designs, optimising industrial efficiency.

By addressing the key challenges in steam reforming, Omega technology by Paralloy provides a technical and economic advantage for industries looking to enhance performance while reducing environmental impact.

For hydrogen producers, ammonia plants, and syngas manufacturers, Omega reformer tubes set a new industry standard, ensuring a sustainable, cost-effective, and future-ready approach to high-temperature reforming. ■

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Low carbon hydrogen and its derivates

M.J. Cousins of Johnson Matthey and **K. Nölker** of thyssenkrupp Uhde discuss the integration of LCH™ technology and the uhde® ammonia process in providing low carbon ammonia at scale, efficiently, reliably and safely today.

Following Johnson Matthey's (JM) article on strategies and technological solutions for large-scale blue hydrogen production in *Nitrogen+Syngas No. 393*, in this article JM explores the use of its LCH technology in the production of blue ammonia.

Johnson Matthey's LCH technology with reforming flowsheet provides an efficient way to produce blue hydrogen commercially today. It consists of either an autothermal reformer (ATR) flowsheet, or an ATR coupled with a gas heated reformer (GHR) flowsheet. These schemes are illustrated in Fig. 1, alongside the traditional steam methane reforming (SMR) option.

LCH technology with ATR flowsheet

The ATR combines two processes that take place in a primary reformer:

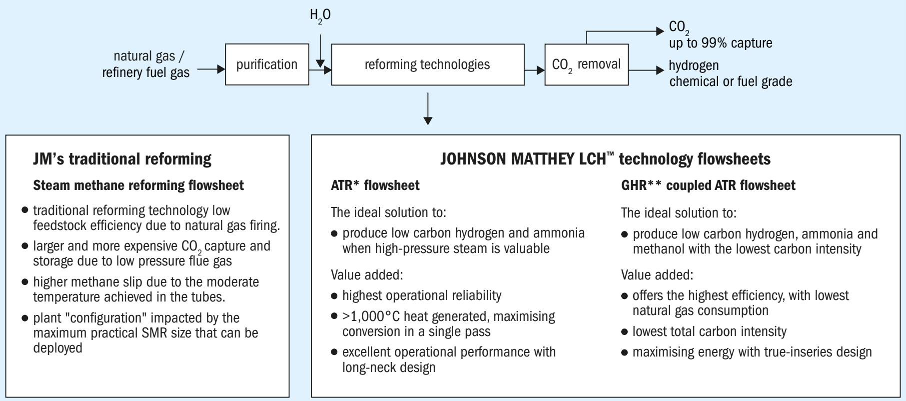
- heating of the process gas
- reforming of the feedstock.

The ATR carries out both these functions on the process side of the flowsheet, meaning there is no low-pressure atmospheric CO_2 release. It does this by introducing oxygen through a burner, which entrains the oxygen flow with the process gas. This happens in the area directly below the burner. Simultaneously the gas stream ignites due to the flammability of the gas mixture, and it is partially oxidised (burnt) creating heat, resulting in the formation of COx and H_2O. These processes take place in the neck of JM's ATR design, indicated by the flow paths in the ATR's neck shown in Fig. 2. This is not the case with all ATR designs. Some use more complex burner arrangements located at the base of the neck, meaning there is less separation between the combustion and catalytic reforming processes. This places stress on the burner and catalyst that JM's long neck design avoids.

The adiabatic ATR reactor is energy balanced, considering energy from combustion, and energy consumed by the endothermic reforming reaction and energy loss from the vessel. The net difference is the sensible heat energy. The process gas exits the ATR and then passes through the reformed gas boiler where a portion of sensible heat can be used to raise steam. This energy balance is illustrated in Fig. 3.

Involuntary steam raising from the ATR is necessary for its operation, additionally it has a positive effect on the energy balance of the overall flow sheet, providing energy to drive machines. However, raising additional steam requires burning more feedstock in O_2. Where the sensible heat is too high, this will stress the ATR. The focus should be to optimise the operating conditions to allow for long stable operating cycles lasting at least four years.

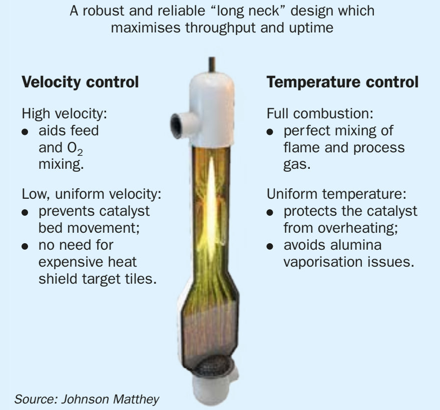
Fig. 1: **An overview of JM's traditional SMR and LCH technology flowsheets**



Source: Johnson Matthey

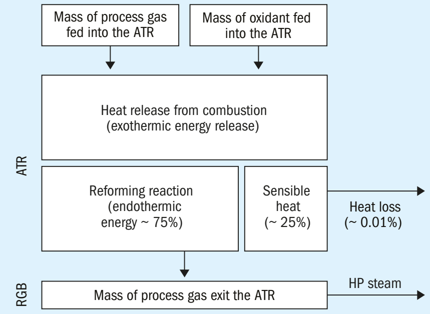
*ATR - Auto Thermal Reformer, **GHR - Gas Heated Reformer

