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Good COP, bad COP?

> **"China's large scale commitment to investment in clean technologies has put it in the driving seat..."**

As I write this editorial, the 30th meeting of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change – aka COP-30 – is taking place in Brazil. It is fair to say that the attempt to try to restrict a large greenhouse gas-driven temperature rise across the planet has become one of the defining issues of our age, and particularly for an energy-intensive industry such as our own, responsible as it is for up to 2% of global carbon and carbon equivalent emissions. The move towards lower carbon intensity production of hydrogen, ammonia and methanol, via carbon dioxide capture and sequestration, gasification of biomass or waste, or electrolysis of water using renewable power, has come to dominate our news coverage, and in this issue we also carry articles on the state of play of both 'blue' and 'green' ammonia production, as well as technology for 'cracking' ammonia back to hydrogen and nitrogen for its potential use as a hydrogen carrier.

But even though global temperatures have already reached the aspirational limit of a 1.5 degree Celsius rise over pre-industrial averages, the attitudes towards the issue of climate change of the two largest emitters, and the two most powerful global economies – the United States and China – seem to have diverged sharply. Although it is frequently criticised for its reliance on coal-fired power generation, China has acknowledged the problem and committed itself to tackling it in a way that perhaps only a large, centrally-planned economy can do. Renewable power now makes up one third of China's electricity generation, and China represents 32% of all renewable power worldwide, and will represent 60% of incremental additions over the next few years. It is responsible for 70% of electric vehicle production, and EVs are now half of all new car registrations in China. Though these industries certainly have their problems, China's large scale commitment to investment in clean technologies has put it in the driving seat in these areas of the new economy. And the investment seems to be finally bearing fruit; a recent analysis by the Centre for Research on Energy and Clean Air (CREA) showed that Chinese CO_2 emissions appear to have peaked and in fact have been falling for the past 18 months.

Conversely, under the Trump administration, the United States has turned its back on many of its previous commitments and settled back to 'business as usual', cushioned as it is by its self sufficiency in oil and gas production, driven by US technological advancements in fracking and horizontal well drilling. The US has declined to attend COP-30 at an official level, and in the absence of the US, many have begun to ask if the COP summits are worthwhile. The difficulty remains that the costs of tackling climate change are in the here and now, while the benefits are more diffuse and come only in the future. However, as more energy enters the world's weather systems and storms become worse and more frequent, there are also steadily increasing costs in the present.

But perhaps the difference between the US and China is not quite as sharp as it appears. The US has, in fact, already made considerable steps to tackle emissions. US carbon emissions per capita have actually fallen by 25% since the 1990 baseline of the Kyoto agreement, primarily because of the replacement of coal-fired power generation by less carbon intensive natural gas, as well as a considerable uptake in renewables. Furthermore, via the clean energy subsidies offered in the 2022 Inflation Reduction Act, the US has become the leading country for investment in blue ammonia production, though as we report this issue, some of these projects now face the uncertainty of US policy changes. Some states, such as California, Oregon and Washington, continue to push a green agenda, and even Texas now draws 40% of its energy from renewable sources.

Multinational agreements are difficult and frustrating, and have become unfashionable in an era where national leaders have pushed more nationalistic policies and globalisation is in retreat. However, there is no other way of tackling a global problem than via a global agreement. ■

Richard Hands, Editor

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Price Trends

By the end of October the ammonia market was facing an acute shortage of spot tonnage, reflected in a $60/t jump in the Tampa price for November. The benchmark Tampa price increased for the sixth straight month to its highest since February 2023 as the global ammonia supply crunch deepened. The surge at Tampa was said to be driven by good demand in the US for direct application combined with a lack of supply. Contributing factors included Nutrien shutting down its nitrogen production in Trinidad, potentially removing around 85,000 tonnes/month from the market. So far, there is no suggestion that other producers in Trinidad will follow suit, and they may even benefit from a boost natural-gas supply given the Nutrien outage, although it is unclear whether the spare gas will be directed to ammonia as opposed to other demand sources.

An outage at Ma'aden's MPC unit in Saudi Arabia is expected to last at least until the end of the year, with lost production of at least 300,000 tonnes, and potentially more if the outage persists into the New Year. Ma'aden is not currently offering spot tonnes and is maintaining its estimate of a return to of MPC's ammonia production in December. Elsewhere, Mosaic's standalone ammonia plant at Faustina is still down for planned maintenance but on-track to return mid-November.

A large purchase by Yara of 60,000 tonnes from Sorfert in Algeria for November/December loading is considered by some to be spurred by the introduction of CBAM in Europe on 1 January next year; imports after that date will attract additional costs of around $50/t. The delivered duty paid price to northwest Europe was assessed higher again this week based on last week's Algerian sales at $625/t f.o.b. There remains little relief in sight for ammonia buyers before the end of the year, and concern is mounting over demand destruction at these levels.

The global urea market underwent a rebound in late October as bullish sentiment ahead of yet another anticipated India tender announcement saw prices on both sides of the Suez gain ground. India's Rashtriya Chemicals and Fertilizers (RCF) issued letters of intent for less than a quarter of the 2 million tonnes of urea it initially sought in its 15 October tender, so the market now expects India Potash Limited (IPL) to return with a fresh tender in 1H November in an attempt to fulfil Indian import requirements.

In the Middle East, values advanced again, with Oman's SIUCI understood to have sold December tonnes at $410/t f.o.b. Further east, markets in Southeast Asia were largely dormant with both buyers and sellers alike awaiting future price direction from India. In Indonesia, Pupuk Indonesia was reported to have awarded two PIM cargoes to Aditya Birla at $364/t f.o.b., almost $20/t down on last prilled sales out of the region.

European buyers have been active in securing tonnes for delivery prior to the Christmas off-season in 2H December and subsequent imposition of the European Union's Carbon Border Adjustment Mechanism. In Brazil, both bids and offers also gained momentum, with the latter now heard in the $420-430/t c.fr range. ■

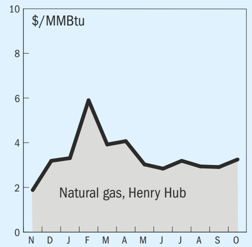
Table 1: Price indications

Cash equivalent	mid-Oct	mid-Aug	mid-Jun	Mid-Apr
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	550	445-450	350-355	395
f.o.b. Arab Gulf	400-420	320-340	280-300	270-305
c.fr N.W. Europe	620-630	560-570	410-465	470-520
Urea ($/t)				
f.o.b. bulk Black Sea	380-385	460-470	355-365	350-355
f.o.b. bulk Arab Gulf*	330-410	386-515	300-390	345-389
f.o.b. NOLA barge (metric tonnes)	375-377	420-445	343-355	300-315
f.o.b. bagged China	389-390	445-490	353-360	n.m.
DAP ($/t)				
f.o.b. bulk US Gulf	770	787-805	713-715	628-640
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	310-315	327-330	310-320	340-345

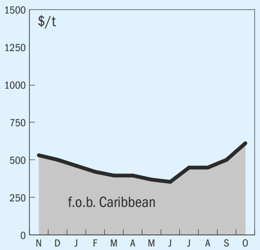
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

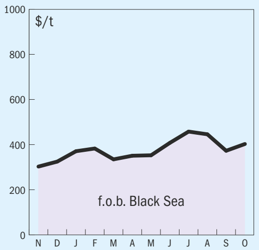
natural gas



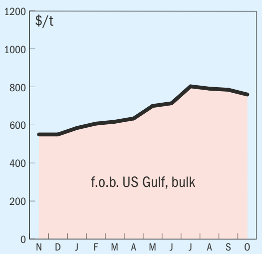
ammonia



urea

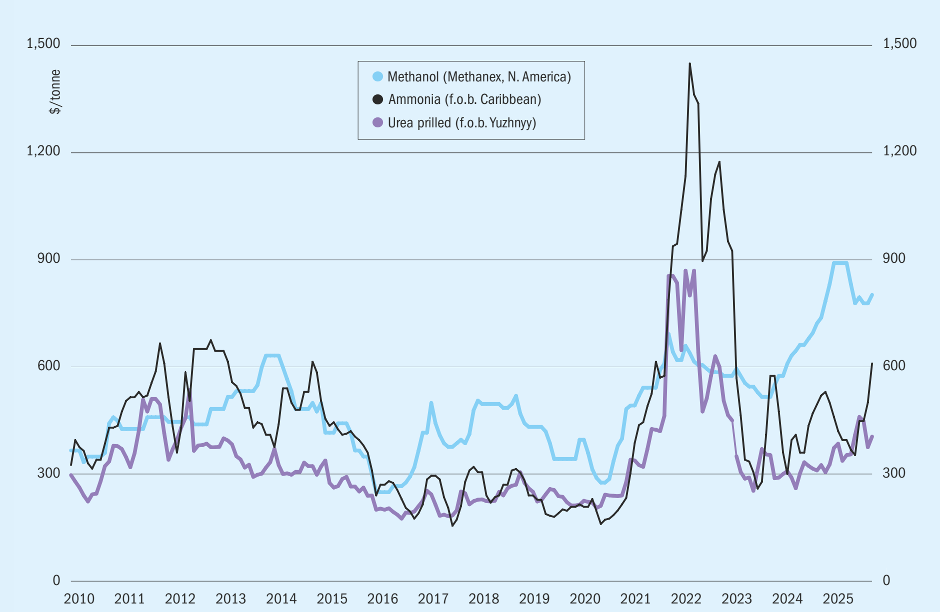


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: CRU

AMMONIA

- The market looks very tight through the end of the year, though some expect supply to improve in Q4. Prices are unlikely to ease in the coming weeks.
- Woodside's Beaumont New Ammonia Project is now 97% complete, and the producer expects production from the first train in late 2025. There is no information from Gulf Coast Ammonia on when to expect commercial production.
- There was an absence of fresh confirmed business into northwest Europe. Still, producers with ammonia capacity in the region are expected to be maximising output given the favourable economics at current spot natural-gas prices at the Dutch TTF.

UREA

- The issuing of a fresh purchase tender by India's IPL should sustain current upwards price momentum, though values could undergo a temporary reset should India delay its anticipated enquiry by a few weeks.
- The question of Chinese participation in any new Indian tender – or indeed Chinese exports in general - remains a point for contention, with availability under the country's current export quota understood to be dwindling. An upcoming convening of the China Nitrogen Fertilizer Association (CNFA) is not expected to coincide with the issuing of any new export quota for at least the remainder of 2025.
- Prices in Iran edged up after 140,000 tonnes of granular material was committed by producers in the $367-370/t f.o.b. range. Iranian supply will likely tighten towards the end of the year as seasonal shutdowns come into play.
- In the US, barge values at NOLA leapt to $395-398/st f.o.b. in keeping with global sentiment, though meaningful American demand is expected to emerge towards the end of the year.

METHANOL

- Methanol prices are currently varied by region, with the European posted contract price at €535/tonne, North America's non-discounted price at $802/tonne, and Asia Pacific at $360/tonne.
- Increased production capacity in North America, such as the Geismar 3 plant in the US, has put downward pressure on some regional prices, particularly in Europe. Conversely, production disruptions, as seen in the Middle East and Europe, have caused price volatility. US sanctions affecting Iranian methanol exports have created supply constraints for markets like India, contributing to price spikes.
- Demand from key sectors like automotive and construction typically slows down during summer and monsoon seasons, affecting prices in regions like Asia and the Middle East. Demand for biomethanol and e-methanol in the shipping industry is expected to increase due to regulations like FuelEU Maritime. ■

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Nitrogen Industry News

NETHERLANDS

Technology agreement for floating green ammonia production vessel

Swiss technology company ABB has signed a term sheet agreement with SwitchH2 to engineer and supply automation and electrification solutions for SwitchH2's floating production, storage and offloading (FPSO) unit dedicated to producing green ammonia from green hydrogen, to support future demand for low-carbon marine fuels.

The FPSO facility will be built in the Netherlands and be stationed off the coast of Portugal, powered by certified renewable electricity from the national grid under a Power Purchase Agreement. It will feature a 300 MW electrolyser with the potential to produce sufficient hydrogen for up to 243,000 t/a of green ammonia.

"This collaboration represents a key step in advancing offshore production capabilities for next-generation marine fuels," said Saskia Kunst, CEO of SwitchH2. "By integrating ABB's advanced electrification and automation systems, we are demonstrating how technology-driven partnerships can accelerate innovation, shaping the future of energy at sea."

The FPSO will use treated seawater to feed the electroysers and produce green hydrogen. This hydrogen will be combined with nitrogen extracted from the air to create green ammonia. Once synthesised, the ammonia will be condensed and stored onboard. It will then be transferred to carrier ships via a floating hose system for transport to ports where it can be used as a marine fuel or cracked back to hydrogen for industrial use.

"As with other hard-to-abate industries, we are committed to helping the marine sector operate leaner and cleaner. Our leading technologies in automation and electrification will enable this project to run with greater efficiently," said Per Erik Holsten, President of ABB's Energy Industries division. "Green ammonia offers a technically viable method for decarbonizing marine transport, and this FPSO concept showcases how renewable energy can be leveraged to unlock low carbon energy value chains."

Front-end engineering and design (FEED) work is expected to run until summer 2026, with a Final Investment Decision (FID) due by the third quarter of 2026. Detailed engineering and construction will then follow in 2027. ■

JAPAN

Ube to close ammonia production

Ube Corporation has accelerated closure plans for its nitrogen products in Asia as part of its Vision 2030 plan. The company says that it aims to halt ammonia and related product production at its Ube City plant in Japan by March 2028, two years ahead of its previous schedule. Production of caprolactam and polyamide materials at the same plant will end by March 2027. Post-restructuring, the facility will prioritize specialty chemicals such as polyimides, separation membranes, ceramics, pharmaceuticals, and high-purity chemicals.

In Thailand, Ube will stop producing cyclohexanone, caprolactam, and ammonium sulphate, shutting down one of its two polyamide production lines. The site will shift focus to composite materials, polycarbonate diols, and elastomers, while Ube Fine Chemicals Asia will cease producing 1,6-hexanediol and 1,5-pentanediol.

METI funds hydrogen for steel and ammonia production

As part of the Japanese government's Green Transformation scheme, two hydrogen producers have been selected to receive subsidies for low-carbon production projects. Out of the overall $1 trillion GX scheme, $51 billion is earmarked for hydrogen and ammonia investments, with the bulk going towards a long-term programme that subsidises the increased production costs. The first two recipients are a Toyota Tshuho-led consortium (electrolytic hydrogen for steel), and Resonac (hydrogen from used plastics for ammonia). In the programme, production projects are required to have the support of a major hydrogen consumer – in Resonac's case, this is Japanese chemicals giant Nippon Shokubai, who will offtake the ammonia produced from lower-carbon hydrogen.

Operational since 2003, Resonac's Kawasaki Plastic Recycling (KPR) plant gasifies used plastics and other materials at high temperatures, breaking them down to produce (amongst others) hydrogen and carbon dioxide. The hydrogen is then mainly used as feedstock for ammonia production within Resonac, which is then used in synthetic fibres, resins, chemical fertilizers, and as denitrification agents for thermal power plants. In 2023, Resonac obtained ISCC PLUS certification for three products – hydrogen, ammonia, and acrylonitrile – partially derived from used plastics at Kawasaki.

On the back of the awarded subsidies, Resonance has now made the decision to produce ammonia in Kawasaki only using hydrogen from used plastics (hydrogen is also currently produced from city gas onsite). This will be achieved by developing and introducing new processes based on existing operations at KPR. In 2024, Resonac also began demonstration experiments using not only used plastics, but used textiles as feedstock. The new facilities for hydrogen production are scheduled to begin operation in April 2030.

UNITED STATES

MHI delivers turbomachinery for new ammonia project

Mitsubishi Heavy Industries Compressor International Corporation says that it has successfully delivered syngas and ammonia refrigeration compressor trains for the Beaumont New Ammonia Project in Beaumont, Texas. This facility, originally developed by OCI Global as the OCI Clean Ammonia project, now owned by Woodside Energy, will be the first large-scale, lower-carbon greenfield ammonia facility in the world.

MHI's scope of supply includes two API 617 compressors and a double-ended synchronous motor for the syngas train, as well as an API 617 compressor train driven by an API 612 steam turbine for the ammonia refrigeration service. Manufacturing and packaging were shared between MHI's Hiroshima, Japan facility and its Pearland Works facility in Texas, leveraging the expertise of skilled teams across both locations. Local contractors and sub-suppliers also provided key equipment to support the project.

The Beaumont facility will have a production capacity of 3,000 t/d, using carbon capture and sequestration (CCS) technology to produce lower carbon ammonia. This facility's construction highlights the increasing demand for sustainable energy solutions in emission-intensive industries, including the fertilizer, industrial, and power sectors.

The Beaumont New Ammonia project is now 97% complete, the project's Australian owner, Woodside Energy, said in a recent statement. Commissioning on critical equipment at the 1.1 million t/a ammonia production facility is scheduled to begin this month ahead of first production, which is expected by the end of this year.

Wabash Valley project to abandon CCS

The US Department of Energy has agreed a $1.5 billion loan for the Indiana-based Wabash Valley Resources LLC to finance a coal-powered ammonia plant in West Terre Haute. The project will restart and repurpose a coal gasification plant that has been idled since 2016. However, previous plans to include carbon capture and storage in the project, as agreed as recently as May by the US Environmental Protection Agency (EPA), appear to have been abandoned. The loan comes from the Trump administration's Energy Dominance Financing Program financed via the so-called "big beautiful bill". It aims to reduce US dependence on foreign sources of fertilizer and to provide domestic sources of consumption for America's shrinking coal industry. The facility is aiming to produce 500,000 t/a of ammonia using coal from a mine in southern Indiana as well as petroleum coke as feedstock.

Samsung E&A says that it has been awarded the $475 million EPC contract for the plant, with a contract period of 30 months. "This contract represents a successful re-entry into the US market," the company said in a statement. "We plan to leverage this project as a springboard to expand our presence in the North American plant sector."

CF Industries delivers first low-carbon ammonia

Ammonia producer CF Industries says that it has shipped its first cargo of low-carbon ammonia from its Donaldsonville, Louisiana facility. The 23,500 tonne shipment was purchased by commodities specialist Trafigura to be used in Antwerp, Belgium by engineering materials firm Envalior in the production of low-carbon caprolactam.

The site has produced low-carbon – also called 'blue' – ammonia since July, when CF Industries built a carbon capture plant at the facility that can sequester up to two million metric tonnes of CO_2 per year from ammonia production. The company expects to produce approximately 1.9 million t/a of ammonia from the site, verified under the Verified Ammonia Carbon Intensity programme.

RUSSIA

India planning urea plant

India is preparing to set up its first urea manufacturing facility in Russia to secure long-term fertiliser supplies and reduce exposure to global price shocks, according to Indian media reports. The proposed project, backed by Rashtriya Chemicals and Fertilisers (RCF), National Fertilisers Ltd (NFL) and Indian Potash Ltd (IPL), aims to tap Russia's abundant reserves of natural gas and ammonia, key raw materials that India lacks. The venture is reportedly scheduled to be announced during Vladimir Putin's visit to India in December. The facility is said to aim at ultimately producing 2 million t/a of urea. India is currently the second-largest consumer and third-largest producer of fertilisers globally, but it remains vulnerable to global commodity swings.

Azot plant hit by Ukrainian drones

Ukrainian drones attacked the Azot chemical plant in Perm Krai on October 3rd, according to regional Governor Dmitry Makhonin. The strike reportedly disrupted production at the facility, one of Russia's largest nitrogen fertilizer producers, located about 1,700 km from Ukrainian-controlled territory, which produces ammonia, urea, and ammonium nitrate.

"According to updated information, an attack by enemy drones was carried out at night... There was a brief stoppage of the technological cycle at Azot," Makhonin said. "Emergency services specialists continue to work at the scene, and an operational headquarters has been set up."

The attack follows a September drone strike on a chemical plant in Russia's Krasnodar Krai, which sparked a fire and forced evacuations, according to Russian independent media outlet Astra.

SERBIA

HIP Azotara to be dismantled for data centre

The nitrogen plants at HIP's Azotara site are to be dismantled and removed as part of plans to convert the site to a data storage facility. Plants to be removed include the urea plant and urea storage facility, the UAN liquid storage facility, the calcium ammonium nitrate and nitric acid plans, and thegrain storage societies. In addition, the entire Block 6 is planned to be removed, which includes ammonia plants and storage, nitric acid and urea production, all of which have been out of operation for a long time.

PARAGUAY

Offtake agreement for fertilizer plant

ATOME says that it has signed a definitive offtake agreement with Yara for the purchase of the entire 260,000 t/a output of the low-carbon Villeta project. The plant will be based on 100% renewable baseload power, and will displace some 500,000 t/a of carbon dioxide equivalent. ATOME says that the agreement represents the last commercial milestone in its path to a final investment decision (FID), following the successful completion of other key commercial items, including the signing of the $465 million fixed-price, lump-sum engineering, procurement and construction contract with Casale.

Villeta will produce low-carbon calcium ammonium nitrate (CAN) fertiliser, made from green ammonia produced from 100% renewable baseload hydropower, at industrial scale. It will be produced without reliance on subsidies or grants, and close to major demand centres, providing global food producers with much needed cost-effective solutions to decarbonise their supply chains.

UNITED ARAB EMIRATES

Uhde completes hydrogen recovery unit

thyssenkrupp Uhde says that it has successfully commissioned a hydrogen recovery unit (HRU) at the Fertil ammonia-urea plant in Ruwais, owned by Fertiglobe, a global exporter of urea and ammonia. The scope of work included engineering, procurement and site supervision during installation and start-up of the units.

After the plant revamp and successful commissioning of the hydrogen recovery unit, the unit is now in operation. The plant will now have a revised capacity of 2,120 t/d of ammonia. The Hydrogen Recovery Unit (HRU) enables hydrogen recovery from the ammonia synthesis purge gas, allowing for increased feedstock utilisation and a 6% increase in ammonia output.ossible during ongoing plant operations." ■

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Syngas News

GERMANY

Cooperation agreement for e-fuels demonstration plant

Sasol and Topsoe have signed a cooperation agreement with the German Aerospace Centre (DLR) and EPC contractor Griesemann for the construction, operation and research and development activities of DLR's sustainable aviation fuels demonstration plant at the Leuna Chemical Complex, Germany. The demonstration plant is currently under construction and expects to produce 2500 t/a of e-fuels, starting in Q4 2027. The e-fuels produced will comprise mainly of kerosene, using renewable feedstocks such as biogenic CO_2 and green hydrogen. With €130 million of funding secured from the German Federal Ministry for Transport, the plant will be the largest demonstration and research facility globally for the production of e-fuels.

