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Ammonia to power
AI-assisted plant operation
Decarbonising ammonia production
Low carbon hydrogen



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All this and El Niño too...?



A strong El Niño will have a negative impact on the world economy..."

The August deadline for talks between the US and Iran came and went, as expected, with no resolution to the conflict. At time of writing, both sides were exchanging tit for tat attacks on ships in the Strait of Hormuz, with Iran claiming that it would be instituting a new ‘exclusion zone’, and no sign of a diplomatic resolution in sight. With the flow of ammonia, urea and other commodities like oil, LNG and sulphur from the Gulf still slowed to a trickle, the summer of high prices and demand destruction looks set to extend well into autumn at least.

But meanwhile, on the other side of the world, something equally momentous appears to be happening, with the previous two La Niña years ending, and Pacific surface temperature trends moving towards what is shaping up to be one of the largest El Niño events in history. The World Meteorological Organisation (WMO) recently released data on the weather phenomenon showing it could be the strongest for more than 70 years and last until at least February 2027.

El Niño – so called because it was first noticed around Christmas (El Niño means the Christ child) - is associated with a band of warm ocean water that develops near the equator in the central and eastern Pacific Ocean. It develops when the westward winds in the Pacific weaken, allowing warm water to spread eastwards towards South America, bringing with it high rainfall. The event typically triggers drought across large swathes of Asia and Australia, while the Americas typically experience excess rain and flooding. El Niño’s effects are also felt further afield, particularly in Africa.

The last so-called ‘Super El Niño’ event occurred in the winter of 2015-2016, and led to a weak monsoon and summer heatwave in India, followed by flooding in South Asia. Rainfall during September and October 2015 was also the third lowest on record in Australia. There was drought followed by fires in Indonesia and a 60% fall in the maize harvest in Central America. A strong El Niño will have a negative impact on the world economy, mainly driven by four key factors.

- Extreme temperatures caused by El Niño, or in the worst case a ‘Super El Niño’, are likely to increase the number of natural disasters in many parts of the world, including forest fires, droughts and the spread of diseases.
- Droughts will reduce hydropower availability in certain markets, which will increase the costs of producing and processing certain commodities. Demand for energy alternatives will increase, along with rising demand for cooling, particularly in Asia where a large part of the world population will be exposed to these higher temperatures. In other words, an El Niño is likely to result in higher energy prices.
- The heightened risk of natural disasters, coupled with the current and continuing low availability of fertilizers from the Middle East (especially sulphur and urea) and rising energy prices would be disruptive for the world’s agricultural production. This will raise food prices worldwide, or worse, even cause shortages in some regions. This could fuel global inflation and result in interest rates remaining higher for longer.
- Global trade will also be affected. Higher energy prices could raise transportation costs and many inland waterways will be impacted by changing water levels. One of the most important arteries for world trade is the Panama Canal. Throughput was severely disrupted during the brief El Niño period at end-2023, when sea temperatures in the Pacific Ocean only reached 1.5 °C above normal levels.

Fertilizer applications in India are already falling due to a weak monsoon and anticipated later conditions, and potash demand has fallen in anticipation of the coming El Niño. The final quarter of 2026 and 1Q 2027 could see markets in for an even bumpier ride than they have had this summer. ■

Richard Hands, Editor

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Price Trends

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6 The ammonia market continues to be divided on a regional basis during August. In northwest Europe, prices remained high, holding above the \$700/t CFR mark, underpinned by high Dutch TTF gas prices, which stood at €63.93/MWh (\$21.5/MMBtu) as of 20 August. The spot market was active, with two cargoes destined for CF Fertilisers in the UK, one an ex-Trinidad cargo supplied by Koch and the other an ex-Algeria cargo supplied by Trammo. Trammo was also linked to a separate, unconfirmed, sale into Poland for Grupa Azoty.