Fig. 2: **Illustration of JM's single nozzle long-neck ATR design**



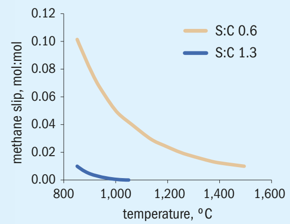
Source: Johnson Matthey

Fig. 3: **Energies within the ATR & RGB, where the ATR is water jacketed and operating at a local S:C of ca. 1.0**



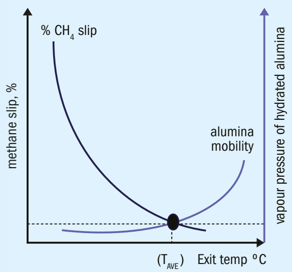
Source: Johnson Matthey

Fig. 4: **Plot of equilibrium methane slip at S:C 0.6 and 1.3 inlet the ATR**



Source: Johnson Matthey

Fig. 5: **Plot of methane slip reducing and increasing rate of alumina volatilisation with increasing temperature**



Source: Johnson Matthey

The hot, well mixed gas stream now passes through a catalyst bed. It is through this bed the catalytic reforming reactions take place, producing hydrogen by reacting process gas with steam as shown by the general reaction equations below. While the CO also reacts with H_2O in the process, to produce H_2, and CO_2 via the water gas shift process.

General steam methane reforming reaction:

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \quad (1)$$

Water gas shift (WGS) reaction:

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \quad (2)$$

Due to the typical temperatures exit the ATR of 950°C to 1050°C, the equilibrium position and kinetics favour high methane conversion. Therefore, when using a robust and active catalyst in a process that is designed to enable it, long lives and high effectiveness can be gained from relatively small volumes of catalyst.

The ATR operation should be considered in the context of the hydrogen (or ammonia) flowsheet it is part of. In either case the target product contains no carbon. So, JM's choice of operating conditions; (i) temperature, effected by level of combustion, and (ii) the ratio of steam to carbon (S:C) should reflect this target.

(i) O_2 level defined by x in the equation below, sets a target achieved exit temperature.

Combustion reaction:

$$CH_4 + xO_2 + 2(1-x)H_2O \rightleftharpoons CO_2 + (4-2x)H_2 \quad (3)$$

(ii) Higher S:C drives the reforming reaction. A requirement when optimising this is to minimise the unconverted CH_4 in reaction 1. Noting the global steam addition can be adjusted downstream of the ATR, with steam addition into the WGS section to convert CO to CO_2 and produce further H_2, from water splitting. Allowing the S:C inlet the ATR to be adjusted independently.

For the same feed-to-oxygen ratio, at the same exit temperature, Fig. 4 compares the equilibrium CH_4 slip for a S:C of 0.6 and 1.3 inlet the ATR. The lower S:C affects the performance as follows

- increases the methane slip, which means the purge (tail gas) is more carbon rich;
- makes the operating conditions more aggressive within the ATR;
- reduces steam raising capability.

To minimise CH_4 a higher exit temperature provides a favourable equilibrium position with respect to reaction 1. However, Fig. 5 shows the risk of increasing the exit temperature to be alumina mobility. This is known to adversely impact performance

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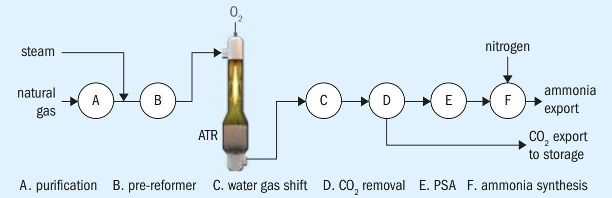
Fig. 6: **LCH technology with ATR flowsheet integrated with an ammonia loop to provide low carbon ammonia**



Source: Johnson Matthey

over a period of weeks and months, showing that excessively high temperatures instigate a process that negatively impacts the catalyst and lowers performance.

So, when optimising of the S:C at the ATR to make blue hydrogen or ammonia we should consider conditions that:

- minimises CH_4 slip, while not unduly stressing the ATR;
- provide long and efficient operating cycles between plant shutdowns.

In doing this the ATR operation will:

- minimise CH_4 (feed): product;
- minimise carbon intensity: product.

Where the hydrogen is further processed, the ATR flowsheet should be integrated, for example, with an ammonia synthesis loop in an analogous way to that we know today, that uses high grade steam exit the secondary reformer. The ATR flowsheet (Fig. 6) uses the involuntary steam raised from the reformed gas boiler(s), exit the ATR, to provide motive steam that powers the syngas and refrigeration compressors.

The LCH technology with ATR flowsheet provides a low level of methane slip exit the ATR and uses a Pressure Swing Adsorber (PSA) to remove any trace CH_4 and CO slip from the ATR and WGS shift respectively So, the hydrogen product has a low inert level.

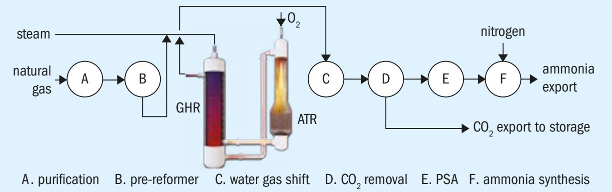
Some benefits of a LCH technology with ATR flowsheet are:

- ATRs are well proven in methanol production, demonstrating high reliability;
- it keeps almost all CO_2 at process conditions to enable easy capture for storage;
- as well as providing low carbon hydrogen, it also raises low carbon steam;
- its deployment uses a mix of steam and electrical power, analogous to current processes;
- the high purity gases supplied to the loop mean it operates for longer, with no purge;
- ready to be deployed today enabling production of hydrogen or ammonia with carbon capture rates of over 99%.