Elena Scaltritti, CCO at Topsoe, said: "Demonstration facilities, like the TPP, are essential for proving the capabilities of new technologies and highlighting the viability of innovative products like e-fuels. We are excited to join forces with DLR, Sasol and Griesemann to develop this demonstration plant as well as the technologies that will support the rollout of power-to-liquid fuels at scale."

Björn Griesemann, CEO at Griesemann Group, added: "Power-to-liquid fuels are the basis for future industrial production and the extensive use of sustainable fuels, particularly in aviation. Our engineering enables the technologies developed by Topsoe and Sasol, as well as the research conducted by DLR, to be transferred into feasible, scalable concepts – thus closing the gap between research and practice. Our long-time experience in the implementation of modular projects and renewable energies flows directly into the development of the TPP."

The TPP facility began construction on October 1, 2024, and is expected to be the world's largest research e-fuels production facility and the first in which electricity-based fuels can be demonstrated and tested across the entire technology value chain. The design of the plant allows various processes and technologies to be analysed. The announcement follows Topsoe and Sasol's selection late last year to deliver their integrated G2L™ e-fuels technology for the SAF demonstration plant, integrating Topsoe's innovative eREACT™ technology and hydroprocessing technologies with Sasol's LTFT™ (low-temperature Fischer-Tropsch) technology. Griesemann Gruppe is working alongside Topsoe and Sasol as the engineering, procurement and construction (EPC) contractor. ■

Clariant to supply catalyst for electric reformer

Clariant has signed a supply agreement with SYPOX to manufacture and deliver catalysts for what is claimed to be the world's largest electric steam methane reformer (e-SMR). The project combines SYPOX's electrical reformer technology with Clariant's expertise to enable syngas production with significantly reduced CO_2 emissions. Scheduled to begin operations in 2026, the e-SMR will use 10 MW of renewable electricity to generate approximately 150 t/d of syngas.

SYPOX is an offshoot of the Technical University of Munich, and has developed an innovative solution to decarbonize chemical production through the electrification of traditional processes, including steam methane reforming. SYPOX reformers directly electrify the chemical conversion inside the reactor, creating a system almost two orders of magnitude more compact. This technology not only enhances profitability and sustainability but also significantly simplifies plant operations, according to SYPOX, while making the technology viable for both small, modular applications and large industrial plants.

UNITED STATES

Technology license for blue methanol

Topsoe has been selected as technology provider by Sandpiper Chemicals LLC, for their new blue methanol plant in Texas City, Texas. Topsoe will license its SynCOR™ technology, which will be combined with carbon capture & storage (CCS) for the production of blue methanol. The project, when operational will produce 3,000 t/d of blue methanol. The IEA estimates that methanol demand is expected to grow to 120-150 million t/a by 2030. Today, methanol is primarily used within the chemical industry, but growing demand is coming from the shipping industry as it looks to lower emissions.

SAUDI ARABIA

Kent appointed to Yanbu Green Hydrogen Hub

Kent, a global leader in integrated energy services, has been appointed by ACWA Power as owner's engineer for the Yanbu Green Hydrogen Hub, a major green hydrogen and ammonia export facility being developed in Saudi Arabia. Situated in the port city of Yanbu on the Red Sea, the project will feature full integration across the green hydrogen value chain. This includes its own dedicated renewable power generation, desalination plants, ammonia production lines and an export terminal. At full scale, the facility will deliver up to 400,000 t/a of renewable hydrogen, converted into over 2.2 million t/a of green ammonia for international markets. With more than 4 GW of electrolysis capacity planned, the Yanbu hub is expected to be nearly twice the size of the NEOM Green Hydrogen Project.

Kent will act as ACWA Power's technical representative throughout the front-end engineering design (FEED) phase being deliver through a joint venture between Técnicas Reunidas and Sinopec. The Kent team will provide independent oversight and assurance to support safe, efficient and technically robust project delivery. Kent's responsibilities include ensuring engineering design compliance with international standards, reviewing safety and constructability, managing technical interfaces and integration across the various workstreams, and advising on risk and design optimisation. The team will also support ACWA Power in planning the transition into the engineering, procurement and construction (EPC) phase.

SPAIN

Agreement on electrolyser technology for methanol plant

Topsoe has signed an offtake agreement to provide its Solid Oxide Electrolyser Cell (SOEC) technology for Forestal's Triskelion green methanol plant in Galicia. The SOEC's will be delivered from Topsoe's manufacturing facility in Herning, Denmark, which is nearing the final stage of readiness for industrial-scale production. The agreement, which includes a 10-year service warranty program, builds on Topsoe's existing agreement with Forestal, announced in December 2024, to provide its e-methanol synthesis technology, catalysts and engineering for highly efficient e-methanol production.

Topsoe says that, by providing a single, integrated hydrogen-to-methanol pathway, it minimises interface risk, improves overall efficiency by up to 30% compared to conventional electrolysis systems and removes the need for intermediate hydrogen storage. This ensures stable operations even during renewable power fluctuations, a crucial requirement for Forestal when assessing project risks.

The Triskelion project is designed to produce 57,000 t/a of green methanol and will capture and use 78,000 tons of CO2 each year to produce it. Power will be supplied from renewable sources through power purchase agreements, ensuring renewable and continuous power supply during operation. The plant received a euro 49 million grant from the European Union Emissions Trading System's Innovation Fund in 2023. It is expected to begin operations in 2028.

NORWAY

Feasibility study on sustainable methanol plant

NextChem subsidiary MyRechemical has been selected by Mana Group and Equinor to conduct a feasibility study for a waste-to-methanol plant at Norway's Mongstad refinery. The project will use NX Circular™ technology to convert urban and industrial waste into chemical grade syngas which will be further processed to produce low-carbon methanol. The facility is expected to produce circular methanol with a low carbon footprint, eligible under the EU Renewable Energy Directive criteria. This methanol could initially replace marine bunker fuel to meet the targets of the FuelEU Maritime regulation, exempting final users from buying ETS credits and paying penalties, and potentially later be used as feedstock for methanol-to-jet facilities to produce sustainable aviation fuel (SAF) compliant with FuelEU Aviation regulation.

Fabio Fritelli, managing director of NextChem, commented: "We are proud to support this early-stage strategic partnership to explore the potential to develop the Nordics' first large-scale waste-to-methanol project at Mongstad, Norway. Northern Europe represents an ideal context for replicable and scalable industrial projects, with tangible environmental and industrial benefits."

ITALY

NextChem and Siemens to cooperate on maritime methanol fuel cells

NextChem and Siemens Energy have signed a memorandum of understanding to cooperate on the development and commercialisation of a high temperature methanol fuel cell, based on a newly designed modularised solution. With an initial focus on the high-end yachting segment, the target market for the cooperation is the maritime industry and beyond. According to the MoU, NextChem will focus on the design and supply of the methanol fuel cell module, while Siemens Energy will leverage its expertise in onboard system integration, complete electrification and energy management with the aim of delivering a complete solution to shipyards and owners.

The fuel cell will reform low-carbon methanol back into hydrogen for onboard power generation, allowing net-zero operations of the vessel both at anchor and during propulsion. This solution will allow displacing significant amounts of fossil marine diesel fuel, and to avoid the emissions of highly regulated nitrous and sulphur oxides.

Giuseppe Sachero, Vice President, Oil & Gas and Chemical Solutions, Siemens Energy, added: "This development highlights the unique value of key players in the energy transition value chain. By working together, we capitalize on each other's expertise and references in adjacent industries. Fuel cells are an integral part of the cle an fuels technologies ecosystem, from electrolysis to electricity generation and storage, and are applicable in multiple industrial applications."

JAPAN

Approval in principle for methanol superstorage

Nippon Kaiji Kyokai (ClassNK) has granted approval in principle to SRC for 'methanol superstorage', an innovative tank design concept that uses a sandwich plate system technology to almost double shipboard storage capacity for both methanol and ethanol. The approval confirms that methanol superstorage is feasible for the intended application in accordance with the society's 'Guidelines for Ships Using Alternative Fuels'.

In contrast to traditional fuel tanks, where internal and external walls are separated by a cofferdam of at least 600 mm, methanol superstorage features SPS technology - a solid elastomer core 'sandwiched' between two steel plates that is 25-millimetre-thick. The solution delivers 85% more storage capacity than a conventional tank.

"With many methanol-ready ships now in operation, under construction or on order and ethanol also gaining traction, fuel storage has become an area of intense industry interest," said Mr Ryohei Sakai, Manager (Project Hull), Technical Solution Department, ClassNK. "Because of its low volumetric energy density compared to HFO, a methanol tank would need to hold over twice the volume to generate the same energy, for example. This has consequences for ship range and design. SRC's methanol fuel tank concept represents an approach to addressing this challenge."

Classification for hydrogen-fuelled tug

ClassNK has added Japan's first hydrogen-fuelled tug Ten-Oh to its register, built by Tsuneishi Shipbuilding Co., Ltd. This vessel was developed and built under the 'Nippon Foundation Zero Emission Ships Project', a grant program by The Nippon Foundation aimed at developing ships with zero CO_2 emissions. Based on discussions among the parties involved during the planning stage of the vessel, ClassNK reviewed the safety requirements and countermeasures for hydrogen-fuelled ships by applying Part GF of its 'Rules and Guidance for the Survey and Construction of Steel Ships' etc. These reviews focused on issues such as preventing explosions caused by the high ignitability of hydrogen and mitigating the potential impacts of hydrogen fuel leakage on crew members and the environment.

ClassNK says that it will continuously support the safe operation of the vessel through surveys in service, and not only that, support industry's effort toward decarbonisation through using the knowledge and experience gained from the surveys for keeping its guidelines up to date and contributing to establishment of the appropriate international standard. ■

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People

BASF SE says that it has made changes to its board of executive directors in line with its "Winning Ways" strategy. The Supervisory Board has appointed **Dr. Mary Kurian** and **Dr. Livio Tedeschi** as members of the Board of Executive Directors effective from May 1, 2026. At the same time, **Michael Heinz** will retire as planned.

Mary Kurian was born in India. After obtaining a PhD in Materials Science in 2004, she held various leadership positions at Air Products in the United States and joined BASF in the United States in the year 2020. Since 2023, she has been heading BASF's Care Chemicals division located in Ludwigshafen. Dr. Kurt Bock, Chairman of the Supervisory Board of BASF SE said: "In addition to her international leadership experience in and outside of BASF, Mary Kurian has deep expertise in the commodities as well as in the specialties businesses, always in direct contact with important partners and key customers of BASF."

Livio Tedeschi has been leading the Agricultural Solutions division, located in Limburgerhof, Germany, since 2022. He joined BASF after completing a PhD in Organic Chemistry in 2003 and had various leadership positions with a focus on crop protection since that time. Regarding the planned partial IPO of the Agricultural Solutions division, he will assume responsibility for this segment with a new Board Ressort and continue to lead the business. Kurt Bock added: "Livio Tedeschi is a recognised expert in the agricultural business. With his many years of experience, strategic foresight and strong operational leadership, he is the right person to lead BASF's Agricultural Solutions business into the next successful phase."

AFC Energy plc says that its chief technology officer, **Dr Mike Rendall**, has been appointed as the inaugural chair of the UK Ammonia Alliance (UKAA), a new industry body formed to advance the nation's low-carbon ammonia sector. The founding members of the UKAA are AFC Energy, Air Products, Blended Products, Clean Air Power, Exolum, Green Cat Hydrogen, HYCAP, Industrial Chemicals Limited, Mitsubishi Heavy Industries, N-Gen Energy, and Statkraft. The alliance aims to promote ammonia's role in decarbonising heavy industry, agriculture and energy systems, and will host its first public event in parliament in November to launch a policy paper on the UK's ammonia opportunity.

EcoUrea has announced that **Kennet Bollerød** has joined the company as CEO for its Norway operations. With this appointment, the company aims to provide customers with faster response times, more flexible supply solutions and a closer, more transparent relationship. "We are delighted to welcome Kennet to the company. With his vast knowledge and experience in the industry this appointment will allow us to work hand-in-hand with our customers, ensuring they receive a fast response, and the delivery schedules they need," said Alex Roberts, Operations Director at EcoUrea.

Fertiglobe has completed the acquisition of the distribution assets of Wengfu Australia Pty Ltd. (Wengfu), a leading fertilizer distribution business. This acquisition reinforces Fertiglobe's commitment to customer proximity in key markets, in line with its 'Grow 2030 Strategy'. The acquired assets are located across five ports with eight warehouses, distributing 700-800,000 t/a of fertilizers to over 200 customers, with capacity to scale up to 1.1 million t/a. Fertiglobe Australia Pty Ltd. (Fertiglobe Australia), a fully owned subsidiary of Fertiglobe, has been established as the legal entity that will operate the acquired distribution assets under the Fertiglobe brand. **Paul Osborne** has been appointed as Chief Executive Officer of Fertiglobe Australia, and commented: "This exciting new chapter will unlock new opportunities for our business and benefit our customers through access to a strong global ecosystem. We are proud to contribute to Fertiglobe's expansion into the Asia-Pacific region and to integrate with a company that shares our commitment to delivering value through global reach, local expertise, and a mutual vision for strategic growth." ■

Calendar 2026

JANUARY

26-28
Fertilizer Latino Americano, MIAMI, Florida, USA
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

29
IMPCA Methanol Mini-Conference America, ORLANDO, Florida, USA
Contact: International Methanol Producers and Consumers Association
Email: meetings@impca.eu
Web: https://impca.eu/events/12th-impca-conference-amercia-orlando-florida/

FEBRUARY

10-12
Nitrogen+Syngas Expoconference 2026, BARCELONA, Spain
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

MARCH

10-11
Clean Ammonia Storage Conference, ROTTERDAM, Netherlands
Web: https://www.stocexpo.com/en/visit/conference/

25-26
Gasification 2026, BERLIN, Germany
Contact: Mohammad Ahsan – Marketing & Delegate Sales, ACI
Tel: +44 (0) 203 141 0606
Email: mahsan@acieu.net

APRIL

21-23
Nitrogen+Syngas Expoconference USA, DALLAS, Texas, USA
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

MAY

4-6
IFA Annual Conference, ABU DHABI, UAE
Contact: IFA Conference Service, Paris, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

5-6
NH3 Event Europe, ROTTERDAM, Netherlands
Contact: Stichting NH3 Event Europe
Tel: +31 10 4267275
Email: info@nh3event.com

11
IMPCA European Methanol Mini-Conference, VIENNA, Austria
Contact: International Methanol Producers and Consumers Association
Email: meetings@impca.eu
Web: https://impca.eu/events/36th-impca-european-mini-conference/

Plant Manager+

Incident No. 7 Nitric acid tank explosion – Part 2

The following case study describes a serious incident and the consequences of erroneously mixing nitric acid with hydrochloric acid. In Part 1 we reported on the incident and the causes that led up to the event. In part 2 the impact, recommendations and lessons learned will be discussed. ■

The impact

The impact of the July 4, 2025 event goes beyond the immediate consequences at the plant site. The storage tank explosion caused a gas cloud composed of gases such as nitrogen dioxide and chlorine to be blown by the wind away from the nearby village. Due to the power of the explosion, the fuel tank lid (note UreaKnowHow.com: looking at the pictures it was more than a lid) landed on a nearby pasture, and environmental damage was another important consequence. Chemicals come into contact with soil and surface water, leading to pollution. As a result, the trees had to be removed and the company began soil and water remediation. The findings of the Water Authority show that the incident did not alter the quality of the water and soil. The incident also had a significant impact on the operational side. Production was stopped and the site was evacuated. Damage to facilities and infrastructure resulted in prolonged shutdowns and recovery efforts. Additionally, confidence in the company has been damaged: the incident has attracted national media attention and led to various regulatory inspections. The organisation must be accountable to external parties, including environmental services, living environment and transport inspections and the country's Labour Inspectorate.

Summary impact

- **Orange gas cloud** – the explosion produced an orange nitrogen dioxide and chlorine gas cloud that was blown away by wind from the nearby village.
- **Environmental damage and remediation** – chemicals contaminated the soil; the trees had to be removed and soil remediation began.
- **Operational consequences** – shutdown, site evacuation, severe damage to the facility, resulting in long-term repair work.
- **Public and media attention** – the incident received national attention.
- **Supervision and accountability** – the organisation must be accountable to regulators such as the Environmental Services Agency, Human Environment and Transport Inspectorate and the country's Labour Inspectorate.

Recommendations

The investigation resulted in a series of recommendations aimed at preventing similar incidents in the future. These suggestions are not only technical, but also focus on organisational and procedural improvements, including strengthening human action. They are based on the analysis of failure mechanisms and safety barriers, and one of the important considerations is to further refine the identification and access control of the site. Clearer gate signage and controls should prevent drivers from unloading at the wrong location. In addition, it should be ensured that the identity of chemicals is verified, including by checking bills of lading and UN codes. This is supported by improved checklists and the application of the six-eyes principle in the workplace for timely notice and correction of errors. Human actions have also received special attention. Employees are retrained in identifying risks, following procedures and reporting anomalies. The company takes this incident very seriously and has developed an extensive package of measures that have been or are being implemented. These apply not only to this site, but also to other locations where chemicals are used.

Summary of recommendations:

- **Broad recommendations** – suggested improvements centred on technical, organisational and procedural aspects with a focus on strengthening human action.
- **Signage and access control** – clearer signage and stricter access control should prevent drivers from unloading at the wrong location.
- **Chemical identity verification** – improved checklists and bill of lading and UN code checks, supported by the six eyes principle, to improve accuracy.
- **Person-centred training** – employees are retrained in risk identification, procedure compliance and anomaly reporting.
- **Six-eyes reception principle** – bulk chemicals are inspected by three people when unloading, greatly reducing the possibility of errors.
- **Stricter procedures** – existing checklists have been expanded with additional checkpoints, although they are already in compliance with regulations.
- **Technical control measures** – connectors can only be installed after clear inspection by safety experts.
- **Organisation** – wide implementation-these measures apply not only to this site, but to all sites where chemicals are used.

Lessons learned

The mistakes that led to the mixing of hydrochloric and nitric acid could have been avoided if the person concerned had followed the correct verification steps. This fact indicates deficiencies in workflow, training and communication and highlights the need for improvement. The incident shows that safety depends not only on

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

Overview of the landing position of the lid of the explosive nitric acid tank (HNO_3).

technical facilities, but also on human alertness, organisational discipline and shared safety awareness. Procedures are only effective if they are known to everyone and applied consistently. The training should match the risk profile of the task. Unloading chemicals requires specific knowledge and experience and should be considered a high-risk task. Furthermore, the incident shows that technical barriers are critical to capturing human error. Crisis management must be prepared for unforeseen circumstances. The lack of a chemical mixing contingency plan leads to ad hoc decisions under time pressure, which increases the risk. These observations should be systematically incorporated into the improvement process so that structural deficiencies can be addressed in a timely manner and recurrence can be prevented, and finally, shared environmental awareness is essential. Information on escalation criteria must be clear and actively shared between the field and crisis teams.

Summary lessons learned

- **Human error** – the incident was caused by not following verification steps, which indicates deficiencies in workflow, training, and communication.
- **Organisational discipline** – safety depends on alertness, shared safety awareness, and consistent procedure application.
- **Task-oriented training** – training should match the risk profile of the task; Releasing chemicals requires specific knowledge and experience.
- **Crisis management** – lack of contingency planning leads to improvisation under time pressure, which increases risk.
- **Monitoring and improvement** – organisations must actively monitor compliance, report deviations and deal with them structurally in improvement processes. ■

Source: https://ureaknowhow.com/4-july-2025-nitric-acid-explosion/

Post-incident overview map

Facility damage.

PHOTO: SHUTTERSTOCK

AI and the nitrogen industry

Artificial intelligence is beginning to extend into all facets of modern life, and the chemical process industry is no exception. This article looks at where and how AI is being applied in the ammonia and downstream industries, what data and infrastructure are required, and the potential risks.

A smart pressure sensor at a chemical process plant

The production of ammonia has underpinned modern agriculture, industrial chemistry and logistics for more than a century, and it now faces the dual challenge of improving operational efficiency while dramatically reducing greenhouse gas emissions. Historically dominated by the energy-intensive Haber–Bosch process, the industry is rapidly exploring electrification, process flexibility and new value chains such as green hydrogen-based synthesis. In this environment, artificial intelligence (AI) is a toolkit which presents opportunities to reduce the energy consumption of existing processes, make plants more resilient and safer, accelerate research into catalysts and materials, and enable economically viable green ammonia supply chains.

Process optimisation

Process optimisation and advanced control remain perhaps the most immediate opportunities for AI to deliver returns in ammonia production. Large-scale synthesis plants operate with thousands of measured variables and hundreds of manipulated variables, creating a high-dimensional optimisation problem that classical control methods struggle to fully exploit. Data-driven surrogate models, hybrid digital twins and enhanced model predictive control can reduce energy consumption and increase conversion efficiency by enabling tighter control of synthesis loop conditions, purge and recycle balances, and heat integration networks. Soft sensors built from supervised learning algorithms can estimate measurements that are expensive or slow to obtain in the laboratory, such as instantaneous catalyst activity or trace impurity concentrations. By replacing or augmenting manual sampling and slow analytical feedback with real-time estimators, plants can maintain operating points closer to optimal, reducing fuel consumption and improving throughput. A typical impact can be energy intensity reductions in the range of 2–15% and conversion/yield improvements of 0.5–5%, depending on asset age and baseline control sophistication.

The emergence of green ammonia - where hydrogen is produced by electrolysers powered by renewable electricity - introduces a new dimension of operational complexity and opportunity. Variable renewable generation requires synthesis plants, electrolysers and air separation units to operate flexibly, ramping up during low-cost power windows and throttling back during scarcity. AI techniques such as stochastic optimal control and reinforcement learning are well suited to derive dispatch schedules that trade off electricity cost, equipment degradation and synthesis stability. These methods can identify when it is economically optimal to operate electrolysis at partial load, to hold ammonia in storage, or to temporarily shut down synthesis loops, all while preserving equipment life and safety margins. In addition, price-aware scheduling combined with short-term forecasting of electricity prices and renewable generation reduces the levelized cost of green ammonia and improves project bankability.