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13 East of Suez, however, sentiment remained bearish. Chinese FOB offers in the \$430/t range continued to anchor the regional floor, putting pressure on other producers. This was reflected in Southeast Asia, where the assessed price range eased to \$420-500/t FOB amid growing length and a reported sale into India at \$450/t CFR for Malaysian-origin material. However, significant regional buying interest is yet to emerge, with demand also muted in East Asia where inventories in South Korea and Taiwan, China remained sufficient for near-term needs.

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In the US, the market was quiet, with attention now focused on the September Tampa contract settlement between Yara and Mosaic. Expectations were for a moderate decline from the August price of \$635/t CFR, with most anticipating a settlement closer to \$600/t CFR, reflecting the broader weakness outside of Europe.

The urea market saw pockets of price rally, but demand remained lacklustre. Prices for granular urea at New Orleans firmed after softening earlier in the month, with September barges trading between

\$403-405/st, following higher priced deals concluding in North Africa. In Egypt, sales were concluded by Mopco at \$450/t FOB and Abu Qir at \$475/t FOB, marking an increase on previous assessments. In Algeria, deals were also reported at progressively higher levels, reaching \$467/t FOB following an AOA sale for September.

Overall, though, demand still remained muted, with the possibility of significant Chinese supply weighing on markets, while 10 vessels carrying around 442,000 tonnes of urea were still held west of the strait of Hormuz. India closed a tender with lowest offers in the low-\$390s/t CFR, expected to be largely supplied by China, with participation estimates ranging from 1.2-1.5 million tonnes.

In the Middle East, prices were indicated in the \$390-410/t FOB range, with the logistical situation in the Strait of Hormuz still uncertain. In Iran, the official price was cut to \$345/t FOB, though several tenders failed to attract buying interest.

In Southeast Asia, a tender from Brunei was rumoured to have been awarded in the \$400s/t FOB, though other regional indications were heard as low as the \$380s/t FOB. In Australia, delivered prices were revised down to the \$450-490/t CFR range, amid ample import coverage for the current season.

European markets have been quiet. In the Baltic, prills prices slipped further, with two cargoes reportedly lined up to supply last week's Indian tender. In the Black Sea, prices eventually climbed, mirroring gains in North Africa. In Northern Europe, prices in France were indicated lower at €480-485/t FCA amid scant demand.

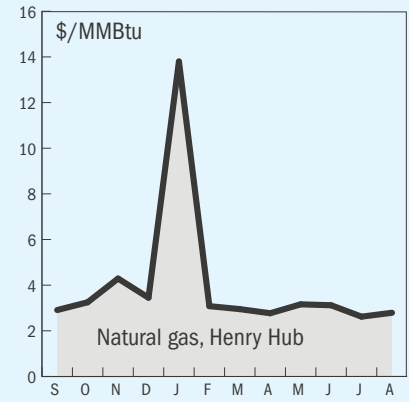
Table 1: Price indications

Cash equivalent	mid-Aug	mid-Jun	mid-Apr	mid-Feb
Ammonia (\$/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	595	735	735	585
f.o.b. Arab Gulf	455-525	750-795	730-775	450-512
c.fr N.W. Europe	700-760	860-910	800-875	670-690
Urea (\$/t)				
f.o.b. bulk Baltic Sea	325-370	365-390	670-700	395-410
f.o.b. bulk Arab Gulf*	347-410	308-425	720-930	437-455
f.o.b. NOLA barge (\$/st)	380-400	340-405	703-785	432-437
f.o.b. bagged China	348-365	490-510	n.m.	n.m.
DAP (\$/t)				
f.o.b. bulk US Gulf	795	785	740-750	625-632
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	420-430	430-435	445	360

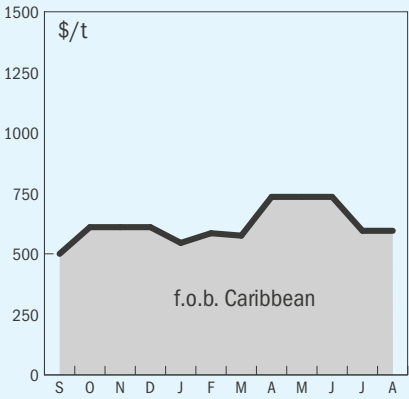
Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.