LCH technology with GHR/ATR flowsheet

Having just described an LCH technology using ATR that provides involuntary steam raising, we now review a flowsheet (Fig. 7) that can be integrated to provide zero steam export from the hydrogen production process. This enables the increased use of external renewable electrical power. This can further lower the carbon intensity of the product, and/or lower the cost of the production as less natural gas is needed per unit of ammonia production.

Fig. 7: **LCH technology with ATR flowsheet integrated to provide low carbon ammonia**



Source: Johnson Matthey

This configuration uses the heat exit the ATR to directly drive more reforming in a gas heated reformer (GHR), where the GHR replaces the reformed gas boiler in the ATR flow sheet, using the high-grade heat on the shell side of the GHR, to drive approximately 30% of the total reforming reaction, on the tube side, before the gas enters the ATR. This JM technology is recognised for leading the way in making best use of the available sensible heat.

The ATR then completes the remaining 70% of the reforming reaction, through the processes already described. In this case the size of the ATR, for the same hydrogen production, can be smaller. It follows that the air separation unit (ASU) can also be smaller, as less oxygen is required. This has two effects:

- it lowers operational costs, as less power is needed for the ASU;
- it is capex neutral, as while the GHR adds a unit-operation, the reformed gas boiler is removed and the ASU is smaller, and so lower in cost.

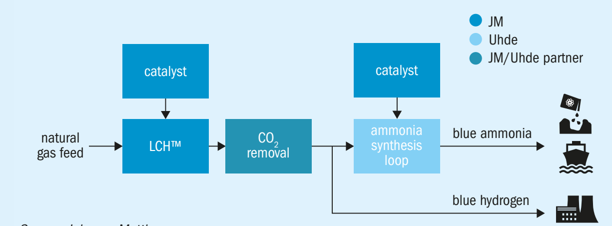
Some benefits of an GHR/ATR flowsheet are:

- The natural gas requirement per unit of hydrogen is reduced by >10% as no gas is used to raise steam.
- It follows the CO_2 production is also reduced proportionally by the same amount.
- If an operator is aware there will be renewable energy in the future, it allows them to access the benefit after the plant is commissioned without modification.
- The benefits from the high purity gases supplied to the ammonia loop are still provided. These advantages are fundamental traits of LCH technology flowsheets.

Integration of LCH technology with uhde® ammonia process

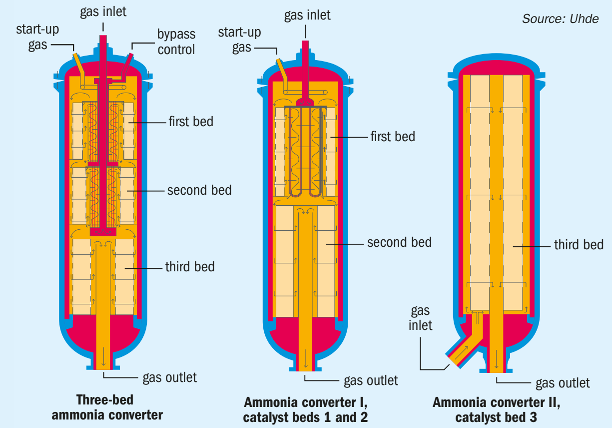
To develop the low carbon hydrogen market, the development of the infrastructure to move the H_2 from the place it is produced to the consumer is crucial. Where possible these places being in the same location has clear benefits. Places of production will tend to be ones with (i) availability of cost competitive gas and (ii) the geology and infrastructure that allow CO_2 to be injected underground for storage. Where these are not at the place of use, the infrastructure to move H_2 will be needed. For shorter distances pipe networks will be created. For longer distances ammonia is an ideal energy vector for the movement of H_2.

Fig. 8: **JM and Uhde partnership to provide the leading blue ammonia technology**



Source: Johnson Matthey

Fig. 9: **The Uhde ammonia synthesis design incorporates three radial-type catalyst beds arranged in either one or two ammonia converters**



Source: Uhde

Fig. 10: **Some examples where LCH technology has been selected**

HyNet, Vertex & EET Fuel Stanlow, UK	**LCH** (GHR+ATR) BEP complete, FEED complete Start up est. 2026	**350 MW** for refinery and local industry users
Confidential North America	**LCH** (GHR+ATR) BEP complete, FEED in progress Start up est. 2029	**1.4 GW** for refinery and local industry users
H2H Saltend, Equinor & Linde Saltend, UK	**LCH** (GHR+ATR) BEP in progress, FEED in progress Start up est. 2028	**600 MW** for power generation and local industry
H2NorthEast, Kellas Midstream Teesside, UK	**LCH** (GHR+ATR) BEP in progress, FEED in progress Start up est. 2029	**355 MW** for local industry users
H2Teesside, bp Teesside, UK	**LCH** (GHR+ATR) BEP in progress, FEED in progress Start up est. 2028	**700 MW** for refinery and local industry users
Confidential Europe	**LCH** (ATR) BEP in progress, FEED in progress Start up est. 2028	**1.2 GW** for industrial decarbonisation

Source: Johnson Matthey

JM and Uhde announced their collaboration in May 2024 to integrate the LCH technology with uhde® ammonia process. Together this partnership offers world leading blue ammonia technology (Fig.8). This technology provides a competitive edge through the use of the referenced flow sheet to provide rapid pay back through world scale plants, designed for exceptional efficiency, reliability, and performance to protect investment and drive down costs.