Predictive maintenance

Predictive maintenance and reliability analytics are another area where AI has delivered rapid payback in industrial settings and where ammonia plants can expect similar gains. Rotating equipment such as compressors, pumps and refrigeration systems are both critical and

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expensive to replace; unplanned failures cascade into lost production and costly restarts. By aggregating vibration signatures, motor currents, bearing temperatures, oil analysis and operational logs, machine learning models can detect anomalous behaviour and estimate remaining useful life well in advance of catastrophic failure. Techniques ranging from unsupervised anomaly detection using autoencoders to supervised remaining-useful-life models built with gradient-boosted trees provide different trade-offs in label requirements and interpretability. Transitioning from calendar-based maintenance to condition-based strategies driven by live analytics typically reduces unplanned downtime, optimizes spare parts inventories and lowers maintenance cost per tonne produced.

Energy management

Energy management, decarbonisation planning and retrofit evaluation are strategic applications where data-driven optimization can reveal opportunities that are not apparent from static engineering studies. AI-enabled scenario analysis can combine physics-based process models with data-driven corrections to evaluate the economics of electrification, waste-heat reuse, heat pumps or advanced heat integration under realistic electricity price trajectories. This capability is particularly important for large assets with long lifetimes; choosing the wrong retrofit or timing it poorly can lock in higher operating costs or suboptimal emissions profiles. By simulating a range of dispatch strategies and retrofit configurations under stochastic power prices and policy scenarios, organisations can prioritise investments that yield the most durable financial and environmental gains.

HSE

Safety, environmental monitoring and compliance are the core to any industrial process, and AI can augment these functions through improved detection, localisation and root-cause analysis. Multi-sensor fusion combining gas detectors, acoustic sensors, infrared cameras and meteorological data enables faster and more accurate leak detection than single-sensor approaches. Machine learning classifiers and probabilistic models can reduce false alarms while providing confidence scores that support operator decision-making. For emissions reporting and incident investigation, analytics applied to continuous emissions monitoring data and process logs can identify unusual release patterns, correlate them with upstream events and quantify environmental impact. Importantly, in safety-sensitive applications, AI systems should be deployed initially in advisory or shadow modes, with human operators retaining final authority until models have demonstrated robust performance across operating regimes.

Research

The use of AI to accelerate research in catalysts, materials and process design represents a strategic long-term opportunity with potentially high returns. Materials informatics approaches use Bayesian optimisation, Gaussian process surrogates and active learning to explore vast experimental spaces more efficiently than grid searches or purely manual experimentation. By combining experimental data, first-principles simulations and surrogate models, researchers can converge on promising catalyst compositions, supports and operating conditions with fewer laboratory runs. These methods have already shown success in related chemical domains and, when integrated into research and development work flows, shorten the development cycle for improved catalysts or process recipes that could increase conversion, reduce energy demand, or reduce reliance on scarce materials.

Data requirements

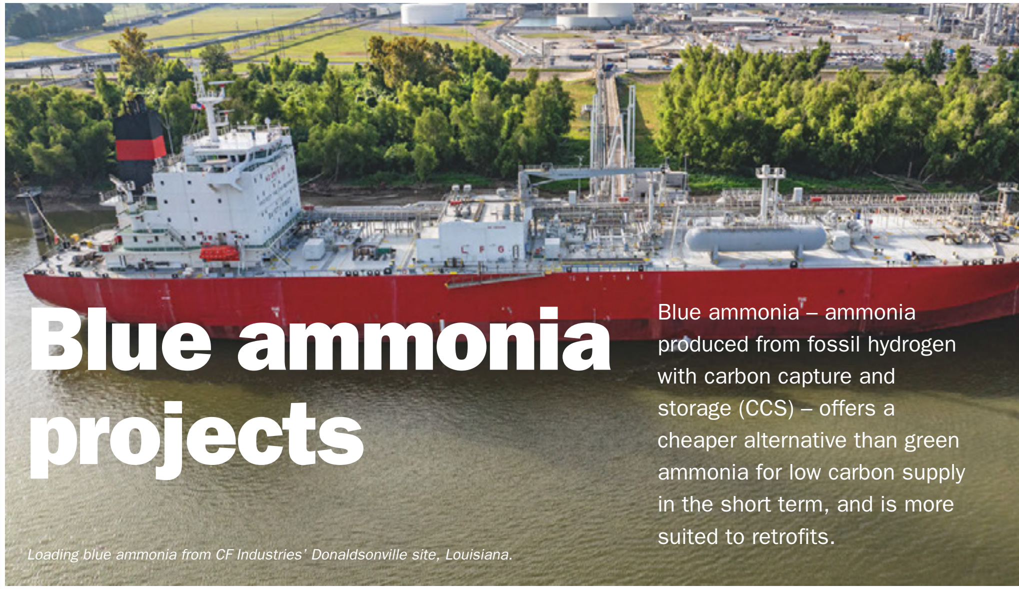
Delivering on these opportunities requires attention to data architecture and quality. The backbone of modern industrial AI is a reliable historian or time-series database that archives sensor data, event logs, laboratory results and maintenance records. Industrial protocols such as OPC-UA and telemetry standards like MQTT enable connectivity between programmable logic controllers (PLC), supervisory control and data acquisition systems (SCADA) and analytics platforms. Frameworks for training and serving models typically include libraries such as PyTorch, TensorFlow and scikit-learn, while plant historians like OSIsoft PI (or equivalent systems) provide the operational data foundation. Practical challenges are common: missing timestamps, inconsistent units, sensor drift and sparse failure labels can undermine model development. A focused data audit that inventories available signals, assesses sampling rates, checks clock synchronisation and quantifies label availability is a critical first step that informs whether additional instrumentation is required or whether advanced methods for label-scarce learning are needed.

Risks

Despite clear benefits, teams must plan for and mitigate several risks. Data quality and availability present the most immediate hazard; poor historical records and sparse failure examples create brittle models. The practical mitigation is to run an initial data-quality sprint, instrument missing critical signals, and design pilots around use cases with sufficient label density or where unsupervised approaches are effective. Model brittleness and distributional shifts are inevitable as plants change feedstocks, retrofit equipment or alter operating practices; continuous performance monitoring, automated drift detection and conservative operational guardrails reduce the risk of unsafe or suboptimal automated actions. Cybersecurity and data governance are non-negotiable; network segmentation, encrypted telemetry, strong authentication and role-based access to analytics platforms protect both operational integrity and commercial data. Finally, workforce acceptance must be addressed through early inclusion of operators, transparent model outputs and training programs that build data literacy among engineers and technicians.

Selecting partners for implementation is as important as selecting use cases. Organisations that combine deep process domain expertise with demonstrated machine learning capabilities offer the best chance of success, and avoiding lock-in through open APIs and standards-based connectivity preserves optionality. A pilot-first approach, contracted around measurable KPIs and staged deliverables, aligns incentives and reduces up front risk. Over the medium term, building internal capability ensures sustainability and lowers dependence on external vendors. ■

PHOTO: CF INDUSTRIES



Blue ammonia projects

Blue ammonia – ammonia produced from fossil hydrogen with carbon capture and storage (CCS) – offers a cheaper alternative than green ammonia for low carbon supply in the short term, and is more suited to retrofits.

Loading blue ammonia from CF Industries' Donaldsonville site, Louisiana.

Blue ammonia has moved from demonstration projects into large commercial builds over the past few years. The technology has been attractive to existing producers because it leverages existing steam reforming and ammonia synthesis infrastructure, while allowing them to address fertilizer sector decarbonisation. On the demand side, it serves as a potential low-carbon fuel export to Asian coal-fired power stations or future maritime fuel uses. However, project delivery depends on long-term offtake agreements, the complicating factor of CO_2 transport and permanent storage, and government funding and associated certification regimes.

Policy driving markets

Low carbon incentives such as the US 45Q tax credit and industrial decarbonisation goals in Japan, Korea and the EU have created tangible demand signals for low-carbon ammonia. Importers in Japan and Korea are sponsoring offtake and equity partnerships to secure supply. Major Japanese utilities and trading houses have stepped forward as anchor customers (and in some cases equity partners), improving project bankability. That buyer demand is a decisive factor for convincing lenders and export credit agencies to support projects financially. Japan and South Korea have mandates for low carbon ammonia co-firing in coal-fired power stations, and blue ammonia offers a concrete pathway for Asian power sectors to cut CO_2 emissions quickly while leveraging existing logistics and suppliers. Its ultimate scale will depend on CCS credibility, terminal and handling investment, certification rigor, and how fast green alternatives fall in cost.

Europe's carbon border adjustment mechanism (CBAM) is also a potential demand pull for low carbon ammonia imports as the additional cost burden of grey ammonia increases over the next few years. In the near term, low-emission ammonia is expected to compete with grey ammonia, pending a ramp-up in the end-use market demand, and CRU does not expect price differentiation between blue and green ammonia to emerge before 2032. As free carbon allowances are phase out towards 2034, there is likely to be increasing differentiation in the carbon value between green ammonia and blue ammonia. Price premiums across blue ammonia grades are expected to remain limited before 2030 or until demand from end-use markets strengthens.

Some of this demand will come from the maritime sector, where the IMO's net-zero framework has been approved in draft form and is highly likely to be formally adopted in the MEPC/ES.2 scheduled in October 2025. Approval of the framework is expected to accelerate adoption of low-emission ammonia in marine fuels. As LNG faces Tier penalties from 2030 and potential Tier 2 carbon offset costs from 2033 due to its GHG intensity, ammonia is positioned to gain a competitive edge, supporting stronger demand growth. Ships calling at EU ports are now subject to the EU ETS, with the first surrender deadline in September 2025 for 40% of 2024 emissions. FuelEU Maritime also began this year, with compliance reports due in early 2026 and a Document of Compliance required by mid-year. CRU expects these EU measures to evolve once a global IMO framework is adopted, supporting greater alignment and a level playing field.

There is however some uncertainty as regards US tax credits, which have driven a lot of the investment in blue ammonia to date (see Table 1). In a proposal introduced earlier this year, House Republicans called for ending the 45V clean hydrogen tax credit ahead of its

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original 2033 deadline, requiring hydrogen facilities to begin construction before 31st December 2025 to qualify for up to 10 years of support worth up to $3/kg. This posed a potentially devastating blow to green ammonia developments, but may still allow blue ammonia projects to be economically viable.

There remain some areas of policy uncertainty; the classification of blue ammonia remains ambiguous, as no globally standardised threshold currently exists. Ultimately however the price of low-emissions ammonia will vary according to the level of carbon tax avoided.

Producer response

Existing fertilizer producers have tended to see blue routes to ammonia production as the more rapid path to lowering product carbon intensity, allowing retrofits to existing facilities (such as CF Industries at Donaldsonville or LSB Industries at El Dorado). But there is also now some evidence of carbon capture and storage hub development: there are now large CO_2 transport and storage projects being developed in the Arab Gulf region, the North Sea and the US Gulf Coast, which could enable aggregation of point-source CO_2 from multiple ammonia and hydrogen producers into a shared sequestration infrastructure.

Table 1 shows blue ammonia projects currently under development. CF Industries has been a leading player, retrofitting and expanding activity at its US Gulf assets with CCS linkage and is a central player in some other multi-partner blue projects such as the CF–JERA–Mitsui Blue Point project in Louisiana. Existing producers already have an established sales and distribution infrastructure to tap into which gives them a head start in blue ammonia developments.

The combination of cheap shale gas and relatively easy access to mature/declining oil and gas wells in the US Gulf Coast, coupled with the tax credits mentioned above have made the US Guld Coast region at hotspot for blue ammonia developments, as the Table shows. Woodside (after acquiring an OCI asset) is close to delivering the Beaumont ammonia plant in Texas, with CCS linkage targeted to make the product low-carbon from the mid-2020s. Some of the other projects are more speculative, but the US is set to be producing several million t/a of blue ammonia by 2030.

Table 1: **Large scale blue ammonia projects worldwide**

Company	Site	Capacity	Project status
United States			
CF Industries	Donaldsonville, LA	1.9 million t/a	Operational
CF Industries	Yazoo City, LA	0.5 million t/a	CCS agreement signed, 2028
Blue Point LCA*	Louisiana	1.4 million t/a	FID agreed, 2030 startup
Woodside	Beaumont, TX	1.1 million t/a	Construction complete, 2026
Yara/Enbridge	Corpus Christi, TX	2.8 million t/a	FEED, targeting 2028-30
Idemitsu/Proman/MHI	Lake Charles, LA	1.2 million t/a	FEED, targeting 2030
Inpex/Air Liquide	Houston Ship Canal, TX	1.1 million t/a	Feasibility study
LSB Industries	El Dorado, Arkansas	0.4 million t/a	Operational 2026
Air Products	Louisiana Clean Energy	Not yet known	Feasibility study
Rest of world			
QAFCO	Mesaieed, Qatar	1.2 million t/a	Under construction, 2027
ADNOC/TAZIZ	Ruwais, UAE	1.0 million t/a	Under construction, 2027
SABIC	Jubail, Saudi Arabia	1.2 million t/a	Awaiting FID
Yara	Sluiskil, Netherlands	0.8 million t/a	Operational
Barents Blue AS	Markoppneset, Norway	1.0 million t/a	FEED, targeting 2029-30
H2biscus	Sarawak, Malaysia	0.1 million t/a	Feasibility study
Pupuk Indonesia	Yamdena, Indonesia	1/8 million t/a	Awaiting FID

Source: CRU **CF/JERA/Mitsui*

Outside the US, there is another development hotspot in the Arab Gulf, where again there is existing oil and gas infrastructure to tie the carbon capture and storage into. ADNOC and its TA'ZIZ partners are building a 1 million t/a low-carbon ammonia plant in Ruwais with a planned CCS pathway and strong state backing, and QatarEnergy/QAFCO is building a world-scale Ammonia-7 train (~1.2 million t/a) at Mesaieed and integrating CCS plans.

In Europe the North Sea may play a similar role. Yara is advancing cross-border transport and storage in Europe by transporting CO_2 by tanker from Sluiskil in the Netherlands to the Northern Lights project in Norway.

Key obstacles

Carbon capture and storage remains a relatively new technology. Permitting of long CO_2 pipelines and securing injection permits in the US or seabed licensing in Europe can be complex and can materially delay timelines. Local opposition to CO_2 infrastructure also remains a political factor in some US Gulf communities.

Certification also remains an open question. Buyers and regulators are tightening low-carbon criteria. Projects that rely on CO_2 utilisation or temporary enhanced oil recovery rather than verified permanent storage may face challenges for export markets demanding low carbon intensity.

Finally, lower-carbon ammonia must find sustained demand beyond early offtakers.

However, a base case based on the projects already under construction and those likely to secure approval means that up to 8 million t/a of blue ammonia could be being produced by 2030. If CCS permitting, or EPC or offtake slips push projects past 2030, and a couple of projects do not reach a final investment decision, this could fall to around 6 million t/a based on already committed projects. On the other hand, if some of the proposed Saudi greenfield projects (not included in the table) make significant progress, and all FEED projects hit a final investment decision with no major delays, total achievable blue/low-carbon capacity could reach 10–11+ million t/a by 2030. ■

Status of renewable ammonia projects and technology licensors

Globally, operational renewable ammonia projects have exceeded one gigawatt (GW) of installed electrolyser capacity for the first time. **Kevin Rouwenhorst** of the Ammonia Energy Association (AEA) provides an overview of well-advanced projects and the associated technology options for ammonia synthesis.

While a large number of renewable ammonia projects have been announced, one of the concrete steps toward their realisation is the selection of the ammonia technology provider. In this article, we highlight how project momentum is building globally, as shown by the increase in licensor selection for renewable ammonia synthesis.

Envision green ammonia production plant, Chifeng City, Mongolia. This wind-powered plant has been operating since 2024.

PHOTO: MARUBENI

Status of renewable ammonia production

The Ammonia Energy Association (AEA) tracks progress on ammonia decarbonisation globally via its Low-Emission Ammonia Data (LEAD). The database is updated quarterly and includes information about ammonia plants, ammonia-fuelled maritime vessels, and ammonia infrastructure. The underlying source data for LEAD are available to the AEA's membership.

LEAD shows a large number of announced renewable ammonia plants, mainly powered by solar and wind generated electricity. In the third quarter of this year, operational renewable ammonia projects collectively exceeded one gigawatt (GW) of installed electrolyser capacity for the first time – in excess of 85% of this capacity being based on alkaline electrolysis, with the remainder representing proton exchange membrane (PEM) electrolysis.

Combined, these operational plants are capable of producing around 625,000 tonnes per annum (t/a) of renewable ammonia. Newbuild projects in Northern China, like Envision's Chifeng project and SPIC's Da'an project, collectively represent 500,000 t/a of this production capacity. Smaller 5-25 megawatt (MW) capacity revamps at existing gas-based ammonia plants represent 95,000 t/a of this production total.

Projected capacity for low-emission and transitional ammonia plants by project type (newbuild and revamp) and by technology pathway (gas reforming, water electrolysis, other) are shown in Fig. 1. This includes completed and well-advanced projects that are either:

- **Operational** – already in production
- '**Firm**' – having reached financial investment decision (FID)
- '**Mature**' – at the front-end engineering design (FEED) stage.

It is expected that individual ammonia plants with electrolyser capacities in the gigawatt range will come online in 2026 and 2027. These notably include the 2.2 GW capacity NEOM project in Saudi Arabia which will have the capability to produce 1.2 million t/a of renewable ammonia.

Renewable ammonia licensors

The selection of the licensor is a critical milestone in the development of renewable ammonia projects.

A key requirement for these projects is the flexibility of the ammonia synthesis loop. In particular, the ability of this loop to operate at low loads is desirable, in response to variable solar and wind electricity supply, as

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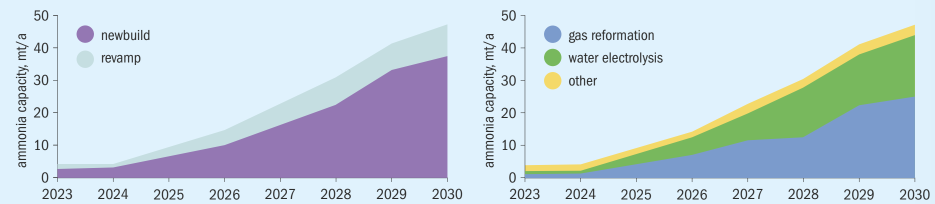
Fig. 1: **Low-emission and transitional ammonia plants*: by project type (newbuild and revamp) and by technology pathway (gas reforming, water electrolysis, other)**



Source: Ammonia Energy Association

**Data represent projects that are either operational, 'firm' (reached financial investment decision) or 'mature' (at the front-end engineering design stage).*

well as being necessary to avoid excessive hydrogen storage requirements.

Most licensors for renewable ammonia projects claim the ability to operate at 10% minimum load, although maintaining a minimum load of 20% is generally preferable to minimise both metallurgical fatigue and the power consumption of the ammonia synthesis loop.

KBR: licenses for 14 K-GreeN® plants

Science, technology and engineering giant KBR is a major ammonia licensor. Around 50% of global ammonia production capacity, excluding China, uses a KBR license, according to the company.

KBR's K-GreeN® technology (*Nitrogen+Syngas* 387, p. 32) offers a fully integrated process for:

- The electrolysis of water to produce hydrogen
- The separation of air to produce nitrogen
- Haber-Bosch synthesis of renewable ammonia
- Plus battery and hydrogen storage capacities.

JGC's Green Ammonia Plant in Japan use KBR technology.

KBR's ammonia synthesis section can use a vertical or horizontal ammonia converter, depending on project requirements, as KBR has designed both types of converter for many plants currently in operation. The other distinctive feature of KBR's renewable ammonia technology is the unitised chiller. This significantly reduces the equipment count, and therefore capex, as well as providing ease of operation.

K-GreeN can run in a dynamic mode, with the ability to turn down to 10% of nominal capacity, and ramp up and down from 100% of capacity within an hour. K-GreeN includes an Advance Process Control to manage dynamic operation. This overarching proprietary control system looks after the whole plant – including the electrolysers, the air separation unit and hydrogen storage – to maximise and optimise ammonia production, factoring in weather forecasts and grid electricity prices, for example, if applicable.

KBR's licensed technology package includes associated performance guarantees alongside the delivery of proprietary equipment such as the ammonia converter and unitised chiller. In developing its K-GreeN concept, KBR has leveraged its 75-plus years of experience in designing ammonia plants, with these ranging from very small capacity (four tonnes per day (t/d) of ammonia) to the largest single-train capacity (6,000 t/d of ammonia).

K-GreeN can be fully modularised to meet the required capacity by following an engineering, procurement and fabrication (EPF) strategy. Alternatively, KBR can use its engineering services to offer an integrated stick-build construction strategy covering the entirety of a project, from its first stages to engineering, procurement and construction management (EPCm) services.

KBR sold its 14th license for a renewable ammonia synthesis loop to Celsia in Colombia. The list of known KBR licenses includes:

- ACME's Green Hydrogen and Chemicals SPC project, Oman, 300 t/d capacity
- JGC's Green Ammonia Plant, Japan, 4 t/d capacity pilot project
- Enaex's HyEx project, Chile, 57 t/d capacity pilot project (full-scale plant later)
- Atlas Agro's Pacific Green Fertilizer Plant, United States
- The MadoquaPower2X project of Madoqua Ventures, Power2X, and CIP, Portugal, 1,200 t/d capacity
- Avina Clean Hydrogen's Nueces Clean Ammonia project, United States, 2,200 t/d capacity hybrid plant
- The H2biscus project of Lotte Chemical, Samsung Engineering and POSCO, Malaysia, 2,286 t/d capacity

PHOTO: TOPSOE

Topsoe is the technology provider to the green ammonia demonstration plant, Ramme, Denmark.

- Fortescue's Holmaneset project, Norway, 675 t/d capacity
- OCIOR's project in Gopalpur, India, 600 t/d capacity
- Project Celsia, Colombia, 84 t/d capacity.