END OF MONTH SPOT PRICES

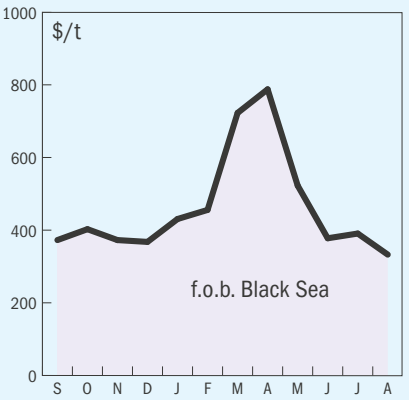
natural gas



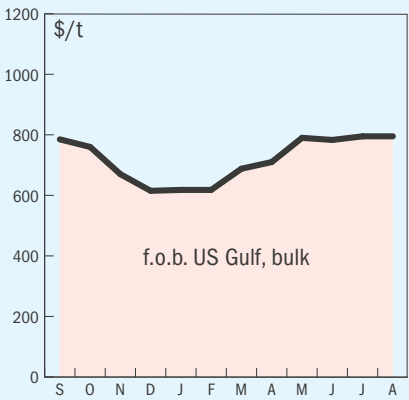
ammonia



urea

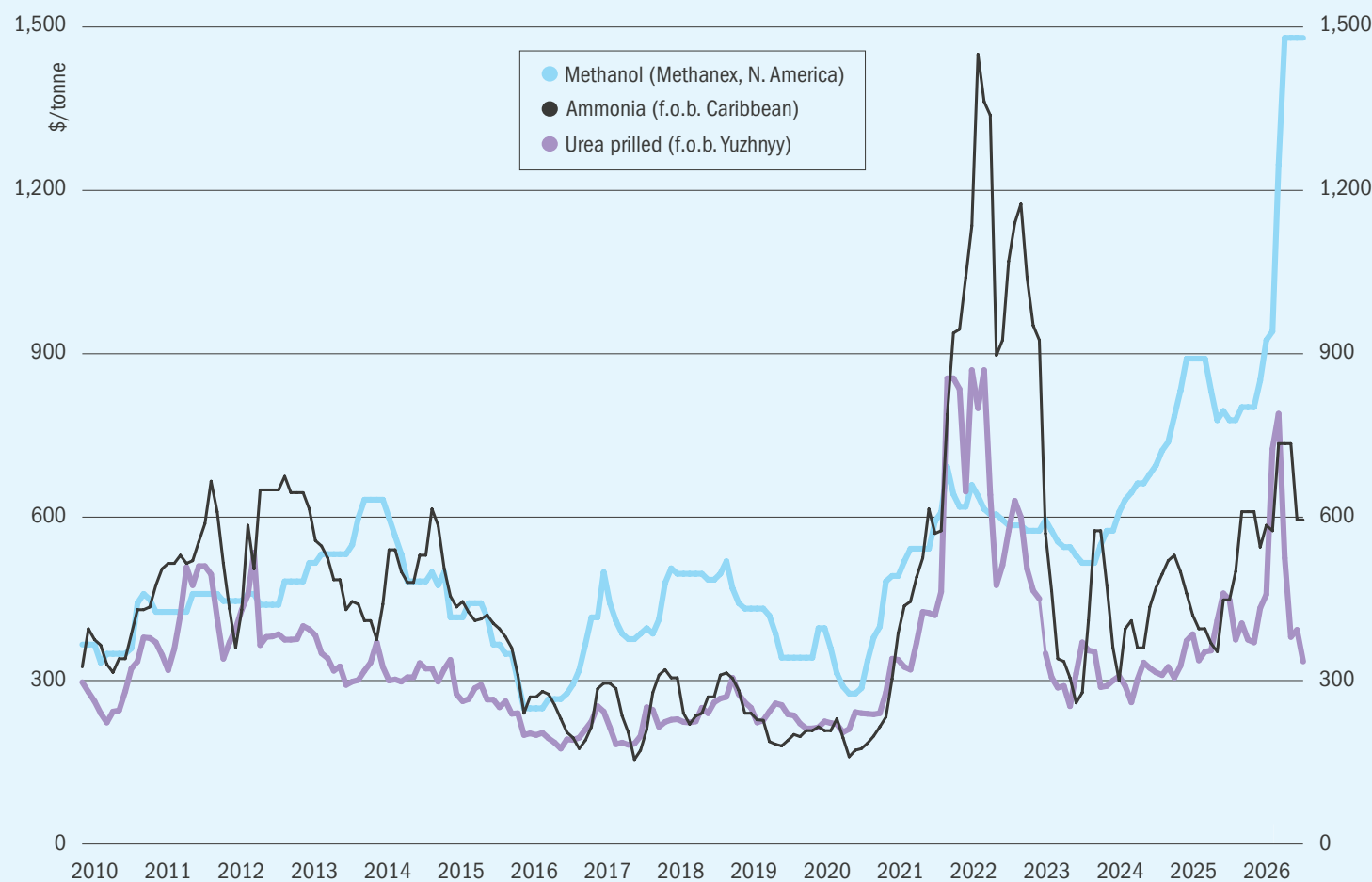


diammonium phosphate



Market Outlook

Historical price trends \$/tonne



Source: BCInsight

AMMONIA

- Prices are expected to hold firm in Europe, though values elsewhere could well undergo further pressure, with Tampa also expected to decline for September.
- US attention was focused on September's Tampa contract settlement between Yara and Mosaic. Expectations are for a moderate decline, with most alluding to an agreement at or close to \$600/t CFR, down on August's \$635/t CFR figure. In the US Gulf, the August export lineup reached 237,000 tonnes by August 20th.
- Northwest European ammonia prices remain supported by increasing FOB indications out of Algeria. Dutch TTF gas prices at €63.93/MWh (\$21.5/MMBtu) also support such levels. Overall EU January-June ammonia imports were up by 4% year on year at 422,000 tonnes for 1H 2026.

UREA

- The urea market was looking to North Africa to see if the recent rally can be sustained through the remainder of August. August 24th saw Mopco sell 5,000 tonnes of granular at \$490/t FOB for September shipment, and Abu Qir also placed 5,000 tonnes of granular at \$490/t FOB. Both sales are \$15/t up on prior activity.
- Chinese urea exports rose in July to 403,438 tonnes, bringing cumulative January-July exports to 907,058 tonnes, 41% up year on year. This surge followed China's opening of its urea export window late May with two rounds "quota allocations" of around 5 million tonnes. The increasing export business has curtailed the downward trend in Chinese domestic prices, but – in addition to new capacity elsewhere – is holding regional and global urea prices down.

METHANOL

- The methanol market remains volatile, with continuing uncertainty over the situation in the strait of Hormuz. Around 4 million tonnes of methanol has not been produced and/or shipped since March, and two thirds of Iran's methanol capacity remains down, with other Gulf producers running at reduced rates. With winter likely to shut down the remainder of Iranian capacity, further supply tightness lies ahead.
- Chinese domestic prices were rising, heading to \$430/t at coastal ports, with feedstock coal supply remaining tight. Supply has risen as plants complete turnaround, while demand, is low for acetic acid and MTO, indicating lower prices may be ahead. Overall Chinese methanol demand may be down 3 million t/a for the year.
- Elsewhere, Southeast Asian methanol prices were around \$505/t, the FOB US Gulf methanol market at 135 cents per gallon (ca \$450/t); and European FOB Rotterdam prices at EUR 395/t.