The Uhde loop design uses the high purity H_2 and N_2 provided from the upstream LCH technology and ASU in a dry low inert loop to operate without a continuous purge. This results in a more efficient process utilising the same equipment, which is already demonstrated to provide a capacity of over 3,500 t/d. Uhde provide industrially proven 2-bed and 3-bed converter designs (Fig. 9) that provide:

- high conversion rates through use of KATALCO™ catalyst with high surface area, whilst keeping the reactor volume small;
- maximum utilisation of reaction heat for the generation of high-pressure steam that is fully integrated with the upstream LCH technology;
- low-pressure drop, which calls for the use of small grain-size catalyst in Uhde's radial-flow design of converter.

Uhde has over 130 reference plants. The higher capacities are typically achieved with dual pressure loop designs that have proven capacities of 3,670 t/d with in total more than accumulated 50 years operational experience. The same concept has allowed designs of over 5,000 t/d to be offered.

References for LCH technology

The LCH technology is a combination of mature, well proven unit operations which are already utilised in other JM technologies.

Its design offers project developers and operators industrially proven operating units, effectively integrated to enable production of low carbon hydrogen and ammonia at a large scale. Fig 10 shows some examples of the projects that have selected LCH technology to meet their needs for low carbon hydrogen production. ■

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Challenges of a green ammonia economy

While green hydrogen and green ammonia promise to be important clean energy carriers in future, there are significant challenges to be overcome not only in production storage and transport, but also financially realising the project. Innovate technology from thyssenkrupp Uhde, embodied in standardised, pre-integrated, modularised plant can deliver low cost of ownership and de-risks execution.

Bernd Keil, Christian Renk, Bernd Mielke, Karan Bagga (thyssenkrupp Uhde)

Green ammonia produced with renewable energy can be used to decarbonise the fertilizer industry, used as a carbon-free fuel or as a carrier for hydrogen. While green hydrogen and green ammonia promise to be a clean energy carrier, there are significant challenges to be overcome not only in production storage and transport, but also financially realising the project. This has resulted in slow market development to date.

Drivers of the slow market development

One driver for the slow market development are technology integration and execution risks. The financing institutes seek project bankability. For this the end-to-end performance must be proven, the costs and schedule must be manageable and safely estimated. This requires execution-ready solutions to lower the cost of capital for the project developer.

The second driver is the high cost of green ammonia production. If there are no governmental subsidies available, the levelised cost of green ammonia production is two to three times more expensive than the levelised cost of ammonia produced in a conventional ammonia plant which utilises natural gas as feedstock. The high production cost of green ammonia is caused by the price of renewable power. Assuming a specific power consumption of 10 MWh per ton green ammonia produced and a specific power price of 30 EUR/MWh, this alone leads to an expenditure for electricity of 300 EUR per ton of ammonia!

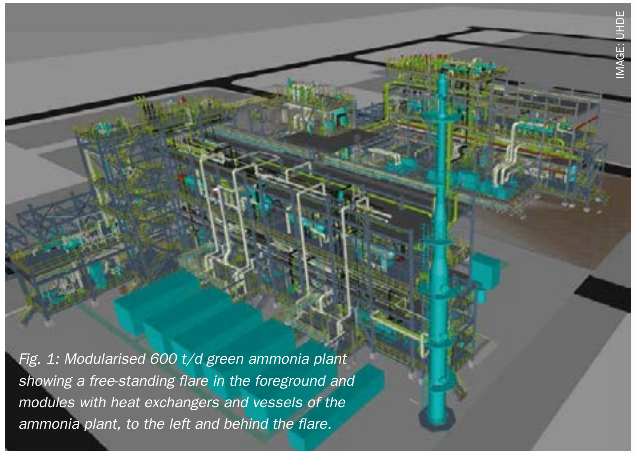

Fig. 1: Modularised 600 t/d green ammonia plant showing a free-standing flare in the foreground and modules with heat exchangers and vessels of the ammonia plant, to the left and behind the flare.

To make matters worse the renewable power is intermittent so that the average plant utilisation is not 100% of its design capacity. This leads to higher specific investment costs per ton ammonia which has a direct impact on the levelised cost of green ammonia production.

The third driver is the variability in definition of clean hydrogen. For example, in South Korea hydrogen with a carbon intensity of 4 kg CO_2/kg H_2 is considered as clean while in the EU hydrogen with a carbon intensity of only 3.38 kg CO_2/kg H_2 is considered as clean. While the US Inflation Reduction Act will give the best tax credits to hydrogen produced with the lowest emissions, its proposed clean hydrogen production standard lends credibility to hydrogen produced with only a 64% decrease (4 kg CO_2/kg H_2) compared to grey hydrogen made from fossil gas. It is the same for Canada's Clean Hydrogen Investment Tax Credit (CHITC) where government subsidies will be available for hydrogen produced with 4 kg CO_2/kg H_2. The UK Low Carbon Hydrogen Standard considers hydrogen with a carbon footprint of less than 2.4 kg CO_2/kg H_2 as clean. There are different definitions of which types of CO_2 emissions are to be considered when calculating carbon intensity. This could be a life cycle analysis (LCA) where not only the direct CO_2 emissions during production are taken into account but also the CO_2 emissions during fabrication of the plant itself and its parts. Another definition "well to gate" includes emissions derived from the production and transport of inputs used in the production process, e.g. generation of electricity with fossil fuels. Additionally, the CO_2 emissions arising from shipping the produced ammonia can contribute to the carbon intensity. Also, the time matching – the alignment of energy consumption for production of green ammonia with renewable energy production on an hourly (or even more granular) basis – is tied to subsidy schemes, e.g. Renewable Energy Directive III (RED III) of the European Commission. The third driver has an early influence on the technical concept, e.g. how fast must the electrolyser respond to changes in renewable power.