Topsoe: licensing DynAMMO™ to NEOM

Topsoe licenses its DynAMMO™ ammonia loop for renewable ammonia production. The company claims a load flexibility of between 10-100% with full ramp up within minutes, as well as fast restarts after stand-by mode or total shutdown. The technology is demonstrated at the 24 t/d capacity REDDAP ammonia demonstration plant in Lemvig, Denmark. Small ammonia plants of up to 600 t/d capacity, known as Topsoe ModuLite Green Ammonia, can be prefabricated rather than stick built on-site.

Topsoe has licensed the world's largest renewable ammonia synthesis loop so far – the 3,500 t/d capacity unit for NEOM's solar and wind project in Saudi Arabia. Other examples of synthesis loops licensed by Topsoe for renewable ammonia projects include the:

- 1,650 t/d capacity unit for Project Nujio'Qonik in Newfoundland, Canada
- 1,800 t/d capacity unit for Mintal Hydrogen Energy Technology in Baotou, China
- 2,500 t/d capacity unit for Allied Green Ammonia in Gove, Northern Territory, Australia
- 750 t/d capacity unit for Hygenco in Gopalpur, Odisha, India.

Additional to its leading capabilities as a catalyst provider and ammonia licensor, Topsoe has also constructed a factory for manufacturing solid oxide electrolysers in Denmark, with 5 GW of capacity already secured by project developer First Ammonia.

thyssenkrupp Uhde: dynamic Uhde® ammonia synthesis technology

thyssenkrupp Uhde is an ammonia licensor and a full engineering, procurement and construction (EPC) provider to the chemical industry. It licenses its flexible ammonia synthesis loop, dynamic Uhde® ammonia synthesis technology, with capacities available from 50 t/d up to 6,000 t/d.

thyssenkrupp Uhde's RHAMFS® methodology also offers full concept process optimisation, from the renewables stage up to ammonia production (*Nitrogen+Syngas* 394, p. 48). With the company's proprietary Master Controller, it is possible to ramp the ammonia plant up and down between 10-100% load in response to fluctuating renewable energy availability. Overall, thyssenkrupp Uhde's design offers a combination of operational flexibility and energy efficiency.

The world's oldest operational electrolysis-based ammonia plant, the 50 t/d capacity in Cuzco plant operated by Enaex in Peru, is based on thyssenkrupp Uhde technology.

As well as providing licenses, thyssenkrupp Uhde has built four operational electrolysis-based ammonia plants – including KIMA's 400 t/d capacity ammonia plant in Egypt.

As an experienced chemical engineering and EPC provider, thyssenkrupp Uhde has the capability to deliver fully integrated and modularised ammonia plants This combination of technology and deployment expertise allows thyssenkrupp Uhde to significantly de-risk the overall project – via schedule and cost assurances and performance guarantees.

As of 2024, thyssenkrupp Uhde has conducted numerous techno-economic,

IMAGE: THYSSENKRUPP

Graphic visualisation of a Thyssenkrupp Uhde renewable ammonia plant.

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pre-FEED and FEED studies for renewable ammonia projects globally, with a production capacity equivalent to 30 million t/d. Examples include studies in Australia, Pakistan, Spain, the United Arab Emirates, and Vietnam. Notable pre-FEED and FEED studies have been performed in:

- Australia for Fortescue, CQH2 and CIP
- Spain for Hive Energy
- South Africa for Prieska Power.

Floating ammonia production concepts have also been developed by Uhde for SwitchH2 and BWO.

Spin off company thyssenkrupp nucera, meanwhile, is a leading OEM for alkaline electrolysers. It will supply the more than 2 GW of electrolyser capacity needed for the NEOM project in Saudi Arabia.

Casale: Flexigreen® Design for Green Ammonia Plants

Licensor Casale is well known for its proprietary axial-radial vertical converter which lowers the pressure drop and improves the performance of the ammonia synthesis loop. Casale has installed these converters in over 250 plants globally, most recently using the AmoMax®-Casale catalyst jointly developed with Clariant. Casale also provides revamping solutions for horizontal ammonia converters.

Casale's experience with electrolysis technology goes back to the origins of the ammonia industry. More than a dozen of the first grassroot ammonia plants licensed by Casale in the 1920s were based on hydrogen generated by electrolysers.

Casale licenses the Flexigreen® Green Ammonia designs for renewable ammonia plants. To ensure optimal performance, small-scale plants utilise the company's SMART-N synthesis loop, with minimal equipment items and relatively higher pressures, while large-scale plants utilise its FlexAMMONIA synthesis loop.

Casale offers operational flexibility down to 10% of nominal load. This has been industrially tested in a world-scale ammonia plant with 1,500 t/d capacity. Fast load changes in ammonia synthesis capacity – of 3% per minute – are also claimed.

Casale offers an advanced process controller to optimise plant operations under varying power supply conditions. The operation and design of the ammonia synthesis loop avoid fatigue issues for various components by taking account of potential load cycling. Additionally, optimisation tools and dynamic analysis are available to minimise ammonia production costs.

ATOME's Villeta project in Paraguay will incorporate Casale's Flexigreen® technology.

Casale has licensed 12 renewable ammonia plants, as of 2024. Examples of renewable ammonia synthesis loops licensed by Casale include:

- SkiGA's Skipavika project, Norway, 300 t/d capacity, modularised design
- ATOME's Villeta project, Paraguay, 240 t/d capacity
- Incitec Pivot's (now defunct) Gibson Island revamp project Australia, 1,100 t/d capacity
- AM Green's revamp project in Kakinada, India, two plants with a capacity of 1,500 t/d each
- Avaada's project in Gopalpur, Odisha, India, 1,500 t/d capacity
- EverWind Fuels' Point Tupper project in Nova Scotia, Canada, 750 t/d capacity
- ACME's Gopalpur project in Odisha, India, 1,200 t/d capacity
- RTI International and the University of Minnesota's pilot project in Morris, Minnesota, 1 t/d capacity.

Casale has also developed hybridisation projects with MIX-N technology, such as Fertiglobe's 1,350 t/d capacity EFC 2 plant revamp in Egypt. This is partially converting the existing plant to renewable ammonia as part of the Egypt Green project.

Computer generated 3D model of a Stamicarbon Green Ammonia plant.

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Stamicarbon (NEXTCHEM): NX Stami Ammonia™ for various scales of ammonia production

Stamicarbon, the nitrogen technology licensor of NEXTCHEM, offers two distinct ammonia technologies as part of its NX STAMI™ Ammonia portfolio (See article p. 34). The medium-pressure design is available for large-scale plants of up to 3,500 t/d capacity.

The alternative high-pressure design is suited to medium-scale renewable ammonia production (50-500 t/d) and is flexible and responsive – being able to operate down to 10% of nominal load and quickly ramp up and down. The relatively high pressure of the ammonia synthesis loop enables capex savings by reducing the number of equipment items. This also means the plant has a relatively small footprint (e.g., 50 x 50 metres for a 500 t/d capacity unit).

Notably, Stamicarbon has secured the technology license for JWC Gburg's wind-powered 450 t/d capacity Meadowlark green ammonia project in Nebraska in the United States. Stamicarbon is also the ammonia technology licensor for FertigHy's low-carbon fertilizer project in Northern France.

The company is also involved in renewable ammonia projects in Angola, Indonesia, Kenya, Qatar and the United States.

GoodChina: ammonia converters for renewable ammonia production

Nanjing GoodChina Chemical Technologies (GoodChina) is a Chinese ammonia converter manufacturer. While, historically, the company has mainly delivered ammonia and methanol synthesis converters for coal-based processes, it has also successfully delivered equipment for renewable ammonia projects in recent years.

In fact, GoodChina delivered the ammonia converter for ACME's renewable ammonia pilot in India back in 2021, a 5 t/d capacity plant constructed by KAPSOM. It also supplied the reactor for Envision's 20,000 t/a demonstrator in Chifeng, Inner Mongolia, which began operating in March 2024.

Various GoodChina ammonia converters have been ordered for commercial-scale renewable ammonia plants, including:

- Two ammonia converters, each producing 150,000 t/a of ammonia, for Phase 1 of Envision's Chifeng project which began operating in July
- The ammonia converter for SPIC's 180,000 t/a capacity Da'an project in Jilin province which also entered production in July
- The ammonia converter for Phase 1 of China Energy Engineering Group's Green Hydrogen-Ammonia-Methanol Integration Project at Songyuan Hydrogen Energy Industrial Park, which is scheduled to start producing 200,000 t/a of ammonia from late 2025 onwards
- The ammonia converter for Shenzhen Energy's 150,000 t/a capacity project in Otog Banner, Inner Mongolia
- The ammonia converter for Ningxia Baofeng Energy's 80,000 t/a capacity project in Ningdong, Ningxia. ■

Indonesia's push for new urea capacity

Already a large urea supplier to the region, Indonesia has plans for several new plants to monetise its natural gas resources.

Indonesia's economy is the largest in Southeast Asia, with GDP projected to grow at around 5% in 2025. Already a G20 member, the country is focused on structural reforms and sustainable development to become one of the world's top five economies by 2050. The economy expanded by around 5% in 2024, with similar growth rates projected for 2025 (the official government forecast is 5.2%, though other forecasts like the OECD and IMF are around 4.7-5.0%). This growth is mainly underpinned by private consumption, which accounts for over half of GDP, and robust investment.

One key to the development of Indonesia's economy has been exploitation of its considerable natural resources. Indonesia holds the world's largest nickel reserves and significant deposits of other critical minerals, the government has banned exports of unprocessed minerals to force domestic processing ("downstreaming"), attracting foreign direct investment in higher value-added industries like electric vehicle (EV) battery production. However, with the world's fourth-largest population and a large, growing working-age demographic, domestic consumption is the primary engine of economic growth.

PHOTO: SEETAO

The Pusri site, Palembang, Indonesia

Feedstock resources

Indonesia holds substantial natural gas reserves, the third highest in the Asia-Pacific region after China. Proven reserves were estimated at 49.7 tcf in 2021. It is also the fourth-largest natural gas producer in Asia, behind China, Australia, and Malaysia. However, a key challenge is decreasing production from older, mature fields, necessitating the development of new resources. Production has fallen from 76 bcm in 2015 to 63 bcm in 2022, although this picked up in 2023 and 2024. The government has a goal of 120 bcm/year production by 2030, which will require substantial investment.

The industrial sector is the largest consumer, accounting for around 77% of total final consumption, with the fertilizer industry prominent among these consumers. The "Specific Natural Gas Price" (HGBT) program caps prices at $6.50/MMBtu for certain industries to support growth.

The scattered island nature of the country has discouraged pipeline building and prompted a focus on LNG development; Indonesia and Malaysia were among the pioneers of the LNG industry, dating back to the gas boom of the 1980s. But there are also several high-profile projects to generate future supply, including Abadi LNG (Masela Block), operated by Inpex, which is aiming for production in the early 2030s after numerous delays. BP operates the Tangguh gas project in West Papua, which is undergoing a $7 billion expansion (Train 3) to boost LNG production capacity significantly. Eni has acquired Chevron's stake in this project in the Makassar Strait and has made a significant discovery at the Geng North field, which is expected to come online around 2027 and channel gas to the Bontang fertilizer complex.

As Table 1 shows, Indonesia is not the largest gas producer or exporter in the region; that title now goes to neighbouring Malaysia, also a significant urea producer, though by no means as much as Indonesia. Brunei, Myanmar and New Guinea are also now large LNG exporters, while Vietnam is self sufficient and Thailand remains a net importer in spite of recent improvements in domestic natural gas production.

Table 1: **Gas production and exports in Southeast Asia, 2023 (billion cubic metres)**

	Production	Exports
Brunei	10.0	5.5
Indonesia	64.3	18.9
Malaysia	81.1	35.0
Myanmar	15.2	10.9
Papua New Guinea	14.0	11.0
Thailand	25.7	-2.2
Vietnam	7.2	0

Source: Statistical Review of World Energy

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There are also major coal reserves in the region. Indonesia has by far the largest reserves, and produced 775 million tonnes of coal in 2023, of which it exported two thirds, mainly to China. Coal production has increased by 60% over the past decade, and Indonesia is actually the world's largest coal exporter, surpassing even Australia.

Fertilizer production

Indonesia's ammonia and urea production developed on the back of natural gas discoveries in the 1970s and 80s, when the fragmented nature of the region with its myriad islands meant that local outlets for many gas finds were limited due to lack of pipeline capacity, and a number of ammonia-urea projects were built based on what was then 'stranded' natural gas. By 1989 Indonesia had 5.3 million t/a of urea capacity and was the largest exporter in the region. Six more urea plants followed in the 1990s and 2000s; two at Bontang, one at Lhokseumawe, one at Cikampek, one at Gresik, and a replacement plant for Pusri at Palembang, which added in total another 2.7 million t/a of urea capacity. However, by now rapid industrialisation was leading to greater domestic demands for gas for power production, while maturing gas fields began to reduce feedstock availability to some locations, leading to the closure of the ASEAN Aceh urea plant in 2004. Urea consumption also rose within Indonesia, and the government began to restrict exports at certain times of year. Urea exports peaked in 1997 at 2.4 million t/a, and by 2004 fell to below 500,000 t/a. Rising gas prices meanwhile were impacting upon company margins.

In spite of this, Indonesia has continued to build newer more modern facilities to replace older plants that are being taken out of service. In 2015, Kaltim started up its Kaltim-V urea plant, with a capacity of 1.1 million t/a of urea, to replace the ageing Kaltim-I plant, and in 2017 Pusri likewise replaced the Pusri II plant with the 900,000 t/a Pusri IIB. By 2018, Indonesian urea production had risen to 7.4 million t/a, and exports were back up to 1.1 million t/a. In December 2018, a new 700,000 t/a standalone ammonia plant was commissioned by PT Panca Amara Utama (PAU) in Sulawesi, and Indonesian urea production has average around 7.7 million t/a since 2019. By 2021 urea exports had increased back to 2 million t/a, though a recovery in domestic demand since then means that this has fallen back to 1.4 million t/a in 2024.

Table 2: **Urea production and demand, Southeast Asian countries, 2024, million t/a**

	Production	Consumption	Imports	Exports
Brunei	1.1	0.0	0.0	1.1
Indonesia	7.7	6.3	0.0	1.4
Malaysia	2.3	0.5	0.2	2.0
Myanmar	<0.1	0.5	0.4	0
Philippines	0	0.9	0.9	0
Thailand	0	2.7	2.7	0
Vietnam	2.5	2.5	0.5	0.6
Total	13.6	13.5	5.0	5.1

Source: CRU

Regionally, as shown in Table 2, Indonesia remains the largest producer of urea, though Malaysia is actually a larger exporter due to increasing domestic Indonesian demand for urea. Vietnam is roughly self-sufficient in urea, while Thailand, Myanmar and the Philippines are all significant importers. Overall, however, the Southeast Asian market is roughly balanced.

Self-sufficiency

The Indonesian government continues to prioritise national food self-sufficiency and reduce reliance on imports. In 2024, the government said that it was working with state fertilizer groups on around $6 billion of new ammonia/urea plants to help curb food costs and reduce import dependence. The announcement, though slightly speculative, envisaged a combination of new plant construction and the revitalisation of existing facilities, in order to dramatically increase its domestic urea production capacity.

The primary catalyst for this is Indonesia's long-standing goal of bolstering national food security. Agriculture is a cornerstone of the Indonesian economy, and ensuring farmers have access to sufficient, affordable fertilizer, particularly urea and NPK, is critical for boosting crop yields, especially for key commodities like rice and soybeans. Historically, the country has navigated a complex balance between domestic needs and export opportunities. In recent years, concerns over food security have led the government to implement stricter controls on urea exports, prioritising local market demand. This policy shift became more pronounced in 2024 and 2025, with state-owned fertilizer group PT Pupuk Indonesia (Persero) directed to ensure the availability of subsidised fertilizers for domestic farmers before considering international sales. The government has increased its fertilizer subsidy allocation to around IDR 39 trillion (approximately $2.5 billion) to aid farmers, a clear indication of the priority placed on domestic agricultural productivity.

The new production facilities are central to this strategy, designed to guarantee a stable and plentiful domestic supply, thereby stabilizing food costs and enhancing the resilience of the agricultural sector.

New urea plants

At present there are two large scale expansion projects under way; a new greenfield plant in Fakfak, West Papua, and the revitalisation of the Palembang complex on South Sumatra via the new Pusri-IIIB facility. Pusri IIIB is a continuation of the company's modernisation programme, as when it replaced the ageing Pusri II plant several years ago. PT Pupuk Indonesia is replacing its old Pusri-III and Pusri-IV trains with the advanced Pusri-IIIB plant. This project represents an investment of around $670 million and is expected to produce approximately 900,000 t/a of urea and 445,000 t/a of ammonia. Pupuk Indonesia has licensed KBR's Purifier™ ammonia technology, improving energy consumption on the older plants, with a quoted specific energy consumption for urea production at 21.97 MMBtu per tonne and for ammonia at 32.89 MMBtu/tonne. Toyo is providing its ACES21 technology for the urea unit. Construction began in 2023 and the plant is expected to be on-stream in 2027.

The Fakfak Project on West Papua is being spearheaded by PT Pupuk Kalimantan Timur (Pupuk Kaltim), a subsidiary of Pupuk Indonesia. With an investment exceeding $1 billion, this facility is designed to produce 1.15 million t/a of urea and 825,000 t/a of ammonia. The Fakfak plant is strategically located to meet the growing fertilizer demand in Indonesia's eastern regions, where logistical costs for transporting fertilizer from western production hubs have historically been a challenge. Expected to be operational around early 2028, the plant is also aligned with the government's plans to expand agricultural land, particularly for paddy fields in nearby Merauke, which is projected to create a local demand for around 500,000 t/a of urea and NPK fertilizers.

Other potential projects include a blue ammonia and possibly urea plant being developed by PT Pupuk Indonesia on Yamdena. A heads of agreement was signed this year with a provisional on-stream date of 2030, but it is not believed that FEED work has been completed. Pupuk Indonesia says that it plans to use gas supply from the Abadi Field to operate the ammonia plant. This plant is estimated to require a long-term gas supply of 150 million scf/d.

Pupuk Kujang has also discussed a gas-based ammonia-urea project at Senoro on Sulawesi, but there has been no update for some time. There have also been discussions around a coal-based urea plant, but this seems to have been shelved due to environmental concerns.

Recently, however, the Indonesian government has announced that it aims to establish a total of seven new fertilizer plants across the country, with five of them completed by 2029, at an estimated total investment of around IDR 50 trillion ($3 billion). The figure includes the Pusri and Fakfak plants already under development, as well as the Yamdena CCS project, and other potential projects at Gresik, Kujang and Bukit Asam. The ultimate goal is to increase the total subsidised fertilizer production capacity significantly, ensuring a robust national supply that can handle fluctuations in global markets and reduce dependence on external sources. Pupuk Indonesia has signed two preliminary agreements to explore cooperation in the utilisation of natural gas from two oil and gas projects, namely the Masela Working Area and the Andaman South Working Area as feed for the plants. Agriculture Minister Andi Amran Sulaiman said during a press conference in October this year that the new plants will be energy-efficient, helping reduce production costs. While older factories allocate up to 43% of their operational costs for gas, the new facilities are expected to spend only around 22–23%, he said. He added that the construction budget will be sourced from efficiency programmes implemented by the ministry. Adjustments to subsidised fertilizer management, which emphasise upstream aspects, have also contributed to funding the new plants. The minister further stated that the establishment of new plants will create opportunities to gradually increase subsidised fertilizer production to 700,000 t/a by 2029.

Challenges

Ambitious plans tend to require overcoming significant hurdles. While the government insists that the funding required can be met from existing budgets, securing the substantial funding required can be a complex endeavour, involving syndication from various state-owned and private entities. Furthermore, ensuring a stable and cost-effective supply of natural gas, the primary feedstock for conventional ammonia and urea production, remains crucial. There are also still question marks over the use of CCS technology such as is anticipated at Yamdena. As a result, CRU currently only considers the Pusri IIIB project to be firm, with Fakfak likely, though potentially with slippage in its timeline, and the others still speculative at this stage.

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2025 AIChE Ammonia Safety Symposium

Venkat Pattabathula reports on the American Institute of Chemical Engineers' (AIChE) Safety in Ammonia Plants and Related Facilities Symposium, held from September 7–11th 2025, in Atlanta, Georgia, USA.

Atlanta, venue for this year's symposium.

PHOTO: F11PHOTO/SHUTTERSTOCK.COM

From September 7–11th, 2025, approximately 350 engineers representing more than 100 companies from over 30 countries attended the AIChE's 69th Annual Ammonia Safety Symposium, held at the Atlanta Marriott Marquis in Atlanta, Georgia, USA. The event brought together global experts, engineers, and safety professionals to share insights, case studies, and innovations aimed at improving safety performance in ammonia production and handling facilities.

The Ammonia Safety Committee is committed to enhancing safety across facilities that produce ammonia and related chemicals – including urea, nitric acid, ammonium nitrate, and methanol. The primary goal of the annual symposium is to advance safety performance within the ammonia industry by fostering the exchange of insights on incidents, best practices, and technological innovations through presentations and open discussions.

Participants include plant managers, production and safety leaders, process and reliability engineers, and other professionals responsible for the safe operation of ammonia plants and handling facilities. Global experts share the latest developments in ammonia safety, present case studies, and discuss lessons learned to promote continuous improvement.

Safety excellence

The symposium's keynote address, titled "Mastering the 5 Core Capacities for Safety Excellence," was delivered by Shawn Galloway, Chief Executive Officer of ProAct Safety, Inc. Shawn opened his presentation with a thought-provoking question about the three paths to achieving zero injuries and emphasized that safety excellence is founded on Insight, Mindset, Systems Confidence, and Ability. He then introduced the five core capacities essential to safety excellence: System, Leadership, Engagement, Cultural, and Strategic, and explained that these capacities form the foundation for building resilient safety cultures and driving continuous improvement.

In the segment on understanding people and performance, Shawn Gallaway highlighted five key principles. First, people will make mistakes. Second, the manner in which leadership responds to those mistakes matters greatly. Third, behaviour is shaped by contextual influences rather than by simple willpower alone. Fourth, learning from normal operations, from deliberate post-work reviews, and from incidents is vital to continuous improvement. Fifth, error-likely situations are predictable and therefore can be identified and managed proactively.