UNITED STATES

CF begins construction of Blue Point ammonia plant



In its second quarter 2026 results filing, CF Industries said that construction of its new Blue Point ammonia plant will begin in August this year. The Blue Point One project is a joint venture with JERA Co., Inc. and Mitsui & Co., Ltd. for the construction, production and offtake of low-carbon ammonia from a new facility at Modeste, Ascension Parish, Louisiana. CF Industries holds 40% ownership in the \$3.7 billion joint venture, with JERA taking a 35% stake, and Mitsui the remaining 25% ownership in the plant, which is funded by the equity partners according to their ownership percentages. The plant consists of an autothermal reforming-based ammonia facility with a carbon dioxide (CO₂) dehydration and compression unit to prepare captured CO₂ for transportation and sequestration. CF Industries says that it will also build scalable infrastructure to supply the ammonia production facility with services, including production storage and vessel loading. In July 2026, the State of Louisiana and the US Army Corps of Engineers issued permits required for civil construction activities for the ammonia plant and common infrastructure. Nameplate capacity for the plant will be 1.4 million t/a of blue ammonia, with first production expected in 2029. The associated infrastructure will sequester 2.3 million t/a of carbon dioxide via Occidental subsidiary 1PointFive. ■

Topsoe to provide technology for Texas green ammonia project

Topsoe has signed an agreement with First Ammonia, a company developing modular, commercial-scale plants to produce green ammonia from renewable energy sources, to provide Topsoe's dynamic ammonia synthesis technology for First Ammonia's planned green ammonia production facility in Victoria, Texas. Topsoe says that the project marks another important step toward commercial-scale green ammonia production in the United States. Based on green hydrogen generated by electrolysis using renewable electricity, the facility is designed to produce green ammonia for both international and US markets. Financial close is expected later in 2026, with commercial operations anticipated to begin in 2029.

Yassir Ghiyati, Chief Commercial Officer, Topsoe, said: "As green ammonia projects move from ambition to execution, operational flexibility becomes increasingly important. We're proud to support First Ammonia with technology designed to enable efficient and reliable green ammonia production. We look forward to continuing to work with the First Ammonia team to help bring this important US project to life."

Under the agreement, Topsoe will provide its dynamic ammonia synthesis technology, designed specifically for green ammonia plants. The technology enables production to ramp up from 10-100%, or to decrease at similar rate, within thirty minutes, allowing the ammonia synthesis loop to respond to fluctuations in power generation while maintaining safe, reliable and efficient operations.

ALGERIA

Sonatrach hires Saipem and CHEC for Algerian phosphate build

Algeria's Sonatrach and the Algerian Fertilizers Company (AFC) on 12 August signed engineering, procurement and construction contracts with Italy's Saipem and China Harbour Engineering Company (CHEC) for the first phase of the country's Integrated Phosphate Project (PPI). The ceremony at Sonatrach's Algiers headquarters was chaired by Hydrocarbons Minister Mohamed Arkab and attended by the Chinese and Italian ambassadors.

Saipem's Limited Notice to Proceed is worth approximately €500 million (\$580 million) and covers EPC of the phosphate processing and fertilizer production facilities at Bled El Hadba (Tébessa province) and Oued El-Kebrit (Souk Ahras province). CHEC will build the associated port facilities at Annaba. The full EPC contract with Saipem is still being finalised.

Once operational, the complex is designed to mine 5.5 million tonnes/year of run-of-mine phosphate rock and to produce 3.2 million tonnes/year of phosphate concentrate, 2.4 million tonnes/year of phosphate fertilizers and 570,000 tonnes/year of urea, along with by-product sulphuric acid, phosphoric acid and ammonia.

Sonatrach said the project would allow Algeria to transform its phosphate and natural gas resources domestically before selling the output "on the national market and for export".