The fourth driver is the slow roll-out of policy seeding incentives. Policy support is limited to a few regions and trading chains, e.g. US (US National Clean Hydrogen Strategy and Roadmap, June 2023, Infrastructure Investment and Jobs Act, Inflation Reduction Act), EU (REPowerEU Hydrogen Policy, 2020, Hydrogen Accelerator plan, European Hydrogen Bank, 2023), China (China's Hydrogen Industry Development Plan, 2022), India (India's National Green Hydrogen Mission, 2023), Australia (Australia's National Hydrogen Strategy) and South Korea (First Basic Plan for the Implementation of the Hydrogen Economy, November 2021).

All four drivers for the slow market development have a strong impact on the feasibility of a green ammonia project and influence the investment decision of project developers.

Techno-economic concept development

There are different sources of renewable energy available. The renewable energy source which is most reliable and predictable is hydro power. Here the timescale for changes of available hydro power is in the range of months. The power profile of solar power is to some extent predictable but it hourly changes and during nighttime there is no energy at all. Wind power is less predictable and the timescale for changes of available wind power is in the range of hours.

Generally, three different concepts for an integrated power-to-ammonia plant are possible:

- **Grid connected**: The operator of the green ammonia plant obtains the required electricity exclusively from an existing power grid with a power purchase agreement or buys renewable energy at the spot market. This has the advantage that there is always power available. However, the power price can fluctuate depending on the season or time of day. Then the spot price for renewable power can trigger the operation of the plant for arbitrage. If the spot price is low, the hydrogen production and ammonia plant are operated at maximum capacity and the hydrogen inventory is filled up. If the spot price is high, the electrolysis and ammonia plant are operated at minimum turn-down-ratio and the hydrogen storage tank is emptied. Grid connection enables a steady or with a low frequency cyclic ammonia production.
- **Island mode with battery**: The green ammonia plant is connected to a dedicated wind or/and solar park, a battery provides power in case of unavailable renewable energy. The size of the battery is only sufficient to operate the plant at minimum turn-down ratio or in hot-standby-mode where no ammonia is produced, and the ammonia loop is kept at catalyst light-off temperature so that ammonia production can be resumed quickly when renewable energies are available again in sufficient quantities. The power input to the plant is highly fluctuating and as a result the production profile of hydrogen and ammonia has a high intermittency.
- **Hybrid – island mode with grid**: The green ammonia plant is connected to a dedicated wind or/and solar park and to an existing power grid. If renewable power is high, no power from the grid is fed into the ammonia plant. If there is little or no renewable power available, the operator obtains electrical power from the grid. The level of ammonia production can be determined by current electricity price. The combination of island mode and grid enables an ammonia production profile with moderate intermittency.

More considerations may be important during the concept development phase. Concurrent variables affect the project viability, e.g. a project is more feasible in a country where subsidies are high and a market for green ammonia exists than in a country where there is no strategy for subsidising ammonia produced with renewable energy and there is no buyer for green ammonia. Energy intermittency may be deliberate – lower power consumption with high electricity prices, or natural – caused by a wind calm or cloud field. Energy intermittency leads to uncertainty regarding the energy pattern and price of renewable energy. Energy intermittency also influences the size of energy storage. A renewable power profile which is less fluctuating requires less battery and hydrogen storage than a strong fluctuating power profile. The size, form and technical readiness level of the hydrogen storage contributes to the cost of the storage and thus directly to the capital expenditures of the plant. The offtake pattern may be constant (if there is another plant on site which uses ammonia as a feedstock) or diurnal (if the ammonia is transported by truck) or seasonal (to meet the demand of agriculture). The offtake pattern has a direct impact on the size of ammonia storage in the plant. Finally, the ammonia to be produced can be subject to carbon intensity restrictions, e.g. if the carbon intensity for hydrogen must be low in order to receive subsidies or the electrical power must contain a lower share of "grey" produced power as if there were no carbon restrictions.

During development of the techno-economic concept the following topics have to be solved:

- What does the optimal flowsheet look like and what is the optimal production capacity of the ammonia plant? Is hydrogen storage required?
- How to reduce the production cost? For example, production capacity of ammonia plant is adjusted to power price.
- How does the offtake pattern influence cost? For example, the size of the ammonia storage tank is influenced by the offtake pattern.
- What is the best geo-spatial site setting? For example, a good site setting would be a location where is a good mix of solar and wind energy is available and which is close to the off taker of ammonia.
- How to handle future expansion scenarios? For example, acquiring sufficient land from the outset for the installation of additional equipment.
- How to comply with the carbon intensity limits? For example, when concluding the power purchase agreement, determine how high the proportion of grey electricity may be.