Shawn also described common motivators and demotivators for safety engagement. Typical motivators include opportunities for input, a sense of ownership, meaningful involvement, teamwork, scorekeeping, continuous improvement, healthy competition or "winning," task variety, and recognition. Common demotivators include constant or poorly managed change, withholding of information, perceived hypocrisy or dishonesty, unfairness, unproductive activities, unhealthy internal competition, lack of follow-up, over-control, and ignoring frontline input. His central message was that aligning leadership, systems, and culture creates environments

PHOTO: AICHE

The 2025 AIChE Ammonia Safety Committee Seated (L to R): Samuel Okulaja (Nutrien), Seshu Dharmavaram (Air Products), Mohamad Noueiri (Yara), Ahmed Esmael Rahimi (Qatar Fertiliser Company), Marc Gilberston (East Dubuque Nitrogen Fertilizer), Kristina Balch (Dyno Nobel), Venkat Pattabathula (SVP Chemical Plant Services). Standing (L to R): John Brightling (Johnson Matthey), Klaus Noelker (thyssenkrupp Uhde), Lari Bjerg Knudsen (Topsoe), Ashutosh Shukla (FFI), Federico Zardi (Casale SA), Mark Schroeder (Koch), Taylor Archer (Clariant), Eugene Britton (CF Industries). Not in the picture: Umesh Jain (KBR)

where safety is not only a stated priority but a shared organizational value.

The symposium also featured a number of technical papers addressing recent safety incidents and their investigations. The key safety-related papers are summarised overleaf:

1. Ammonia leak on a marine loading arm

On February 4, 2024, at approximately 10:50 AM, a leak developed at the emergency release system (ERS) of a marine loading arm while ammonia was being loaded into the Marcella, an LPG carrier. Operators mitigated the release by reducing loading rates from 600 t/h to 300 t/h, and completed operations at the lower rate. The event was classified as a Tier 2 process safety event and was caused by failure of the double ball valve assembly, resulting in a loss of primary containment that was confined to the immediate area; no injuries were reported. Post-incident inspections revealed seal failure due to deformation of mating flanges between upstream and downstream ball valves and a crack on the external surface of the valve body. A metallurgical analysis and finite element analysis (FEA) modelling supported the investigation and identified the root cause as an overpressure scenario caused by trapped liquid ammonia within the valve assembly. A novel repair method validated through a level 3 fitness-for-service assessment was implemented; the repair process included non-destructive examinations, functional checks, and validation of integrity and performance. The repaired system has since operated reliably for more than ten months without recurrence. The investigation used a root cause incident investigation framed by the human and organisational performance (HOP) approach to identify causal factors and improvement opportunities, and it recommended enhanced pressure relief strategies, mitigation of stress corrosion cracking, and improved design and operational controls for valve assemblies, along with continued monitoring of repaired components.

2. Chloride ingress into steam system

An ammonia plant commissioned in late 2021 experienced significant operational disruption when high conductivity in outsourced water produced out-of-specification boiler feed water, which led to chloride contamination of the steam system. Early in 2023, outsourced water conductivity reached 450 μS/cm, well above the design limit of 175 μS/cm; the polished water system, designed for 0.2 μS/cm, could not meet the specification. In March 2023, two portable reverse osmosis units were rented to reduce conductivity, but their performance was inconsistent because of frequent membrane cleaning, chemical dosing, system trips, and intermittent reverse osmosis bypasses.

In August 2023, a reformer trip caused by a low steam-to-carbon ratio initiated a cascade of issues, including a dry gas seal failure in the refrigeration gas compressor, partial plant operation at 70% with venting downstream of the CO_2 removal section, increased polished water conductivity that raised CO slip in the high temperature shift (HTS) reactor from roughly 3.0 mol% to about 7 mol%, and failure of a high-pressure steam superheater coil that led to a full plant trip. Inspections found that the HP steam superheater coil failure resulted from detached liner sleeves that plugged coils and caused flow starvation and overheating, with commissioning debris contributing to the blockage. White deposits on the HTS catalyst were confirmed to contain chlorides, indicating catalyst poisoning.

The root cause analysis identified high water conductivity in outsourced water as the primary cause, which led to chloride contamination, catalyst deactivation, corrosion and mechanical damage across steam turbines, syngas systems, refrigeration systems, and auxiliary boilers, and posed significant process safety risks. Corrective actions included upgrading water treatment by replacing the two RO units with five high-capacity osmosis units sized to 120% of plant load, and replacing resins in demineralised and polished water units; performing mechanical repairs such as installing new rotors in syngas and refrigeration turbines and replacing corroded boiler components; and implementing catalyst management measures including removal of approximately 30% of the HTS catalyst, collection of spent catalyst for analysis, and installation of a chloride guard with catalyst to prevent future poisoning. These measures successfully restored plant operation and efficiency and underscored the critical importance of water quality control, robust water treatment systems, and early detection of contamination.

3. High temperature exposure of HTS catalyst

A fresh charge of HTS catalyst was exposed to elevated inlet temperatures of 680°F (360°C) for 18 days, exceeding the recommended start-of-run range of 620–630°F (326–332°C). That prolonged exposure caused the exotherm to shift from the top to the middle of the catalyst bed and

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degraded catalyst performance, as shown by increased CO slip and a higher approach to equilibrium. The root cause investigation traced the problem to a refractory repair performed during the 2023 turnaround under time pressure; a bulged liner section and prior refractory loss had been known since commissioning, and the repair was compromised by limited access, catalyst dust inhibiting proper bonding, and omission of dry-out procedures. After startup, detached castable refractory was carried downstream and partially blocked inlet tube ferrules, and on April 29, 2023, refractory lodged in the bypass valve seat prevented full closure and allowed uncontrolled hot gas bypass. Continued refractory carryover increased the blockage, forcing more hot gas through the bypass line and gradually raising the HTS inlet temperature to 680°F.

Corrective actions included removal of loose refractory, welding repairs to restore bypass valve sealing integrity, development of a detailed refractory repair procedure with post-application quality checks, and implementation of a preventive maintenance regime that includes inspection of the 1101-C bypass components every three years during major turnarounds, mechanical testing of valve internals, and condition monitoring of the transfer line to detect localized refractory loss. Key learnings emphasised following OEM-recommended refractory procedures including dry-out protocols, ensuring bypass valve integrity through routine internal inspections, and operating the HTS reactor at the minimum practical inlet temperature that achieves the required CO conversion to minimise sintering and preserve catalyst activity; the plant expects a reduction in HTS catalyst life by one to two years based on the elevated inlet temperatures and CO slip trends.

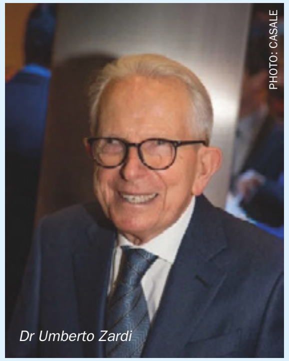
4. Runaway reaction of an oxidised LTS catalyst bed

In 2024, an ammonia facility experienced a potentially destructive runaway reaction in its short shift reactor during startup, after a catalyst bed replacement, but before the reduction process had been completed. Although the reactor had been isolated from the normal process flow path, a rapid increase in temperature and pressure occurred, exceeding the vessel's maximum allowable working temperature; no equipment damage was found, but catalyst life was significantly shortened. The root cause investigation found that hydrogen had entered the reactor via process gas vented through the high vent system, which contained approximately 43% hydrogen rather than the roughly 2% typically used for reduction.

The likely reverse flow path was the pilot-operated pressure safety valve (PSV) on the reactor outlet: the pilot PSV, despite having a backflow preventer, leaked backward and allowed hydrogen-rich gas and steam to enter the vessel. Temperature indicators showed bottom-up heating consistent with gas entry through the PSV, and vessel pressure remained elevated during emergency shutdown even as high vent pressure fell, supporting the reverse-flow hypothesis and subsequent sealing of the dome. Contributing factors included unusual startup conditions in which the short shift bed was replaced and reduced while the plant was offline, a design oversight that did not consider the pilot PSV flow path as a reverse-flow risk, and the identification that the LTS reactor shared the same vulnerability.

Corrective actions and recommendations were implemented: modifying standard operating procedures to pressurise oxidised short shift and LTS beds with nitrogen during startup until reduction begins; installing block valves beneath pilot PSVs on both reactors to allow isolation during catalyst handling or startup; adding conditional temperature alarms to detect runaway conditions earlier because existing high-temperature alarms were set too high to be effective; and sharing the findings across company sites while including potential problem analysis in future short shift changeouts. The key learning was that pilot PSVs, while effective under normal conditions, can present unexpected reverse-flow risks during atypical startup scenarios, and startup procedures must explicitly account for these atypical flow paths.

Umberto Zardi: a lifetime of engineering innovation



Dr Umberto Zardi

The Symposium also paid tribute to the life and work of **Dr Umberto Zardi** (July 1929–March 2025) of Casale, a mechanical and process engineering pioneer whose ideas reshaped modern ammonia and urea production. His career combined practical engineering, bold innovation, and mentorship to generations of engineers.

Zardi's development of the self-stripping urea technology beginning in the 1960s became an industry benchmark, enabling efficient large-scale urea plants and, by the early 2000s, single-line capacities exceeding 3,000 t/d. More than 140 urea plants were built using his original concepts, demonstrating the technology's long-term competitiveness on both capital and operating costs. In 1979 he introduced the axial-radial ammonia converter, a design that reduced pressure drop, improved catalyst utilisation, and delivered higher yields with lower energy consumption.

Beyond new designs, Zardi championed an ammonia converter and plant revamping concept that prioritized modernisation over full replacement. This approach allowed hundreds of plants to be upgraded cost-effectively, along with large annual energy savings and across some 300 plants a multi-million-ton reduction in CO_2 emissions.

A prolific innovator, Zardi registered more than 130 patents across multiple countries, and led teams at Snamprogetti and later Casale to expand technologies that made fertilizer production more efficient and sustainable. His leadership combined technical rigor with integrity and generosity, and he remained an active member and contributor to AIChE throughout his life. His legacy lives in the plants, patents, and people who continue to apply his principles of elegant, efficient engineering — a lasting influence on the fertilizer and chemical industries worldwide.

5. Nitriding and crack propagation in a waste heat boiler seal

In March 2023, a jet fire occurred at the inlet nozzle lip seal of a waste heat boiler (WHB) in an ammonia plant's synthesis loop. The failure was traced to nitriding-induced cracking of a UNS S34700 stainless steel lip seal, and the problem was exacerbated by incorrect application of external insulation. The root cause analysis revealed similar failures at identical WHB lip seal locations in other regional plants, indicating a systemic vulnerability. Technically, nitriding is a high-temperature degradation mechanism whereby nitrogen diffuses into stainless steel to form a hard, brittle nitride film about 100–400 µm thick; these nitride films crack under thermal cycling, especially in flexible components such as lip seals and bellows, and, once cracked, the nitride layer creates a notch that initiates fatigue cracks into the ductile base metal. In this case, the WHB shell was SA336 F22 (2¼Cr–1Mo) and the inlet flange was SA965 F347 (UNS S34700); a welded gasket lip seal was used to join the dissimilar alloys. During a prior shutdown, external ceramic insulation was mistakenly applied to the lip seal and flange bolts, which trapped heat and elevated bolt temperatures to approximately 425°C (797°F), causing thermal elongation and stress relaxation; finite element analysis showed that ASTM A193 B16 bolts retained only 43% of residual stress after 1,000 hours at that temperature. Although the lip seal temperature reached 247°C (477°F), below the 300°C (572°F) critical threshold, the insulation eliminated ambient cooling and accelerated nitriding and cracking.

Industry outreach showed that plants without external insulation or those using pup pieces to transition between dissimilar alloys did not experience failures. Recommendations included never externally insulating lip seal joints in syngas service, removing existing insulation from lip seals during shutdowns or depressurised conditions, barricading and monitoring insulated lip seals that have been in long-term service until replacement, verifying lip seal skin temperature with calibrated infrared cameras (with <300°C indicating lower nitriding risk), and replacing UNS S34700 lip seals with alloys less susceptible to nitriding such as UNS S31008 (310S). Material selection guidance noted that UNS S31008 (310S) is recommended for flexible components like lip seals and bellows because of superior nitriding resistance, while UNS S32100 and S34700 remain acceptable for rigid components such as internal piping, supports, and catalyst bed structures.

6. Weld failure leading to reverse flow and a major unplanned shutdown

In April 2024, a major mechanical failure at an ammonia plant caused a Tier 1 loss of primary containment and an emergency shutdown when the outlet header-to-end cap weld on the mixed feed coil (MFC) of the primary reformer failed and the end cap detached and was projected to grade. This event produced reverse flow that exposed downstream components to temperatures beyond design limits and caused extensive damage. The root cause analysis identified creep cracking exacerbated by formation of sigma phase in the weld metal as the primary damage mechanism; other mechanisms such as dissimilar metal weld cracking, thermal fatigue, and short-term overheating were investigated and ruled out. Inspections used visual assessment and non-destructive testing including penetrant testing and ultrasonic testing focused on high-stress areas; repair actions included joint preparation and bevelling per OEM design, root and hot pass welding followed by radiographic testing and phased array ultrasonic testing, completion of fill and cap welds with full circumferential inspection and pickling to restore corrosion resistance.

Post-incident mitigation measures included updates to safety instrumented system (SIS) logic to trigger fuel valve isolation and process air compressor shutdown, configuration of alarms to alert the distributed control system (DCS) via Modbus in cases of high steam or gas flows, planned installation of pressure sensors on MFC crossover piping to detect sudden pressure loss and initiate automatic mitigations, and institutionalisation of inspection techniques and locations into the inspection & test plan with cross-site sharing of findings. Key recommendations emphasised considering sigma phase formation in weld metallurgy, designing instrumentation and SIS logic to detect and respond rapidly to reverse flow scenarios, updating inspection protocols to include high-risk welds and crossover piping, and ensuring cross-site communication so similar facilities can implement preventive measures.

7. Catastrophic tube failures while starting up a reforming furnace

During a 2023 startup, a hydrogen plant commissioned in 2004 experienced multiple tube failures and furnace damage. The top-fired reforming furnace is designed for 85 million scf/d (94,000 Nm³/h) of 99.9% pure hydrogen, and contains 300 tubes across six rows and 105 burners across seven rows. The plant was on hot standby and initially fired with imported refinery fuel gas while the feed gas compressor was offline for steam turbine cleaning. After maintenance, natural gas feed and PSA tail gas were introduced as fuel, and an outside operator unfamiliar with the burner light-off task began lighting burners without following a defined sequence. All burners on one side of the furnace were lit, creating uneven heat distribution; after approximately three hours, an operator discovered broken and glowing tubes and discoloration on the furnace wall. Although PSA tail gas was blocked, the furnace tripped six minutes later when the flue gas temperature exceeded 2000°F (1093°C).

Root causes included an excessive heat-up rate of 500–700°F/h versus the recommended 100°F/h, overheating of outer row tubes above 1500°F (816°C) for 30 minutes, and multiple instrumentation failures where protective sensors and indicators were non-functional. Human and procedural failures included assignment of an untrained operator to a critical task, absence of a startup procedure for hot standby conditions, lack of a defined burner lighting sequence and communication protocol, and normalisation of prior deviations that had not previously caused issues. Lessons learned stressed that only trained operators should perform furnace startups, defined roles and communications are essential, startup procedures must include burner lighting sequence and visual inspection requirements, protective instrumentation must be reliable and configured with appropriate alarm and trip setpoints, frequent visual monitoring of the furnace box should supplement instrumentation, deviations from standard procedures must trigger formal risk assessments, and safety must not be sacrificed for speed.

Round table

On day four of the conference, a roundtable session provided an open exchange of ideas through brief presentations from panellists followed by a question-and-answer period. Topics of interest discussed included grey, blue, and green technologies and computational methods and learning for improved reliability and safety.

Next year's symposium will be in Montreal, Quebec, Canada, from August 30th to September 3rd, 2026.

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70 years of the Ammonia Safety Symposium

Venkat Pattabathula of SVP Chemical Plant Services, **Taylor Archer** of Clariant and **Seshu Dharmavaram** of Air Products, all AIChE Ammonia Safety Committee members, look back at some of the key lessons learned from the Symposium's 70 year history.

The AIChE Ammonia Safety Symposium began in 1956 in Boston, MA, and over the subsequent seven decades it has become a cornerstone for sharing safety knowledge across the ammonia industry. Unlike many other sectors, ammonia producers and technology suppliers have consistently shared incident information and lessons learned, and that open exchange has materially contributed to the industry's strong safety record.

Originally held as part of AIChE's annual meeting, the symposium grew in size and scope until it became a stand-alone event in 1992, reflecting both its success and expanding global participation. The Ammonia Safety Committee, established in 1958, now comprises 16 members drawn from operating companies, engineering firms, catalyst vendors and technology providers; the committee is responsible for planning the symposium, overseeing technical content and arranging publication of the proceedings. A historical table of symposium meetings documents this evolution and the growing international footprint of the event.

The symposium's first technical manual was published in 1959, compiling the papers and round table discussions of that year. Volumes were numbered sequentially thereafter, with some gaps in the early 1980s; publication resumed in 1983 with Volume 24. Electronic archives compiling papers from the symposium's first 50 years and then the first 60 years were made available at the Toronto (2005) and Boston (2015) symposia respectively, and the archive was expanded at later meetings to improve access to historical content.

Attendance at the symposium has grown substantially and become more international: by 2024 (San Diego) roughly half of participants came from outside North America. Notable international symposia include the 2013 meeting in Frankfurt, Germany, which celebrated 100 years of commercial ammonia production and included a tour of BASF's Ludwigshafen plant, and the 2023 meeting in Munich, Germany, which was organised specifically to increase European participation and enjoyed strong attendance and engagement.

Incident reporting and lessons learned

A consolidated table of safety incidents from the past decade (2015–2024) highlights recurring themes and reinforces the value of shared experience for preventing recurrence (see Table 1). The symposium continues to provide a platform for technical papers, round table exchanges and awards, all of which foster a culture of continuous improvement and collaborative learning across the industry.

Special awards

Over the decades the AIChE Safety and Health Division (now the Process Safety Division) and the Ammonia Safety Symposium Committee have honoured individuals who made exceptional contributions to ammonia safety, technology and industry advancement. The Norton H. Walton / Russell L. Miller Award was presented in 1995 at Tucson, Arizona to Guy S. LeGendre in recognition of outstanding achievements in loss prevention, safety and health; Guy S. LeGendre was a former programme chair, and enjoyed a distinguished career at Monsanto. The award is named in honour of Norton H. Walton, the first programme chair of the symposium. The Ammonia Safety Committee Distinguished Service Awards have similarly recognised leaders including Hays C. Mayo (1999, Seattle, Washington) for pioneering centrifugal compressor technology, Anders Nielsen (2000, Tucson, Arizona) for lifelong contributions to catalyst research at Haldor Topsoe, and Max Appl (2002, Montreal, Canada) for leadership in ammonia safety and technology innovation during a career at BASF's Ludwigshafen site. In recognition of service to the global ammonia community, all past members of the AIChE Ammonia Safety Committee have been honoured with plaques.

Incident documentation

A comprehensive listing of incidents presented at milestone symposia includes those from 1956–2004 (compiled for the 50th anniversary symposium in Toronto, 2005), from 2005–2014 (presented at the 60th symposium in Boston, 2015), and from 2015–2024 (presented at the 70th symposium in Atlanta, 2025). These compilations provide a valuable historical resource for engineers, operators and safety professionals.

The following summaries from 2015-2024 describe notable incidents from the last decade and the principal lessons the industry derived from each event:

Ammonia plant compressor house fire (6 May 2014)

A disconnection of a 12.7 mm (½-inch) instrument tube attached to a differential pressure transmitter on an ammonia plant's synthesis compressor's fourth stage led to a jet fire with an approximate flame length of 10 metres. The event was classified as a Tier 1 loss of primary containment; it resulted in 60 days of shutdown and damage to synthesis and refrigeration compressors, piping insulation, instrumentation, electrical cabling and the compressor room structure, with an estimated cost in excess of \$2 million. Contributing factors included improper thread fitting, poor tube arrangement and securing, possible human error during scaffold removal and physical damage to the tubing. The fire was controlled within an hour by the plant fire station and neighbouring petrochemical fire departments. Lessons included installing mist spray systems inside compressor rooms, increasing the number and capacity of foam fire extinguishers, adding low-pressure steam spray nozzles to suppress small fires and developing a fire action plan specific to compressor rooms.

Overfiring of a primary reformer (early 2015)

During a hot restart at a South American ammonia plant, excessive firing intensity exceeded the technology licensor's recommended limits and caused multiple catalyst tube ruptures, an immediate plant trip and damage to reformer tubes and furnace internals. The absence of automated protection against overfiring was identified as a key deficiency. The root cause analysis combined metallurgical examination with DCS data analysis and comparisons against simulation-derived allowable parameters. Industry lessons emphasised implementing automated overfiring protection systems with multiple safeguards, ensuring operator training on the hazards of reformer startup and promoting inherently safer furnace management approaches.

Fire in a synthesis loop (5 November 2017)

A spool piece rupture at a dissimilar weld joint in an ammonia plant synthesis loop piping caused a fire that was controlled within 15 minutes; equipment, piping, instruments, cables and insulation sustained damage, and full plant restoration was achieved by 30 November 2017. Investigations revealed incorrect pipe material (LTCS A333 Grade 6 used instead of ASTM A335 Grade P22), incorrect filler weld metal (a P11-type electrode used instead of the correct P22-type), defective welds with lack of fusion at the root pass and increased susceptibility to high-temperature hydrogen attack (HTHA) owing to the material mismatch and weld imperfections. Recommended actions included using correct materials for high-temperature hydrogen service in accordance with API RP 941, validating operating conditions against HTHA susceptibility curves, performing positive material identification for all site-sourced materials, treating design changes during outages as stop-job hold points, and improving inspection methods and frequencies to detect early signs of HTHA.