BRAZIL

Brazil approves BRL 10 billion Profert programme

Brazil's Federal Senate on 11 August approved the final text of the Profert bill (PL 699/2023), which will release up to BRL 10 billion (\$1.85 billion) in tax-credit subsidies over five years to build new fertilizer plants or expand and modernise existing ones. The vote confirmed amendments made earlier by the Chamber of Deputies. The bill now goes to President Lula to be signed into law.

The programme will run from 2027 to 2031, with an annual cap of BRL 2 billion (\$370 million) – unused amounts can be carried over to the following year. Federal tax credits will be awarded through a competitive procedure to companies producing synthetic or mineral fertilizers, their raw materials, bioinputs, biofertilisers and remineralisers.

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The credits will be treated as Social Contribution on Net Profits (CSLL) credits and can be used to offset federal tax debts or claimed as cash reimbursements. Total credits will be capped at 20% of a company's Brazilian fertilizer production spend, and beneficiaries must maintain employment at or above the average level of the three months preceding the law's entry into force.

The text creates a Programme for the Development of the Fertilizer Industry (Profert) alongside a suite of complementary measures. The Merchant Marine Freight Renewal Surcharge (AFRMM) will be waived on inputs destined for approved Profert projects between 2027 and 2031, up to BRL 200 million (\$37 million) a year and BRL 1 billion (\$185 million) over the period. The National Fertilizer and Plant Nutrition Council (Confert) will set a mandatory blending percentage of nationally produced synthetic and mineral fertilizers, starting at 2% and rising to 10% by 2031, and will publish an annual monitoring report. A separate provision channels federal resources through BNDES to fund concessional lending for approved projects, with BNDES and participating banks bearing the credit risk and the Monetary Council setting rates and terms.

Brazil, though one of the world's largest food producers and exporters, imports more than 80% of the fertilizers it uses, the Senate said in its notes on the bill, citing the National Fertilizer Plan 2022–2050.

Author Senator Laércio Oliveira said the measure would put Brazil on a path towards autonomy in fertilizers. "From the sanction of the bill, Brazil will have a national fertilizer policy, with incentives for the domestic industry, so that we can move away from this external dependence. Fertilizers mean national sovereignty. And that is what we must pursue," Oliveira said in the plenary.

Senate rapporteur Tereza Cristina, a former agriculture minister, said the Chamber's substitute text "substantially improves" the original proposal, replacing what was mostly a tax-incentive framework with "a broader public policy that combines fiscal, financial, technological and governance instruments". Speaking to the plenary on Brazil's exposure, she said: "The events of recent years, notably the impacts of the war between Russia and Ukraine and the conflicts in the Middle East, have made clear the vulnerability of the national fertilizer supply and reinforced the need to expand installed production capacity in the country."

MOROCCO

US backs \$4.5bn Morocco green ammonia plant

The US Trade and Development Agency has signed a \$5.7 million grant agreement with Morocco-based joint venture ORNX Laayoune 1 SASU (ORNX) to fund a pre-front end engineering and design (pre-FEED) study for a large-scale green ammonia plant in Laayoune, southern Morocco, the two parties said on 28 July. The Laayoune project has a total estimated cost of \$4.5 billion.

ORNX is a consortium of US-based Ortus Climate Mitigation LLC and Acciona-Nordex Green Hydrogen, a Spanish-German joint venture between Acciona and Nordex. The consortium was selected in March 2025 under Morocco's national "Offre Maroc" green hydrogen programme to develop wind- and solar-powered green hydrogen and ammonia facilities at Laayoune, Dakhla and Boujdour. The Laayoune plant is expected to draw on more than 2 GW of on-site renewable capacity to produce around 100,000 t/y of green hydrogen, which will be converted into up to 560,000 t/y of green ammonia for export.