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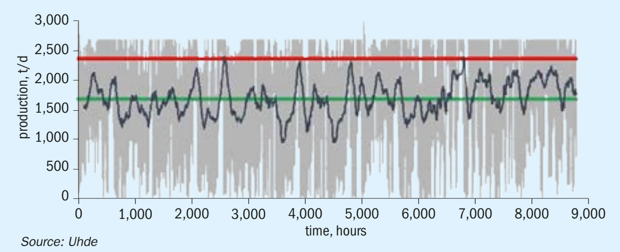
thyssenkrupp's RHAMFS® tool can help to solve these topics. It is founded on decades of technology and integration know-how. It is built for holistic, fast, and credible techno-economic analysis. It enables the concurrent modelling of multi-variable "what-if" scenarios. Based on the total cost of ownership it identifies the optimum end-to-end concepts. The profile of renewable power supply can be configured as a mix of solar, wind and hydro power. Using the time-dependent power profile as input, the hydrogen production and the ammonia production are dynamically modelled. Hereby the hydrogen storage is optimised with regard to size and storage pressure. Parameters, such as size of electrolysis or capacity of ammonia plant, are systematically varied to find the minimum of the specific ammonia production cost.

The following example illustrates the typical results of a RHAMFS® study for a green ammonia plant with a nominal design capacity of 2,400 t/d. Fig. 2 shows the profile of the renewable energy (light grey) and the actual ammonia production (dark grey) for a whole year. The nominal capacity is indicated by a red, constant line and the average ammonia is indicated by a green, constant line. The minimum turndown of the plant is 40% of nominal design capacity.

Fig. 3 shows the corresponding amount of hydrogen stored in the hydrogen storage vessels over one year. Hereby 100% correspondents to the maximum amount of hydrogen stored in case of 2,400 t/d plant with minimum turndown ratio of 40%.

If the availability of renewable power is the same, but the plant is operating between 100% and 20% turndown, then the maximum production capacity of the plant can be slightly smaller and the peak storage requirement is more than halved as shown in Fig. 4.

Fig. 2: Ammonia production (dark grey) obtained from given renewable energy profile (light grey) over one year; average ammonia production (green), nominal capacity (red) enabled by H_2 storage



Source: Uhde

Fig. 3: Hydrogen storage profile, minimum turndown of plant 40%

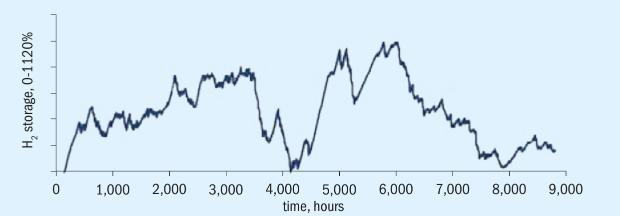


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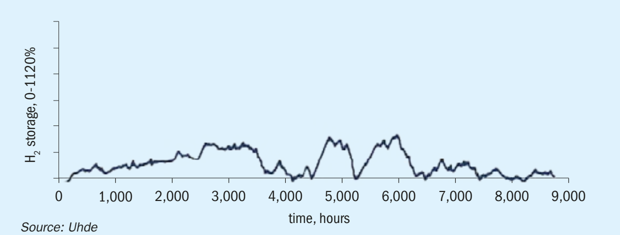
Fig. 4: Hydrogen storage profile, minimum turndown of plant 20%



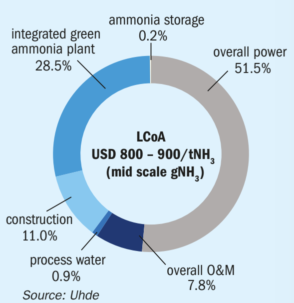
Source: Uhde

Technology and execution solution focus

The economics of green ammonia production drive thyssenkrupp Uhde's technology and execution solution focus.

Fig. 5 shows the cost drivers for the erection and operation of a green ammonia plant. The levelised cost of one ton of green ammonia (LCoA) produced is between 800 and 900 USD for a mid-scale green ammonia plant. Hereby the energy consumption accounts for 51.5% of the costs. The engineering and procurement of the integrated green ammonia plant accounts for 28.5% and the construction share is 11%. The proportion of operating and maintenance amounts to 7.8%. Minor contributors to the production cost of ammonia are process water with 0.9% and ammonia storage with 0.2%.

Fig. 5: Cost drivers to levelised production cost of green ammonia (LCoA)



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The main focus is the power costs. A location should therefore be found where the price of renewable energy is low. The available renewable power must be utilised to a high degree. This can be achieved by a high flexibility (a high turn-down-ratio) und efficiency of the plant. This means a high conversion of hydrogen to ammonia and a low specific energy consumption of the plant. Curtailment of renewable energy is a clear drawback which can be mitigated by battery and hydrogen storage.

Another significant cost driver are the capital expenditures of the integrated green ammonia plant. The capital expenditures of the ammonia plant itself, but not the electrolysis, obey the economy of scale. Therefore, it is advantageous to build large scale ammonia plants with a production capacity larger than 1,000 t/d. The hydrogen storage should be minimised with the help of RHAMFS® tool. An ammonia plant with a high degree of standardisation results in cost savings in engineering and procurement.

Construction cost on site may be high, especially in countries with high labour rates. There is also the risk that the schedule will not be met. These risks can be avoided if the plant is modularised and standardised to a high degree. The modules can be prefabricated in a module yard. The production conditions here are better than on the construction site so that quality can be improved, and schedules are easier to meet. Preferably, module production takes place in low-wage countries to reduce module fabrication costs. The finished modules can then be shipped to the construction site. The dimensions of the modules can also be selected so that they can be transported by truck.