Mixed feed crossover piping rupture (10 November 2017)

A Trinidad and Tobago ammonia plant with a capacity of 1,850 t/d experienced a Tier 1 process safety incident involving multiple fires and explosions in and under the primary reformer radiant box, rupture of mixed feed crossover piping and associated risers and outlet header tees, and damage to tunnel walls; no injuries were reported. The root cause was hot/solidification cracking of the longitudinal weld seam that had formed during manufacture; improper weld geometry produced uneven thermal gradients and initiated crack formation. Lessons included implementing additional non-destructive examination requirements for new pipe procurement, performing NDE on existing piping operating in the creep region, conducting engineering reviews of reforming sections to enhance safeguards against reverse flow and reviewing all high-temperature/high-pressure piping for similar material vulnerabilities.

Secondary reformer outlet header line rupture (17 February 2022)

At the Dyno Nobel ammonia plant, Waggaman, Louisiana, a transfer line rupture between the secondary reformer and the waste heat boiler produced a flash fire that damaged nearby instrumentation and structure; no injuries were reported. The failure was attributed to overheating of the shell caused by refractory degradation and consequent development of process gas flow behind the degraded liner. Key lessons were to implement a robust mechanical integrity programme for pressure equipment, ensure that design and construction controls serve as primary safeguards and recognise that process and inspection controls offer limited additional integrity when the underlying design is flawed.

Fire beneath a reformer furnace

Following a turnaround at a hydrogen plant, a loss of containment from a radiant section process gas tube resulted in a fire that damaged instrumentation, actuators, refractory and furnace structure; no injuries occurred and the fire was safely extinguished. The root causes included improper flange tightening, a quality control failure that did not detect a compromised enclosure and a gasket design with a high relaxation rate that masked leaks during nitrogen checks. Lessons learned emphasised training for critical maintenance tasks such as bolting radiant tube flanges, auditing contractor work to ensure compliance with company standards, following written guidelines for engineering reviews and management of change (MOC) processes, and adopting self-centring gaskets while avoiding corrugated metal-core gaskets in raised-face flanges.

Syngas compressor oil tank explosion (27 April 2017)

An explosion of an ammonia syngas compressor oil tank occurred following a power outage; the blast damaged compressor stages, the turbine and the oil system, but caused no injuries. The investigation identified two independent but coincident failures: removal of a pressure switch on a nitrogen compressor suction side (likely during a 2010 PLC upgrade) and a leak in the fourth-stage compressor end lid, possibly due to a corroded plug in an oil channel, which allowed process gas to mix with lubricating oil. Lessons included revalidating HAZID and HAZOP studies for older plants, designing for inherent safety and implementing high-integrity safety instrumented systems, and maintaining strict configuration control during upgrades and modifications.

Summary

Over the past 70 years the AIChE Ammonia Safety Symposium has proven to be central to the advancement of safety in ammonia production. Through more than 1,700 technical papers, roundtable discussions and the open sharing of lessons learned, the symposium has fostered a culture of transparency, collective learning and continuous improvement. The commitment of companies and individuals to invest in safety knowledge and collaboration has helped make ammonia production one of the safer sectors within chemical processing. As the industry continues to evolve, the symposium must remain a platform for vigilance, innovation and global cooperation to ensure that safety remains at the heart of ammonia production for the next 70 years and beyond. ■

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Technology pathways to clean ammonia

Ammonia is poised to grow beyond fertilizers into energy transition roles, with low-carbon pathways via blue ammonia and green ammonia, supported by existing logistics and market structures. To support this transition, Stamicarbon is expanding its NX STAMI™ ammonia technologies – with a medium-pressure design for large, CCUS-integrated plants and a high-pressure design for small/medium renewable projects – demonstrating efficiency, reliability, and cost advantages.

Deepak Shetty, Rolf Postma, and Nikolay Ketov (Stamicarbon (NEXTCHEM))

While global demand for nitrogen-based fertilizers is sustained, the ammonia production and distribution landscape is undergoing a significant transformation. This change is driven by evolving global supply chains and the ambition to reduce greenhouse gas (GHG) emissions, supported by government regulations and incentives.

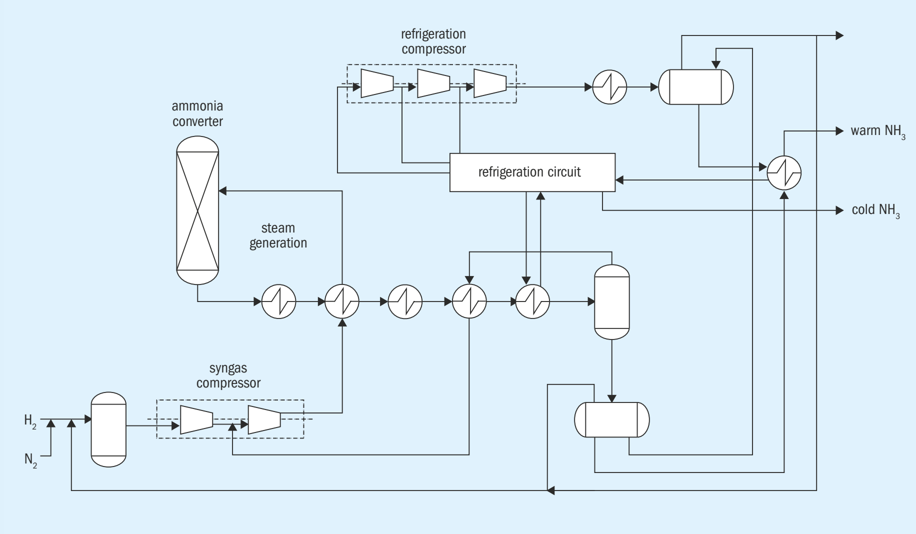
Beyond its role as a feedstock for fertilizer production, ammonia is gaining recognition as a key enabler of the energy transition. Clean ammonia – produced from low-carbon hydrogen – can serve as a hydrogen carrier or fuel, helping to decarbonise hard-to-abate sectors. It is relatively easy to store and transport in bulk, with well-established distribution networks and trading markets. This makes ammonia a practical solution to transport renewable energy from where it is generated to where it is needed.

As a result, ammonia production is expected to continue growing, either in line with global population and economic development or at an even faster pace as it enters new industries. To support this transition, Stamicarbon, the nitrogen technology licensor of NEXTCHEM, is expanding its ammonia technology portfolio to deliver highly reliable and cost-effective solutions for different plant scales and feedstock types (Fig. 1).

IMAGE: STAMICARBON

Fig. 1: NX STAMI™ Ammonia High-Pressure Design Plant 3D Model

Fig. 2: NX STAMI™ Ammonia Medium-Pressure Design



Source: Stamicarbon

Paths to low-carbon ammonia

Reducing the carbon footprint of conventional ammonia production can be achieved by integrating carbon capture, utilisation, and storage (CCUS) systems. This way, over 95% of the CO_2 that would normally be emitted can instead be captured for storage or use in other processes.

Alternatively, ammonia can be produced with near-zero carbon emissions using hydrogen generated by water electrolysis powered by renewable sources such as wind, solar, hydro, or geothermal electricity.

Both approaches are essential for the sustainable transformation of the ammonia industry. Blue ammonia leverages established large-scale processes with added carbon capture to deliver immediate CO_2 reductions, while green ammonia offers fully renewable production pathways.

Stamicarbon's ammonia technology portfolio includes two designs tailored to different project sizes, feedstocks, and sustainability goals. These technologies can be applied to large-scale production from fossil sources with CCUS integration, or to small- and medium-scale production from renewable electricity.

Economy of scale

To meet the demand for cost-effective and energy-efficient ammonia production, Stamicarbon offers the NX STAMI™ Ammonia Medium-Pressure Design. This optimised Haber-Bosch process is suited for capacities from 50 to 3,500 t/d. A conventional large-scale plant using this design can produce low-carbon ammonia by integrating carbon capture at the front end. With more than 45 industrial references worldwide, this design is a proven, reliable, and economical solution for achieving efficiency at scale.

In Stamicarbon's medium-pressure design (Fig. 2), ammonia synthesis is carried out in a reactor configuration that minimises pressure drop. This design maximises the per-pass conversion of hydrogen and nitrogen with effective catalyst utilisation. The converter's first catalyst bed has superior temperature control, enabling more efficient operation and extending catalyst life by avoiding hot spots. The result is a highly efficient loop that ensures more ammonia yield while consuming less energy. By fine-tuning operating parameters, such as pressure, flow rates, and recycle ratios, the process can be adapted to specific project needs and conditions.

For blue ammonia projects, Stamicarbon provides advanced autothermal reforming (ATR) technology through its parent company, NEXTCHEM. ATR produces a high-pressure syngas stream with a high CO_2 concentration, making downstream carbon capture significantly more efficient. This approach can achieve CO_2 capture rates above 98% with 40% less solvent circulation (compared to conventional amine-based solvent technologies).

NEXTCHEM's ATR operates at high pressure (above 60 barg), reducing the compression duty in the synthesis loop. This leads to lower capital and operating costs. The process uses robust, well-proven equipment and a simplified scheme that improves overall energy efficiency.

When combined with CCUS, an ATR-based ammonia plant can deliver world-scale output with a considerably smaller carbon footprint, offering "big blue" ammonia with strong economic performance.

Designed for renewables

The NX STAMI™ Ammonia High-Pressure Design (Fig. 3) opens up new possibilities for producing ammonia from renewable electricity. Engineered for capacities

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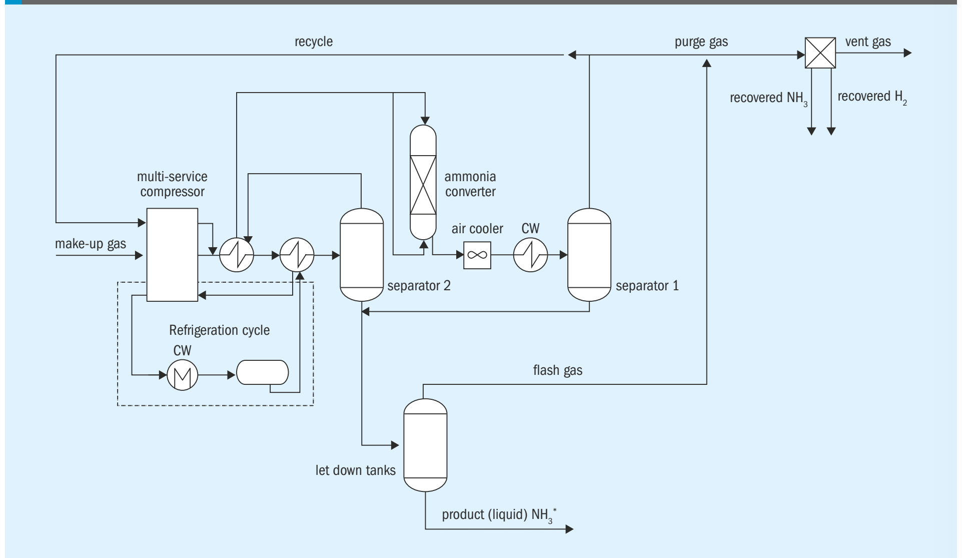
Fig. 3: **NX STAMI™ Ammonia High-Pressure Design**



Source: Stamicarbon

**warm (ambient temperature) or cold ammonia (-33 °C)*

between 50 and 500 t/d, this process maximises efficiency and simplicity. Its high-pressure synthesis loop (operating above 300 bar) achieves high per-pass conversion, reducing the need for recycle compression and refrigeration – an important advantage for smaller plants where simplicity and efficiency are critical. This setup can lower capital expenditures for the synthesis section by approximately 25–30%.

The high-pressure design uses a single-bed axial-flow ammonia converter with a compact tubular reactor design. Inside the converter, heat exchanger tubes are submerged within the catalyst bed to carefully control the temperature profile. Precise temperature control prevents hot-spot formation and catalyst sintering, prolonging catalyst life and maintaining performance. An integrated start-up heater is also included within the converter, allowing the reactor to heat up smoothly during plant start-up. Thanks to the high operating pressure, the converter and other equipment can be made more compact, and the overall footprint of the plant remains very small – a key benefit for decentralised or modular green ammonia installations.

The entire synthesis loop, including both fresh make-up and recycle gas, is handled by a single, electrically powered reciprocating compressor. This reduces the number of compressors required, enhances reliability, and minimises maintenance costs. The NX STAMI™ Ammonia High-Pressure Design is well-suited for distributed, small-scale green ammonia projects that can later be scaled up as renewable capacity expands.

With four operating references, Stamicarbon holds the strongest track record in the sub-500 t/d segment. By leveraging this proven technology, early adopters in the green ammonia market can achieve their decarbonisation goals and prepare for future expansion as renewable electricity becomes cheaper and electrolyser capacity grows.

Reducing the footprint of nitrogen fertilizers

In an integrated low-carbon fertilizer complex, shared process streams, such as oxygen from water electrolysis, can significantly enhance efficiency. These synergies save energy, lower emissions, and reduce both capital and operating costs through shared utilities and infrastructure.

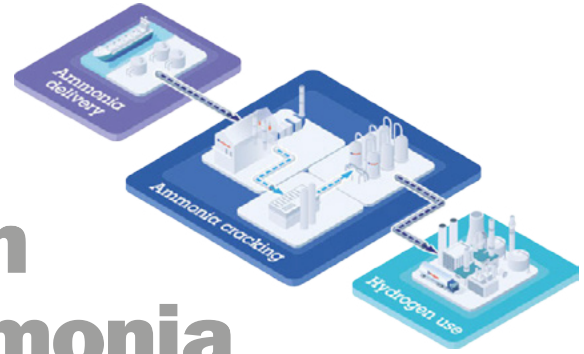
A notable example of such integration is the FertigHy project in France, which is expected to start construction in 2027. The plant will produce 500,000 tonnes of low-carbon nitrogen fertilizers per year using hydrogen from renewable and low-carbon electricity. NX STAMI™ Ammonia and NX STAMI™ Nitrates technologies will enable ammonia and nitric acid production with minimal greenhouse gas emissions.

Stamicarbon is also engaged in renewable ammonia projects in Angola, Kenya, Indonesia, Qatar, and the United States, further supporting the global shift toward cleaner fertilizer production.

Conclusion

The availability of advanced ammonia technologies tailored to different feedstocks, scales, and applications is enabling a new generation of economically viable, low-carbon ammonia plants. By combining clean ammonia production with downstream processes such as urea and nitrates, fully integrated fertilizer complexes can be designed to meet both environmental and commercial goals. These facilities make low-carbon production across the agriculture and energy vectors achievable and viable. ■

Cracking it back: Hydrogen from ammonia



Air Liquide is developing a new ammonia cracking technology based on its proven steam methane reforming (including SMR-X™) technology, which introduces a heat exchange concept to cut energy use, lower environmental impact, and potentially eliminate steam export. Leveraging extensive SMR design expertise, a robust R&D programme, and an industrial-scale NH_3 cracking pilot plant, it aims to rapidly mature all technology blocks and deliver safe, reliable, and customisable low-carbon hydrogen solutions to meet growing demand.

Michael Lutz, Laurent Prost, Dieter Ulber, Sebastian Trunk, Mirko Huebel (Air Liquide)

Ammonia, a widely known chemical, is emerging as a promising low-carbon hydrogen carrier due to its high energy density, its ease of liquefaction as well as its potential to ensure a low-carbon footprint throughout its entire value chain. The process of ammonia cracking, which releases hydrogen from ammonia, plays a crucial role in enabling the utilisation of ammonia as a hydrogen- and energy carrier. Air Liquide is committed to decarbonise the industry by providing its customers with safe, efficient and reliable solutions for a sustainable future[1].

Inspired by steam reforming (SMR)

Air Liquide's extensive experience in handling and delivering diverse molecules, combined with its expertise in the construction and operation of steam methane reformers (SMR), positions it as a leader in ammonia cracking solutions. The capacity for SMRs can be up to 230,000 Nm³/h of pure hydrogen. The SMR technology has been further developed resulting in the SMR-X™ technology. Developed in the mid-2010s to promote decarbonisation, SMR-X™ introduces a heat exchange concept, leading to energy savings, a reduced environmental footprint, and the potential for zero steam export[2].

This technology, proven at large scale, uses a heat exchange within the reforming tube. Hot reformed gas is diverted by 180° at the end of the reformer tube and flows counter-current to the feed flow within a helix-like tube. The helix is within the reformer tube, surrounded by the catalyst, providing energy for the reforming reactions. This lowers reformed gas exit temperatures and allows flexible steam production, even steam-free operation. The principle is illustrated in Fig. 1.

By taking advantage of its SMR-X™ technology, Air Liquide decided to develop a state-of-the-art ammonia cracking solution. The fundamental principles of heat exchange and flexibility of steam production have been transferred in order to benefit from improved energy efficiency and to be able to design crackers without steam export. By adopting this referenced technology, Air Liquide's ammonia cracking solution guarantees optimal performance and reliability.

Air Liquide ammonia cracking technology development

General overview

The basic layout of Air Liquide's ammonia cracking technology is illustrated in Fig. 2. **Ammonia conditioning**: The ammonia feedstock is processed to remove unwanted components and conditioned to the appropriate pressure and temperature.

Fig. 1: A model of the Air Liquide SMR-X™ tube with the internal helix heat exchanger

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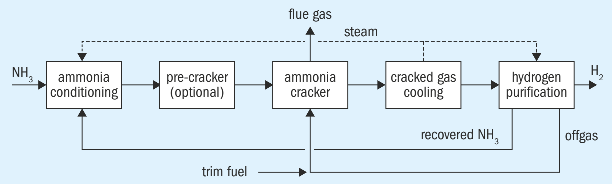
Fig. 2: **Block flow diagram of the Air Liquide ammonia cracking technology**



Source: Air Liquide *Note: Pre-heating and WHRS not shown.*

Pre-cracker (optional): In some configurations, a partial conversion of ammonia into hydrogen and nitrogen occurs in a dedicated equipment, allowing for additional energy recovery.

Ammonia cracker: The primary conversion of ammonia into hydrogen and nitrogen takes place in a radiative furnace using SMR-X™ technology.

Cracked gas cooling and steam production: The cracked gas is cooled, and some of the steam generated is used as a heat transfer fluid in the process.

Hydrogen purification: The cracked gas is purified to achieve the desired hydrogen purity.

To maximise efficiency, a flue gas waste heat recovery system utilises energy from the main cracker's flue gas. Unconverted ammonia from the purification stage is recycled back to the first step. To close the heat balance, a trim-fuel is needed. Air Liquide can offer solutions with different trim-fuel depending on customer requirements and local availability.

Flexibility of the technology

Recognising the plurality of customer needs in terms of hydrogen quantity, pressure and use such as for chemical processes, combustion or pipeline injection, the Air Liquide ammonia cracking process is flexible. It is adapted to the specificities of each project while meeting local regulations and offering an optimised total cost of ownership (TCO). The capacity range is up to ~500 kNm³/h of pure hydrogen at a purity up to 99.999% and up to 40 barg without the need for a costly hydrogen compressor.

In addition to the fuel stream derived from the off-gas of the pressure swing adsorption (PSA), an ammonia cracker requires an additional fuel source called trim fuel. The choice of the trim fuel can be adapted to the specificities of each project. For example, the Air Liquide process can self-produce its own trim fuel or utilise an external fuel source.

The type of trim fuel has a significant impact on the ammonia consumption. For example, when the cracker self-produces its own trim fuel, (i.e. cracked gas) or utilises feedstock ammonia trim fuel, a specific ammonia consumption as low as 7.2 kg NH_3 / kg H_2 can be achieved. If the trim fuel is an external fuel, (i.e. natural gas, hydrogen) the specific ammonia consumption is significantly reduced.

Thus, the use of an external trim fuel can be particularly advantageous depending on the cost difference between this trim fuel and ammonia. Also, the carbon intensity of the potentially external fuel needs to be regarded. Nevertheless, whatever the fuel chosen, SMR-X™ technology makes it possible to achieve a thermal efficiency of at least 97%.

State-of-the-art and development needs

Some ammonia crackers were developed decades ago for metallurgical applications, electronics and for the niche market of heavy water production. The integration of these ammonia crackers in the whole production process of heavy water, for example, leads to process scheme layouts that are not fitting to the production of low carbon hydrogen by ammonia cracking.

Therefore, the technological blocks implemented in those ammonia cracking processes are not suitable for the development of large capacity units. Ammonia cracking is a new process. In particular, the following items are needed:

- a new generation of catalysts;
- metallic materials resistant to nitriding while minimising manufacturing cost;
- low NOx burners to meet today's emission regulations;
- design margins to account for degradation phenomena to meet safety and reliability requirements.

Although there are many similarities between the SMR process and the ammonia cracking process, it is not possible to directly use the SMR technological blocks. Therefore, the ammonia cracking technology development strategy is based on:

- Air Liquide's long experience in the design, engineering and operation of SMR;
- an extensive R&D programme;
- an NH_3 cracking pilot plant at an industrial scale.

Strategy to rapidly reach full commercial maturity

Innovation is at the core of Air Liquide[4]. In 2021, Air Liquide started its technology development based, among other things, on an assessment of the maturity of the technological blocks using the technology readiness level (TRL) scale[5]. It is essential to have access to reliable data. Fig. 3 describes the development strategy for the specific technological blocks of key interest. For each of them, development pathways have been defined to ensure that Air Liquide's ammonia cracking process will reach TRL level 8 (system complete and qualified) in 2025.

The technological blocks concerned and how they are addressed in various pilot plants as described below:

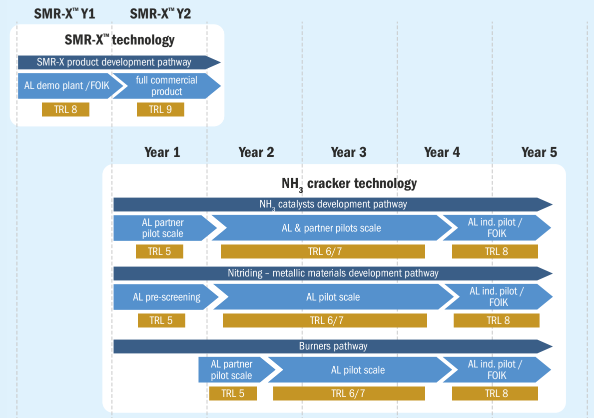
NH_3 catalysts

The challenge for catalysts is to minimise the splitting energy while ensuring good conversion. The related pilot at technical scale allows the testing of NH_3 splitting catalysts available on the market. This pilot operates with the full pellet size, instead of crushed catalyst or powder, and under representative operating conditions. In long-term tests, the lifetime of the catalysts can be assessed, also with respect to impurities in the ammonia feed.

Selection of metallic materials for critical equipment

Air Liquide understands in depth the impact of the nitriding phenomenon on commercial alloys. The related pilot was launched at an early stage and is focusing on the impact of the nitriding phenomenon on metallic materials under the conditions targeted for the operation of future commercial crackers. These insights are instrumental in selecting the most economic but still

Fig. 3: **Technology blocks pathways including development of SMR-X™ technology**



Source: Air Liquide

Fig. 4: The Air Liquide ammonia cracking pilot plant

suitable materials for heat exchangers and the cracking tubes, also taking into account mechanical properties. Further, the results validate material degradation models.

Burners

The possibility to use different trim fuels is an important attribute of the Air Liquide ammonia cracking process. However, the choice of the trim fuel influences the quantities of NOx and N_2O generated and the extent of deNOx technologies. In order to ensure the technical feasibility of using different fuels, Air Liquide has early launched commercial burner tests in one of its R&D pilots. These tests are described in detail in reference 6.

PSA

Air Liquide adapted its proprietary PSA technology to purify reforming gases to ammonia cracking by optimising adsorbent materials and cycles to optimise hydrogen yield. In one of its proprietary R&D pilots, it is demonstrated how the PSA manages low ammonia levels in the feed.

Modelling, design and sizing tools

Air Liquide´s dual experience (design and operation) is capitalised in various proprietary design and sizing tools. These tools have been developed both on the basis of substantial R&D work and on the integration of data returned by the operation of the global Air Liquide SMR fleet. These tools have been adapted to the new ammonia cracking process. For example, the team works with kinetic data of new ammonia splitting catalysts but also utilises three-dimensional CFD (computational fluid dynamics) simulations to model industrial furnaces. In order to do so, data close to the industrial operating conditions are required, which is produced not only but especially by the industrial-scale pilot unit located in Antwerp.

Challenges addressed by the industrial-scale NH_3 cracking pilot plant

A special focus in the Air Liquide technology development is the industrial-scale ammonia cracking pilot plant in Antwerp, Belgium, which was announced in 2023[7]. This pilot plant is the cornerstone of the development strategy; its design and scale validate the performance of all the main technological blocks used in the future commercial crackers and will provide essential data for the calibration of multi-scale design and sizing tools. The experience accumulated by the engineering teams during the construction, commissioning and start-up phases is instrumental to optimise execution strategies for future projects around the world. Furthermore, this pilot plant is a powerful tool for demonstrating the safe operation of ammonia cracking technology at scale, building confidence among stakeholders and regulatory authorities. The pilot plant is depicted in Fig. 4 and comprises several full size reformer tubes of different materials and full size burners. This allows testing of multiple commercially available catalysts at the same time. It further comprises all essential elements of an ammonia cracking plant, from ammonia vaporisation to cracked gas cleaning. It is equipped with plenty of instrumentation and sampling points to gather a maximum amount of data. Furthermore, it is equipped with a NOx reduction unit to prove that even the most challenging NOx and NH_3 emission limits can be achieved, when utilising ammonia as fuel. The plant is up and running and first valuable results have been obtained.

Spotlight on materials

In an ammonia service context, the choice of materials for specific equipment is crucial. In particular, the tubes installed in the cracking furnace are exposed to high mechanical stresses and high temperatures. The materials used for these tubes, unlike the materials of the tubes installed in the SMR furnaces, must be resistant to nitriding.

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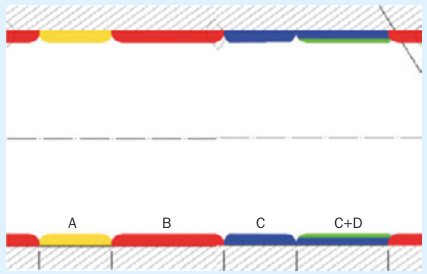
Fig. 5: **A section of a cracker tube in the pilot plant with four different weld overlays. The image does not cover the full length and is not to scale.**



Source: Air Liquide

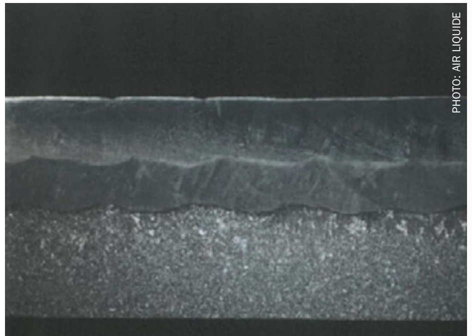


Fig. 6: Photography of a cracker tube with one of the weld overlays installed in the industrial-scale pilot plant

Not only in its industrial-scale NH_3 cracking pilot plant, Air Liquide is testing solutions using commercial alloys and protective coatings to improve the reliability of critical equipment. The latter solution can reduce costs by separating mechanical strength from nitriding resistance. The tested tubes will be analysed to assess changes in their microstructures and dimensions.

Fig. 5 shows a sketch of a tube tested in the industrial-scale NH_3 cracking pilot plant. This tube has industrial dimensions (diameter, length, thickness) equivalent to the dimensions of future commercial plants. Its inner surface is covered with different protective coatings applied by weld overlay.

Fig. 6 shows a picture of the inner wall of this tube on which the reader can see the base alloy material and the protective coating.

Cracking tubes are not the only critical equipment in an ammonia cracker. Nitriding also poses a challenge for components such as piping and heat exchangers handling high-temperature ammonia gas. While increasing preheat temperatures improves energy efficiency and reduces specific ammonia consumption, it also intensifies nitriding.

In an ammonia gas atmosphere, the effects of nitriding on materials vary considerably depending on the alloy. In order to select the most resistant materials for each critical equipment according to its operating temperature, Air Liquide launched at an early stage tests of many alloy grades in its R&D material testing pilot at different temperatures and under pressure and gas atmosphere conditions equivalent to industrial operating conditions.

Fig. 7 shows the results of these tests on two different alloy grades that were exposed to the same atmosphere for an identical duration. The material on the left picture shows greater susceptibility to nitriding and spalling compared to the material on the right picture which shows greater resistance.

Conclusion

Air Liquide is developing a new ammonia cracking technology for sustainable hydrogen production based on its vast experience with the steam methane reforming technology. The strategy involves a dedicated technology roadmap, extensive R&D programmes, and an industrial-scale pilot plant in Antwerp, Belgium. The pilot plant validates the technology at an industrial scale, calibrates design tools, and builds stakeholder confidence. Air Liquide's data-driven approach, coupled with collaboration with key suppliers, ensures increased reliability, a deep process understanding, accurate feasibility assessments, and optimised performance and operating costs. ■

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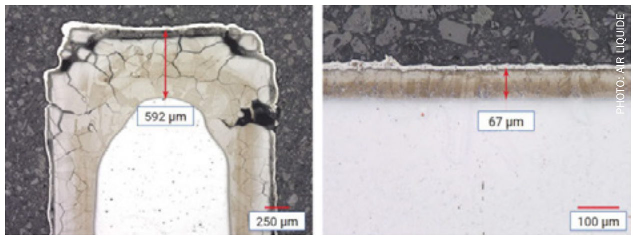

Fig. 7: Pictures of two different alloy grades after being exposed to an ammonia atmosphere during the same duration. Note that the two pictures are not at the same scale.

Sustainable, efficient, and safe urea production

MHI has successfully completed the Ghorasal Polash Urea Fertilizer Project in Bangladesh - the country's largest fertilizer complex. Key features of the project include: the KM CDR Process™ that captures CO_2, cuts emissions and boosts urea output; an energy-efficient granulation unit using a bulk flow cooler to reduce power demand; and reinforced digital safety management.

Junji Asahara, Yuji Higashi, Rhonel Recio, Harunori Nagoya (Mitsubishi Heavy Industries)
Mohammad Al Mamun, Md. Mohaddes Hossain, Md. Abdul Alim (Bangladesh Chemical Industries Corporation)

The fertilizer manufacturing industry is highly energy-intensive and heavily reliant on fossil fuels, making improvements in energy efficiency and emissions reduction particularly challenging. According to Menegat et al. in "Greenhouse Gas Emissions from Global Production and Use of Nitrogen Synthetic Fertilizers in Agriculture," the production of synthetic nitrogen fertilizers accounts for 39% of total CO_2-equivalent emissions across the fertilizer supply chain.

As the pressure to reduce carbon emissions intensifies, several trends and innovations are emerging to lower the carbon intensity of fertilizer production. One of the key global strategies to reduce the carbon intensity of fertilizer manufacturing is by employing alternative ammonia synthesis methods with carbon capture, utilisation, and storage (CCUS). CCUS technologies are being integrated into ammonia production to capture and either store or repurpose CO_2 emissions (e.g., as additional feed to urea plants), significantly reducing the industry's carbon footprint.

Aside from carbon emissions, lean natural gas supply for ammonia plants and the use of power-intensive equipment in urea plants are other challenges in the fertilizer industry since both result in higher energy consumption. Methane-deficient feed gas not only raises production costs but also increases the plant's carbon emissions. In the same manner, utilising equipment with high power requirements to meet quality granule product specifications adds not only to the operating cost but also to the emission impact. In an industry already struggling with energy efficiency and carbon emissions, this exacerbates both economic and environmental challenges.

In response to these challenges, Mitsubishi Heavy Industries (MHI) has been actively working to improve the energy efficiency and reduce the carbon emissions of fertilizer plants through various innovative technologies and solutions. As an example, MHI recently built the Ghorasal Polash Urea Fertilizer Project (GPUFP) with its own carbon capture technology and energy-saving equipment.

Aside from environmental impact reduction, automation and digitalisation of safety management in high-risk industries, such as construction and chemical plants has also become a global trend. MHI leveraged the power of digitalised technology to streamline the work permit approval process and access restriction to enhance the overall security and safety of the GPUFP project.

GPUFP project

The Ghorasal Polash Urea Fertilizer Project (GPUFP) is the largest fertilizer plant in Bangladesh. It is situated in Polash, in the district of Narsingdi, 50 km northeast of the capital city of Dhaka (see Figs 1 and 2). The plant utilises domestically produced natural gas and has the capacity to generate 1,600 t/d of ammonia and 2,800 t/d of urea.

The project was developed for the Bangladesh Chemical Industries Corporation, a government-owned entity, with Mitsubishi Heavy Industries and China National Chemical Engineering No.7 Construction Co. as the contractors. It was executed under an EPC contracting framework.

The project's process plant design for the ammonia plant was licensed by Topsoe, while the urea plant, comprising urea synthesis and urea granulation, was licensed by Saipem and thyssenkrupp

Fig. 1: GPUFP plant location, Bangladesh.

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Ammonia cracking technology

NITROGEN+SYNGAS
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Fertilizer Technology (tkFT) respectively.

The ammonia plant is integrated with a CO_2 recovery plant that utilises the KM CDR Process™ – MHI's proprietary carbon capture technology, which reduces the environmental load and enhances urea production. The urea plant is equipped with a bulk flow cooler, designed for long-term operational energy savings. It has a self-sufficient utility and offsite plant designed by MHI, generating its own treated water from the Sitalakhya River, as well as steam, nitrogen, instrument air, and power.

The plant was built under strict safety management practices and was designed to ensure a high level of operational reliability, maximising inputs to enhance urea production while reducing the environmental load. The plant's performance guarantee test run was completed in March 2024 and has been operated by the owner since then.

High-efficiency CO_2 recovery technology

KM CDR process™

The ammonia plant in GPUFP utilises lean natural feed gas, which leads to lower CO_2 production. To make up for the CO_2 deficiency and meet the urea production requirements, MHI installed its own CO_2 recovery technology known as the KM CDR Process™ – Kansai Mitsubishi Carbon Dioxide Recovery Process™, one of the key features of the project. The feed material to the KM CDR plant is the flue gas from the primary reformer. The overall plant configuration, showing the KM CDR Plant, is illustrated in Fig. 3.

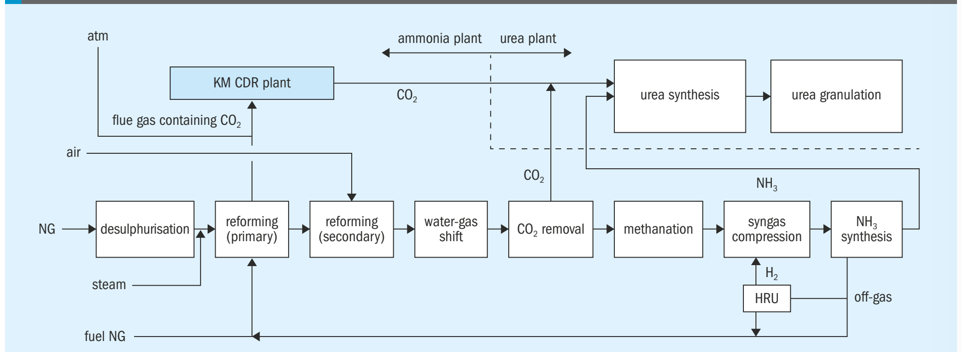
Fig. 2: GPUFP layout.

The KM CDR Process™ not only reduces the plant's environmental impact in terms of CO_2 emissions but also enhances urea production. It utilises MHI's proprietary amine solvent, which has low volatility and is very stable against degradation. It is proven to effectively capture CO_2 from the combustion gas of the primary reformer, up to 90%. The KM CDR Process™ consists of three main sections: the flue gas cooler, the absorber (for CO_2 recovery), and the stripper (for solvent regeneration). Fig. 4 shows the process flow diagram of the KM CDR Process™.

The flue gas cooler (quencher) cools the flue gas before it enters the CO_2 absorber, enhancing the efficiency of the CO_2 absorption reaction and reducing volatilisation losses of the KS-1™ solvent. The CO_2 absorber consists of two main sections: the absorption section at the bottom, where conditioned flue gas flows upward through structured stainless-steel packing, and the washing section at the top.

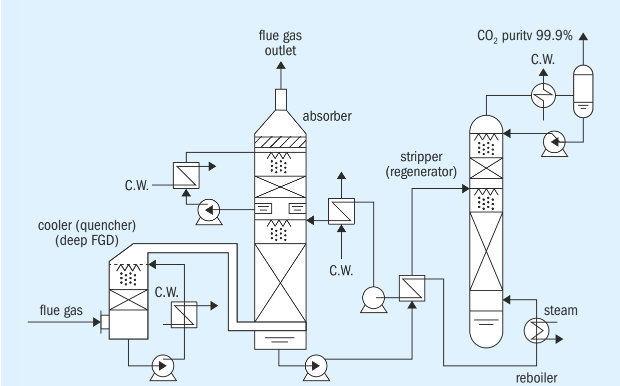
In the absorption section, CO_2 in the flue gas contacts the KS-1™ solvent, allowing for CO_2 absorption. In the washing section, the treated flue gas is cooled to achieve good CO_2 absorption before exiting the top of the absorber. The resulting CO_2-rich solvent is then pumped to the CO_2 stripper for low-pressure steam stripping. It is pre-heated using the heat from the hot lean solvent exiting at the bottom of the CO_2 stripper. The CO_2 is separated from the rich solvent at the top of the stripper and exits with 99.9% purity. It is mixed with the CO_2 produced from the CO_2 removal section of the ammonia plant before it is reacted with ammonia to synthesise urea.

Fig. 3: Overall GPUFP process plant configuration



Source: MHI

Fig. 4: CO_2 recovery process from flue gas



Source: MHI

Result of installing KM CDR Process™

The KM CDR Process™ in GPUFP has a CO_2 production capacity of 240 t/d, resulting in a reduction of 25% of CO_2 from the primary reformer. This corresponds to 326 t/d of urea production (or about 12% of the total granules produced per day). The CO_2 captured by the KM CDR Process™ is converted to urea through a reaction with additional ammonia generated from recovered hydrogen. In GPUFP, about 108 t/d of ammonia is produced from recovered hydrogen from the purge gas stream of the ammonia synthesis section via the hydrogen recovery unit (HRU).

The energy consumption for ammonia production in the base plant, where neither the HRU nor the KM CDR Plant is installed (Case 1), is compared to GPUFP, which includes the HRU and KM CDR Plant (Case 2). In Case 1, if the HRU and CDR plant is not applied, the expected H_2 quantity in the process natural gas is expected to be 7% higher than Case 2. This extra H_2 requirement in Case 1 has an impact on fuel natural gas in the primary reformer and auxiliary boiler.

By installing the HRU, ammonia production is enhanced, and therefore, the required feed natural gas to the primary reformer is reduced. It correspondingly decreased the energy consumption in Case 2. Since off-gas from the purge gas absorber and off-gas absorber in Case 1 can be used as alternative fuel to the primary reformer in Case 1, fuel natural gas consumption in Case 2 is higher. In Case 1, the steam requirement for the ammonia plant compressors is higher due to the 7% increase in feed process natural gas H_2 requirement. This makes the Case 2 boiler fuel NG consumption less compared to Case 1. Overall, the energy consumption is reduced by 0.210 Gcal/tonne urea (around 4%) with the installation of the HRU and CDR plant in GPUFP (see results in Table 1).

Fig. 5: KM CDR plant in GPUFP.

The installation of the CDR plant has minimal impact on the overall energy consumption of the ammonia plant. This is due to the reduced flow of LP steam to the process air compressor turbine (admission steam turbine type), as the steam is redirected to the reboiler for the KM CDR plant. Although the consumption of HP and MP steam increases, the overall energy efficiency still improves because of the reduced natural gas feed to the primary reformer.

In addition to the urea production advantage, the plant's CO_2 emissions from the reformer flue gas are reduced by 25% compared to the system without CO_2 recovery. Reducing CO_2 emissions in the primary reformer not only helps minimise direct emissions but also reduces the overall carbon footprint of the fertilizer plant. This is particularly important as industries are increasingly held accountable for their environmental impact, and companies with lower carbon footprints are more likely to meet sustainability targets and regulatory requirements.

By integrating CO_2 capture technologies like KM CDR Process™, the fertilizer plant can be part of the global effort toward achieving carbon neutrality. The installation of the KM CDR plant also offers operation flexibility in terms of controlling

Table 1: Comparison of energy consumption for ammonia

	Case 1: Base plant (without HRU & KM CDR plant)	Case 2: GPUFP (with HRU & KM CDR plant)
Urea product, t/d	2,800	2,800
Urea (CO_2 conversion from ammonia plant), t/d	2,800	2,474
Urea (KM CDR plant CO_2 conversion), t/d	-	326
Ammonia product, t/d	1,600	1,600
Ammonia (feed NG conversion), t/d	1,600	1,492
Ammonia (HRU H_2 conversion), t/d	-	108
Total, Gcal/tonne urea	Base	-0.210

Source: MHI

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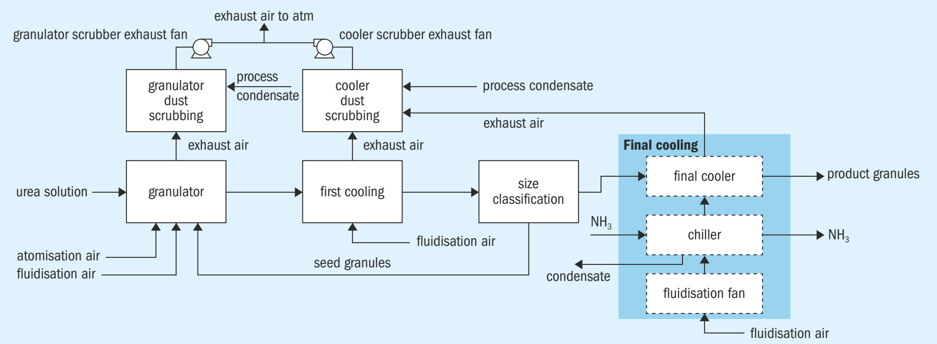
Fig. 6: Conventional granulation plant



Source: MHI

the ammonia storage tank level. When the ammonia storage tank is filled with product ammonia due to an unexpected shutdown of the urea plant or maintenance, the tank level can be easily maintained or reduced by utilising recovered CO_2 from flue gases without plant load adjustment. Through CO_2 utilisation, the loss of synthesis gas in the ammonia plant is also prevented.

Energy saving equipment in granulation plant

Application of bulk flow cooler

The bulk flow cooler is a simple piece of equipment designed for cooling granules using indirect heat transfer. It uses cooling water as the circulating medium in counter-flow with the granules for better thermal efficiency. The integration of the bulk flow cooler offers benefits such as low dust emissions and a compact installation design. More importantly, it also lowers the plant's energy requirements by eliminating the need for a final cooler fluidisation fan and an ammonia chiller, which are found in conventional designs. The simplified block flow diagram of the conventional granulation plant is shown in Fig. 6, and the granulation plant with bulk flow cooler is shown in Fig. 7.

In the conventional design, cooling of granules to the desired product temperature requires fluidisation air to pass through the final cooler. Moisture is removed from the air by condensation using ammonia in the air chiller. However, in GPUFP, since the bulk flow cooler is utilised, cooling water flows countercurrently through parallel plates and is used as the cooling medium for the product granules. The granules pass through the bulk flow cooler in a slow and controlled manner, allowing sufficient heat exchange to achieve the target product temperature. The use of the bulk flow cooler produces low dust, which makes process condensate consumption in the cooler scrubber lower compared to the traditional design. In addition, since the fluidisation fan is not required, the load on the cooler scrubber is lower, making the cooler scrubber exhaust fan design smaller. The typical configuration of the bulk flow cooler is illustrated in Fig. 8.

The benefits of utilising the bulk flow cooler are summarised in Table 2. By replacing the final cooler with the bulk flow cooler in GPUFP, granulation plant power consumption can save 4.9 kWh/tonne urea produced.

Beyond the energy benefits, a bulk flow cooler enables the urea plant to start up using process CO_2 and ammonia from the ammonia storage tank, even if the ammonia synthesis loop has not yet been brought online. The urea production temperature can be controlled by the bulk flow cooler, eliminating the need for an ammonia chiller.

Potential energy saving for future plant

After the GPUFP performance guarantee test run, two tests were conducted by tkFT to check the energy saving potential when operating parameters were adjusted. The tests conducted were:

- Granulator bed level reduction (Test 1)
- Atomisation air pressure/flow reduction (Test 2)

During these tests, it was ensured that the quality of the products would not be compromised for the results to be considered satisfactory.