Operation and maintenance costs also make a noticeable contribution to the LCoA. These can be addressed by a high degree of automation and digitalisation. Automation and digitalisation enhance the operability and safety of the plant.

Dynamic green ammonia process technology

The intermittency of renewable energy poses technical challenges for green ammonia synthesis, which are not fully addressed via the conventional plant design approach. For obtaining the same ammonia production out of a given profile of power over time, one is moving between two extreme cases:

- Oversizing the plant (electrolysis and ammonia plant) to time shift hydrogen availability: high underutilisation over long intervals: cost penalty.
- Sizing the plant for average availability of power: Large hydrogen buffer storage required: cost penalty.

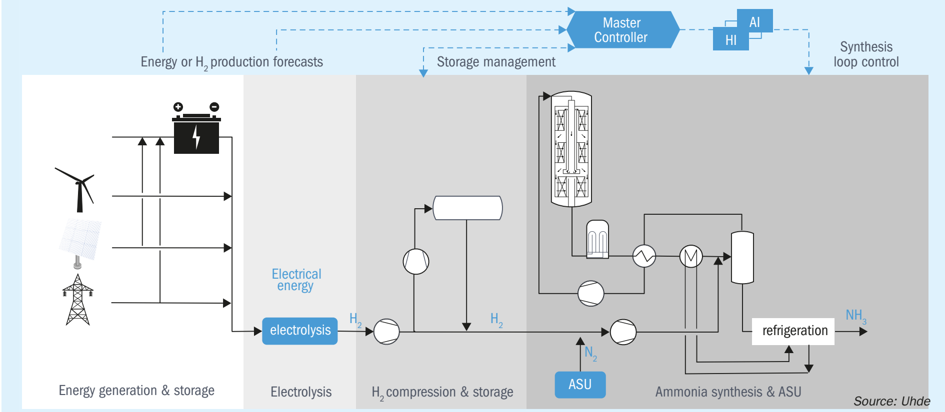
Fluctuating hydrogen production also poses a risk to the safe operation of the ammonia plant. When the operating parameters of the ammonia plant are not adopted to the varying feed flow rate of hydrogen there is the possibility of reaction snuff-out. In case of unstable reaction temperature, the catalyst can be damaged by thermal cycling. A varying synthesis pressure can lead to a loss of containment due to pressure cycling fatigue.

All these topics tend to increase the levelised cost of ammonia and have to be addressed by a dynamic green ammonia process technology during the plant design.

The key technology blocks are the power generation from renewables, the battery for energy in case of curtailment of renewable energy, the hydrogen production by electrolysis, the hydrogen storage in case of less or no hydrogen production and the ammonia plant itself. RHAMFS® is the system sizing tool which carries out an optimal sizing of these key technology blocks. It should be used early in the project development phase to optimise the concepts for the lowest LCoA.

The varying hydrogen feed flow from electrolysis requires an adjustment of the ammonia production capacity. This dynamic load management has been especially developed for green ammonia plants. Dynamic simulations, encompassing power supply to the ammonia production, have been carried out to develop new design features like the patented so-called "Master Controller". A principle sketch of the Master Controller is shown in Fig. 6.

Fig. 6: Master controller for dynamic green NH_3 load management



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Energy is provided by renewables such as wind or solar or from a power grid. The electrical energy is used by the electrolysis for the production of hydrogen. The hydrogen is compressed in a hydrogen compressor. The pre-compressed hydrogen is fed to the suction side of the synthesis compressor, but a portion can be diverted by the hydrogen storage compressor to the hydrogen storage vessel. The hydrogen is mixed with nitrogen from the air separation unit (ASU), the H_2/N_2 mixture is compressed by the synthesis gas compressor and fed as make-up gas into the synthesis loop. In the synthesis loop ammonia is formed in the converter with one or more radial catalyst beds and condensed by the refrigeration system.

The Master Controller needs as input the forecast of the generation of renewable energy or the amount of hydrogen produced by electrolysis. Although the renewable energy, which can be a mix of solar and wind, are fluctuating, a reliable four-hour forecast is possible. Even if the plant is connected to a power grid, this does not mean that hydrogen production is constant. The prize for electrical power can change and adjusting the production capacity for arbitrage may be advantageous. It may also be necessary to adjust production capacities in the event of load shedding. The Master Controller actively manages the hydrogen storage. In the event of high hydrogen production, it fills the hydrogen storage vessel; in the event of low hydrogen production, the Master Controller empties the hydrogen storage vessel. Knowing the current amount of hydrogen produced and the amount of hydrogen stored, the Master Controller determines the amount of hydrogen to be fed into the ammonia plant, thereby also determining the ammonia production. The Master Controller also controls the ammonia plant. It adjusts several operating parameters of the synthesis loop to the varying hydrogen feed flow rate. The Master Controller controls the inlet temperature to the ammonia converter and to the catalyst beds and maintains it above the set-off temperature of the catalyst so that the reaction is not snuffed out. This is achieved by reducing the steam production so that less heat is extracted from the synthesis loop and remains available for reheating the cold synthesis gas. An electric preheater is switched on at very low partial loads. The pressure is controlled by reducing or increasing the recycle flowrate through the ammonia converter via a spill-back valve in parallel to the antisurge-valve of the recycle compressor. The loop pressure is also controlled by a bypass around the cooling train of the synthesis loop. Hereby the ammonia concentration at the inlet of the converter is increased and less ammonia is produced per pass through the converter so that the amount of hydrogen and nitrogen converted to ammonia matches the flowrate of hydrogen and nitrogen that enters the loop. By this means the Master Controller ensures a safe operating envelope and a steady pressure in the synthesis loop. In accordance to ASME code Sec. VIII pressure cycles which are less than 15% of the design pressure do not have to be considered during the design of the pressure vessels in the synthesis loop. A dynamic simulation of the synthesis loop has been carried out to study the pressure fluctuations. The results are shown in Fig. 7.

Using a real power profile the plant capacity has been varied every four hours in the range from 10 to 100% (blue line) of plant capacity 675 t/d and the Master Controller controls the loop pressure (orange line). The set loop pressure is at 100%. The diagram shows that the loop pressure does not deviate more than 5% downwards and 6% upwards from the set loop pressure. This proves that the developed Master Controller concept can cope with fluctuating renewable energy.

The Master Controller is able to keep the temperatures and pressures in the synthesis loop within an acceptable range even if the hydrogen supply fluctuates. Thus, the catalyst is not damaged by thermal cycling and loss of containment due to pressure cycling fatigue does not occur. The ammonia production follows the profile of renewable energy.

Fig. 7: **Loop pressure (orange) at varying production capacity (blue) as a function of time management**

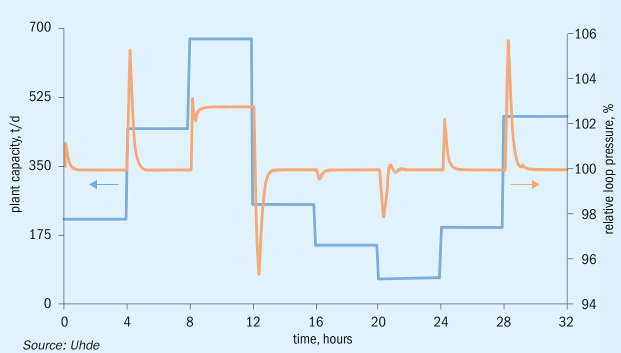
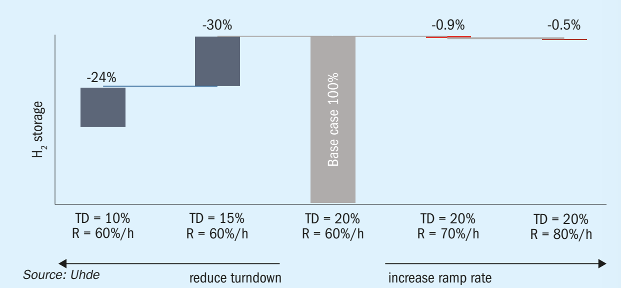


Fig. 8: **Impact of turndown rate and ramp rate on relative hydrogen storage**



A case study has been carried out to investigate the impact of turndown and ramp rates on cost for hydrogen storage. The example is a 6,500 t/d ammonia plant with a power input of 2.7 GW. It is operated in island mode with a battery as power back-up. The renewable energy production is a complementary mix of wind and photovoltaic for high stability of the power supply. The base case with which the other scenarios are compared is a plant with a possible turn-down-ratio of 20% of nominal plant capacity and a ramp rate of 60% per hour. The partial load ratio was varied at a constant ramp rate of 60%/h and, conversely, the ramp rate was varied at a constant partial load of 20%. The results for the necessary hydrogen storage size (100% is the hydrogen storage of the base case) are shown in Fig. 8.

The diagram shows that the hydrogen storage can be reduced by 54% by lowering the turndown ratio of the ammonia plant to 10%. Increasing the ramp rate from 60 %/h to 80 %/h has only a minor effect on the hydrogen storage size; the storage is only decreased by 1.4%. The impact of the ramp rate is muted due to the inherent stability in power input, this means that the plant can faster ramp down or up the production capacity than the renewable power decreases or increases. The capital expenditures for the whole plant can be reduced by 5-10%. In this example the levelised cost of ammonia production can be lowered by 3.8% if the turndown ratio is lowered from 20 to 10%.

Summary

The innovate technology from thyssenkrupp Uhde enables a low turndown of 10% and ramp rates of 2%/min. Therefore, the plant has a high flexibility to respond to changes in hydrogen supply so that the hydrogen storage can be minimal. The energy consumption is around 10 MWh/t NH_3 at a conversion of 98% hydrogen to ammonia product. This leads to a low total cost of ownership. The safe, reliable, and high operability of the plant enables an availability which is larger than 96%.

The green ammonia plant is standardised to a high degree based on pre-integrated standard concepts for core synthesis and critical support units. This can shorten the front end engineering design schedule by three months and the procurement is de-risked. Three different standard capacities, 300/600/1,200 t/d, have already been designed and capacities of 2,400/3,400 t/d are in progress.

The plant can be delivered in modules so that the construction cost can be de-risked. Construction management services can be provided to assure the construction schedule.

Different contract models can be offered by thyssenkrupp Uhde with flexibility for project needs (joint venture, grant requirements):

- standard license with proprietary equipment;
- extended license with integration engineering;
- engineering and procurement/engineering, procurement, and fabrication;
- engineering, procurement, fabrication, and site services (construction management).

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