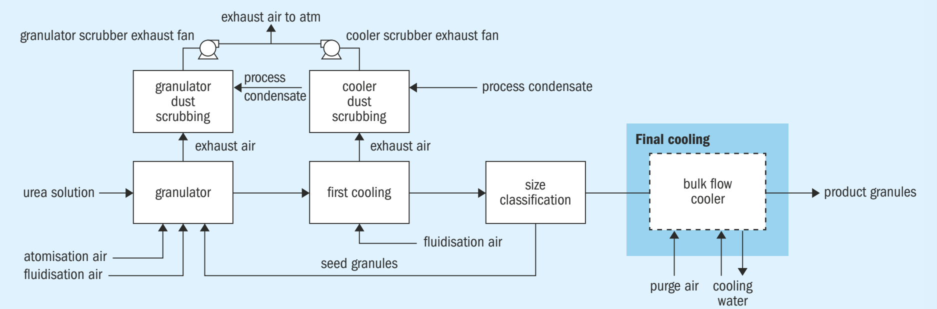
For Test 1, the product quality at the initial level of 50% was compared when the bed level was reduced to 30%. For Test 2, the atomisation air flow was decreased by reducing the atomisation air pressure to confirm the operating range of the spray nozzles. The tests were conducted for four days. The primary parameters changed during the tests are tabulated in Table 3.

When the bed level in the urea granulator (Test 1) was reduced, the process and product quality remained consistent up to a 40% bed level. When the bed level was further reduced to 30%, there was a slight decline in product quality, particularly in terms of moisture content. There was no noticeable change in product size distribution or liquid recycle. The energy savings for Test 1 are estimated at -5.9% at a 40% bed level (without a change in product quality).

After reducing the atomisation air pressure (Test 2), no significant changes in product or process quality were observed, except for a few agglomerate formations on the granulator outlet screen. The reduction of atomisation air pressure to 76% impacted the power consumption of the atomisation air fan by -3.9%. Overall, it was verified that reducing the atomisation air pressure also has an energy advantage. The decision to lower the atomisation air fan pressure or flow should be based on granule quality, ensuring that the product guarantee values in GPUFP are maintained. Product quality is tabulated in Table 4.

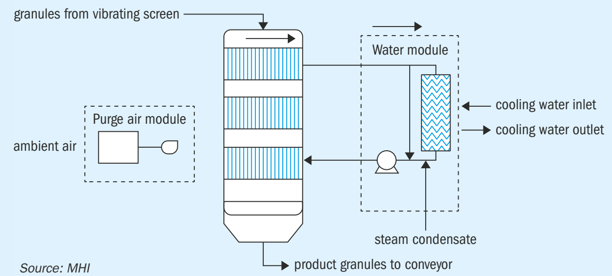
Although the figures in Table 5 show valuable energy reductions, further energy savings in future granulation plants are possible. In the case of lowering the

Fig. 7: Granulation plant with bulk flow cooler



Source: MHI

Fig. 8: Bulk flow cooler configuration



Source: MHI

Table 2: Energy advantage of the bulk flow cooler

	Final cooler	Bulk flow cooler
Granulation plant power consumption, kWh/tonne urea	Base	-4.94
Auxiliary boiler steam consumption, tonne/tonne urea	Base	-0.084
Cooling water consumption, m^3/tonne urea	Base	+0.91

Source: MHI

Table 3: Parameters adjusted during Test 1 and Test 2

	Normal operation (PFD)	Test 1	Test 2
Granulator bed level, %	50	40~30	50
Atomisation air pressure, %	100	100	76-90
Atomisation air flow, %	100%	100	80-90
Average bed temperature, °C	108~110	108~110	108~110

Source: MHI

Table 4: Energy saving in Test 1 and Test 2

	Base consumption	Test 1	Test 2
Energy savings	100%	-5.9%	-3.9%

Source: MHI

Table 5: Product quality Test 1 and Test 2

	Guarantee	Test 1	Test 2
Nitrogen, %	≥46	46	46
Moisture, %	≤0.3	0.24	0.29
Biuret, %	≤0.9	0.74	0.74
HCHO, %	≤0.55	<0.45	0.42
Crushing strength, in kgF @ 3.15 mm	≥3.0	3.6	3.0
Particle size distribution (2-4 mm), %	≥92	96.7	97.6

Source: MHI

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bed level, the material in the granulator becomes more evenly distributed and is more exposed to heat and fluidisation sources. A thinner bed requires lower fan pressure, which means less fluidisation energy is needed to keep the granules in motion. In addition, less heating of fluidisation air is required for cooling. Since there is less fluidisation, the scrubber exhaust fan capacity is also decreased. In GPUFP, this could be further realised if the fan type is changed.

Changing the type of fluidisation to provide a lower pressure increase, such as a variable speed drive (VSD), offers significant advantages not only in terms of energy savings but also in the improvement of process control. With a VSD, the fan can operate only at the required capacity, adjusting to the changing demands of the granulation process. In a lower granulator bed requiring a lower pressure increase, the VSD-type fan speed is more capable of adjusting the flow based on the actual process needs, rather than running at a constant full speed. This leads to substantial energy savings, as fans consume less power at lower speeds.

Digital safety for plant entry and work process

Electronic permit to work

The construction and commissioning of chemical plants requires a high level of coordination and planning, as many companies with their contractual obligations are involved, and the environment itself is considered high-risk. The permit-to-work system serves as a structured mechanism to ensure safety and compliance. It establishes clear protocols for authorising specific tasks and operations, facilitates communication among workers, supervisors, and safety personnel, and ensures that everyone is aware of potential risks, necessary precautions, and emergency procedures.

The transition to an electronic permit-to-work (E-PTW) system began during the COVID-19 period, driven by safety protocols, limited physical contact, and the global shift toward digitalisation and automation. These related issues were addressed in GPUFP and improved safety management control.

The main benefits of E-PTW are:

- easy access from any device with an internet connection;
- fully remote approval and closure process;
- permit status, attachments, and statistics available in real-time;
- instant search and retrieval of digital records.

Being able to check the status of the permit-to-work is one of the key points of plant entry control and is an integral part of safe plant operation: the working group will not be allowed to enter the process area without a PTW issued by the person in charge.

The lockout/tagout procedure (equipment and line isolation) is also established as a separate module of the electronic permit-to-work system, providing the same advantages of fast and remote approval processes and monitoring isolation status.

Access control with QR-code

Restricting access to the process area is crucial for safety, security, and regulatory compliance. Unauthorised access can lead to accidents, putting employees, first responders, and nearby communities at risk. Chemical plants are also vulnerable to sabotage, theft, and vandalism. Tightening access control measures helps protect key infrastructure and materials. Additionally, regulations require controlled access to ensure that only trained and authorised personnel handle equipment and hazardous materials.

The access control system to restricted areas in GPUFP includes the following:

- **Special training for authorised personnel:** Workers, supervisors, and above-level personnel receive training that includes information about main hazards, actions in case of emergency, communication channels, roles and responsibilities, and the procedure for entering restricted areas. After completing the training, the individual will be registered in the authorised personnel database and obtain an individual QR code.
- **Physical access restrictions to the process area:** The installation of fences and access gates with security guards. To enter the restricted area, individuals must have their QR code scanned by security guards for verification, along with an issued permit to work, mandatory personal protective equipment (such as a full-face gas mask with an ammonia filter), and personnel from the worker category must be accompanied by supervisors or above-level personnel.
- **Restricted area entry monitoring:** Scanning the individual QR code by the security guard updates the personnel status in the authorised personnel database, showing the current location of the person and the total number of entries. This information is vital in case of an emergency and evacuation. It can also be used if the number of people in a specific area needs to be limited.

Conclusion

The KM CDR Process™ technology supports sustainability goals and positions future plants to meet regulatory requirements and international climate targets.

The integration of the KM CDR Process™ in GPUFP captures 240 t/d of CO_2, reducing the plant's CO_2 emissions by 25%, resulting in enhanced urea production and a lower carbon footprint. The application of KM CDR and HRU resulted in 0.21 Gcal/tonne urea (around 4%) reduction in energy consumption for the whole plant.

Utilisation of the bulk flow cooler in GPUFP reduces the granulation plant power consumption by 4.9 kWh/tonne urea, enhancing energy efficiency by 0.02 Gcal/tonne urea and correspondingly reducing the environmental load.

In GPUFP, product quality remains unchanged when the bed level is reduced to 40% and when atomisation air pressure is reduced to 76%.

The application of the electronic permit to work (E-PTW) system and QR-code-based entry restrictions have proven to be effective in enhancing safety management in GPUFP. Its integration into future plants is one of the key measures to achieve a more streamlined safety procedure. ■

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Selecting the right cooling technology

Advances in cooling technology are providing fertilizer facilities with new options when it comes to upgrading outdated equipment and improving environmental sustainability of their existing operations. **Igor Makarenko** of Solex Thermal Science explores cooling strategies to improve operational efficiencies while also reducing their energy consumption, greenhouse gas emissions and overall carbon footprint.

For fertilizer operators looking to either improve, optimise or replace existing equipment, there is no simple answer to the question of what's the best cooling technology to handle their process needs. Given the critical role the fertilizer industry plays in global food security, it is essential to evaluate all modern technologies to ensure the world continues to be fed.

For example, product quality plays a critical role in optimising nutrient use efficiency, reducing environmental impact and improving crop yields. Proper drying (e.g., removing excess moisture from the fertilizer using heat) together with cooling represents a pivotal step in preventing clumping. Cooling, meanwhile, ensures the product is stabilised and at ideal temperature for storage and transport, thereby preserving the quality and value of the finished product.

Yet at the same time, operators also need to evaluate whether cooling technologies meet their decarbonisation needs. The fertilizer industry is a significant contributor to global greenhouse gas (GHG) emissions due to the energy required to produce a finished product. According to data collected by member organisations of the International Fertilizer Association (IFA), it is estimated that 1.3% of global carbon dioxide (CO_2) emissions are generated from the production of mineral fertilizers[1]. Implementing decarbonisation strategies at certain stages of fertilizer production is vital for the industry as it seeks to reduce its collective carbon footprint.

PHOTO: SOLEX

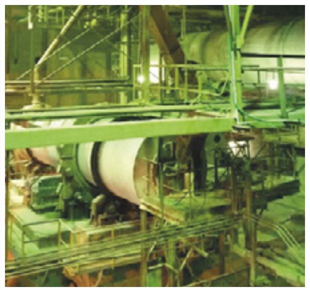

Fig. 1: Rotating drum.

Rotary drums

Rotary drums are a common method for drying and cooling fertilizers given their ability to process different grades and operate with variable feed inlet conditions. In a typical rotary indirect drum, material introduced at one end of the equipment is lifted and dropped numerous times as the material moves through the drum.

Strengths: Robust, well-understood operation, tolerant to feed variability and tramp materials, and available in large sizes with straightforward maintenance programs.

Some considerations with rotary drums include:

- **Excessive fine particle loss:** Fine particles can be carried away with the warm exhaust air, leading to product loss and potential environmental concerns. Adjusting air velocity and using cyclones, bag filters, scrubbers, etc. can help minimise this issue.
- **Sticky materials:** Some fertilizers are more hygroscopic nature than others, and may become sticky during the cooling process, causing agglomeration and affecting flowability. Regular cleaning of equipment internals helps to avoid buildup, which adds extra weight to the drum and places unnecessary stress on all components.
- **Non-uniform cooling:** Inconsistent air flow or temperature distribution can result in uneven cooling, affecting product quality (e.g., transferring hot material to the storage). Regular maintenance of the air distribution system and careful monitoring of operational parameters (e.g., correct bed depth) are essential to ensure uniform cooling.
- **Maintenance requirements:** Rotary drums are generally low maintenance. However, there are several moving parts that require proper lubrication, including bearings, chains, gears, reducers and graphite blocks. Furthermore, drum coolers require regular tire and trunnion grinding, alignment, maintaining proper drum float/distribution systems and checking for wear and tear.

Fluid beds

Fluidised bed coolers, which includes vibrating fluid beds, are also commonly used to dry and cool fertilizers. In this process, large volumes of ambient air is used to directly fluidise the material. This enables the product bed to flow from one end to the other, drying and then cooling (it can be also standalone cooling) as it moves.

Strengths: High heat and mass-transfer rates, compact for combined drying/cooling, and easy integration with waste-heat or heat-recovery air circuits

The air has two functions in fluid bed technology. First, it creates the fluidised state of the material, enabling the product to flow. Second, it either heats or dries the material through direct contact. Fluid bed machines require either dedicated or are part of larger common air-treatment systems to comply with air emission regulations.

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Fig. 2: Fluid bed cooler.

It's common for fertilizer producers to use a combined fluid-bed system, with the first unit operating as a dryer and the second part as a cooler. Alternatively, producers can use a combination of a rotary drum dryer and fluid bed cooler. In this arrangement, the air exhausted from the fluid bed cooler can then be used in the rotary drum dryer, reducing the amount of ambient air required in the process and, being already pre-heated, saving on energy intake.

Traditional cooling equipment such as fluidised beds and rotary drums require large energy inputs (e.g., high horsepower fans and, in some cases, chillers) to get the job done. This is a challenge for producers who are already facing overall high energy costs at their plants.

Some considerations with fluid beds include:

- **Poor fluidisation:** This occurs when the material does not fluidise properly, leading to clumping or channelling across the moving bed. It can be caused by non-uniform particle size (including dust content) and moisture content. Ensuring uniform material characteristics, proper design of the distributor plate and careful operating practices to ensure maintaining correct bed depth can help address this issue.
- **Excessive fine particle loss:** Fine particles can be carried away with the warm exhaust air, leading to product loss and potential environmental concerns. Adjusting air velocity and using cyclones, bag filters, scrubbers etc. can help minimise this issue.
- **Sticky materials:** Some fertilizers are more hygroscopic in nature than others and may become sticky during the cooling process, causing agglomeration and affecting flowability. Regular cleaning/maintenance of the perforated plate is necessary to ensure consistent operation.
- **Non-uniform cooling:** Inconsistent airflow or temperature distribution can result in uneven cooling, affecting product quality (e.g., transferring hot material to the storage). Regular maintenance of the air distribution system and careful monitoring of operational parameters (including correct bed depth) are essential to ensure uniform cooling.
- **Maintenance requirements:** Fluid beds require regular maintenance to keep them running efficiently. This includes cleaning air distribution systems, checking for wear and tear and ensuring proper lubrication of moving parts.

Plate-based heat exchangers

Plate-based heat exchangers (also known as bulk flow coolers) at the cooling stage of production offers operators the opportunity to improve the energy efficiency of their existing processes, with the added benefit of being able to use less air and reduce opex penalties (e.g. energy inputs to drive circulating pumps).

The technology blends the thermal efficiency of plate heat exchange design with the science of uniform mass flow to cool granular bulk solids such as fertilizers. First, a bucket elevator brings the fertilizer from the dryer, granulator or prilling tower into the inlet hopper of the heat exchanger at temperatures typically around 55°C to 85°C. The flowrate of product, ranging from 1 to 200 t/h, then flows at a controlled speed through the heat exchanger bank(s), usually 0.3 m per minute, while cooling water at 18°C to 25°C flows counter-currently within the internal channels of the plates.

The flow of fertilizer is controlled by a discharge extraction device equipped with a variable frequency drive (VFD) that ensures uniform mass flow and even product temperatures at the outlet – typically 30°C to 42°C to avoid caking during storage, or in big-bags or in transit. A level probe/transmitter in the inlet hopper maintains the proper product level as it controls the VFD on the feeder.

Fig. 3: Moving bed heat exchanger.

The heat exchanger is static, with the only moving part being the oscillating feeder at the outlet. Likewise, the unit has side access doors over the height of each plate bank to allow for cleaning and maintenance. The number of heat exchanger banks required is dependent on the duty of the process conditions and necessary surface area to meet the cooling temperature target.

If the moving bed heat exchanger (MBHE) is installed in a hot, humid location, a small amount (1 000 Nm³/h to 2 500 Nm³/h) of, typically, dehumidified purge air needs to be injected between the heat exchanger banks to prevent condensation and caking from forming inside the column.

MBHEs can easily be retrofitted into existing facilities, as they have a small installation footprint (less than 2 m x 2 m) and can be used in conjunction with current equipment. They can also be installed and operated as secondary coolers after existing fluid bed or drum coolers if additional cooling is required due to a capacity increase, this revamp allows for increased production capacity, as well as a higher quality (at the required temperature) of the finished product.

The water source is typically existing plant cooling tower water, natural water sources, chilled water circuit or chilled ammonia. In some cases natural water sources (e.g., river, or sea water) can be used by incorporating a closed-loop fluid temperature control circuit. The system can also operate as a completely standalone system (e.g., no water intake from operator is required) via a dedicated closed-loop circuit using a standalone electric chiller and free-cooling non-evaporative towers.

With the use of a plate-based heat exchangers in fertilizer cooling operations, operators benefit from the following advantages:

- Electrical demand as low as ~0.4 kWh/tonne (site- and product-dependent, excluding optional purge-air dehumidification) of fertilizer.
- Zero product contamination and degradation of granules/prills because of the slow and controlled movement of the product, and because product does not come in contact with air or water.
- The low downward velocity of the product bed between the plates mitigates the creation of fines/dust. Producers can expect amount of dust in worst-case scenarios equal to amount at the feed point.
- Residence time inside the heat exchanger and heat transfer between particles in narrow separate columns providing accurate uniform heat exchange and desired product temperature at the exit of the cooler.
- No large horsepower process-air fans required, eliminating a major exhaust stream and its abatement load.
- Material of construction provides required integrity (e.g. stainless steel 304L, 316L, 254 SMO etc.)
- Constant temperature in storage and direct packaging independent of ambient conditions means no product caking.
- A pneumatically driven discharge device (e.g., gate feeder) is the only moving part in this unit, and requires minimal maintenance.

Some considerations with plate-based heat exchangers include:

- **Caking:** This occurs during the cooling process when the critical relative humidity temperature and interstitial air dew point exceeds the plate surface temperature. The remedy to this is to use a calculated amount of purge air and a cooling water regime (flow rate and temperature)
- **Physical plugging:** When the product contains various particles sizes, this can block space between the plates (calculated for each fertilizer separately). A proper cleaning system upstream and plate spacing in the heat exchanger can successfully preventing this from happening.
- **Cooling-water quality:** Closed loops no longer require tight control of scaling/corrosion and filtration to minimise plate fouling.

Technology considerations

Choosing the right fertilizer cooling technology depends on several factors, including the type of fertilizer, production requirements and desired outcomes. The following represents some key considerations:

Type of fertilizer: Different fertilizers have varying cooling needs. For example, hygroscopic fertilizers such as potash and phosphate bases are more prone to caking, therefore require lower dew point of purge air to prevent clumping. AN-based fertilizers, meanwhile, require a greater heat flow area to provide effective cooling.

Cooling efficiency: Commonly used cooling technologies include fluid beds, rotary drums and plate-based heat exchangers. Fluid bed coolers offer cooling by suspending solid material in a flow with chilled or ambient air. Rotary coolers tumble material in a rotating drum also with chilled or ambient air. Plate-based heat exchangers provide an indirect cooling options, with a packed bed of solids moving downward between stainless-steel plates which contain a countercurrent flow of cold or chilled water.

Product integrity (including coated products): Preserving fertilizer integrity during the cooling process is crucial to maintaining product size, quality and longevity, while also preventing issues such caking and nutrient loss. Fluidisation, as well as tumbling actions, can negatively impact product integrity (e.g., creates dust) due to the mechanical nature of the heat transfer process. Plate-based heat exchangers do not create dust due to the indirect nature of the heat transfer process. This process also preserves product quality – including the coatings in applications involving coated fertilizers.

Throughput requirements: Considering the production scale and throughput needs, all three technologies have improved their robustness in recent years and have been operating in the field with high throughputs. This was not the case several years ago when rotating equipment was often preferred for higher throughputs, making it suitable for large-scale operations.

Capex/opex: Each technology comes with different associated costs, which can include:

- equipment investment cost (e.g., equipment assets and implementation/installation);
- operating costs (e.g., energy input requirement, maintenance costs and required scheduled downtime);
- costs of post-processing working fluid (e.g., air abatement, CW cooling).

Maintenance and reliability: There are several considerations when evaluating the maintenance requirements and reliability of the cooling equipment:

- **Maintenance needs:** Rotating equipment such as rotary drum coolers generally requires more frequent maintenance due to the moving parts. This includes regular lubrication, alignment checks and wear-and-tear inspections. Rotary coolers have a well-earned reputation for reliability, operating consistently and without issue for years providing they are regularly maintained.
- **Failure modes:** Common failure modes include bearing failures, seal leaks and mechanical wear. Proper condition monitoring and preventive maintenance can mitigate these issues.
- **Static equipment maintenance needs:** Fluid bed coolers typically require less frequent maintenance since it has fewer moving parts. This can lead to lower maintenance costs and downtime. Similarly, plate-based heat exchangers require minimal maintenance due to it being gravity fed through the unit and discharged by a low-speed oscillating pneumatic extraction device.
- **Failure modes:** Failures in static equipment are often related to corrosion, fouling or structural issues. Regular inspections and cleaning can help prevent these problems.
- **Stability:** Static equipment tends to be more stable and less prone to mechanical failures, making it a reliable choice for consistent operations.

Cost and availability: Operators must factor in the cost of the equipment and its availability. A few cost considerations when choosing a cooling technology include the degree of difficulty of integrating it into the existing space and required downtime.

Conclusion

When the risk of product quality is in question, cooling in fertilizer production plants is an essential step in product finishing. Furthermore, rising decarbonisation efforts within the fertilizer industry means it's not just what cooling technologies can do, but how they do it. Today's solutions demonstrate how these changes are already taking place. For decades, they have acted as cornerstones in the fertilizer production process. In recent years, they have evolved to further help decarbonise operations.

When it comes to selecting the right cooling technology, operators must understand that there is no one-size-fits-all solution. Many different variables will determine the viability of the installed solution. Yet by investing in the right technology solutions, fertilizer producers have an opportunity to meet their operational and decarbonisation goals while still feeding the world of tomorrow. ■

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