ORNX has selected a US consortium led by Kellogg Brown & Root LLC (KBR) and including GE Vernova, Electric Hydrogen (EH2) and Terabase Energy to carry out the pre-FEED study. KBR will lead the engineering and process integration; GE Vernova will handle grid connection and power conversion; Terabase Energy will design the solar infrastructure; and EH2's electrolyzer technology will be assessed as part of the work. The study will also cover a seawater desalination plant using reverse osmosis to supply ultra-pure water for electrolysis, marine facilities, environmental and regulatory assessment, and a 25-year financial model covering the Levelized Cost of Hydrogen and Levelized Cost of Ammonia.

"Morocco has made ammonia production a top national priority. When our allies are making generational infrastructure decisions, USTDA is proud to partner with U.S. industry to demonstrate the best of what America has to offer," said Thomas R. Hardy, Deputy Director of USTDA.

Peter A. Gish, Chief Executive of ORNX, said: "This funding will allow us to complete the pre-FEED studies with our partners KBR, GE Vernova, Electric Hydrogen, and Terabase, driving both the technical and commercial development of the project as we accelerate toward the FEED and Final Investment Decisions."

ARGENTINA

Tecnimont to provide license and EPC contract for new urea facility

Maire Group subsidiary Tecnimont has been awarded a contract by Fertil Pampa SAU, a wholly owned subsidiary of Pampa Energia SA, for a large-scale fertilizer complex in Argentina. The facility will include a large-scale ammonia plant and two parallel ultra-low energy urea trains, each with its own granulation unit, with a combined capacity of 6,000 t/d (2.1 million t/a), making it the largest urea plant in Latin America by production. It will occupy an 80-hectare site within the Bahía Blanca Industrial Complex, in Buenos Aires province. The location is adjacent to Pampa's existing power generation assets, benefiting from direct access to key infrastructure, including gas pipelines, high-voltage transmission lines, water intake systems, and a deep-water export port, enabling efficient logistics.

Tecnimont's scope of work includes engineering, procurement, commissioning, and start-up activities. Nextchem has been selected as technology provider, leveraging Stamicarbon's urea melt and granulation licensing technologies and process design package, as well as associated proprietary equipment, and the supply of the primary reformer for syngas production by KT Tech. KBR will provide the ammonia technology license. The total value is approximately €1.3 billion, of which €140 million related to Nextchem's technology package. Overall execution of the project will involve SACDE SA, a leading Argentinean company, for the construction. Completion is expected in 41 months.

Alessandro Bernini, CEO of Maire, commented: "This award marks our entry in Argentina, further diversifying our geographical footprint, and highlights our ability to integrate Tecnimont's recognised project execution capabilities alongside Nextchem's technology portfolio to deliver large-scale industrial projects worldwide. We are proud to contribute to the development of this strategic fertilizer complex in the region, which will support the monetisation of natural gas reserves in the domestic downstream sector, and also strengthen the country's fertilizer production."

SOUTH KOREA

South Korea withdraws support for ammonia co-firing

South Korea has acted to de-emphasise low-carbon ammonia co-firing in coal plants from its power sector decarbonisation policy. The government has withdrawn a key implementation mechanism: coal–ammonia co-firing is excluded from support through the 2026 clean hydrogen power auction market. The decision was explicitly linked to the government’s objective of ending coal generation by 2040; the 11th Basic Plan for Electricity Supply and Demand, finalised in 2025, envisaged hydrogen and ammonia as part of the future generation mix, including ammonia blended with coal.

The new policy direction instead prioritises retirement and potential repurposing of coal assets, large-scale renewable deployment, grid investment, flexibility resources and electrification. South Korea’s April 2026 Energy Transition Plan sets out a pathway to retire its operating coal fleet by 2040 and target 100 GW of renewable capacity by 2030. Hydrogen and carbon management technologies remain relevant, particularly for ‘difficult-to-electrify’ industrial applications, but coal–ammonia blending no longer features as a flagship route for power-sector decarbonisation, reducing demand for green and blue ammonia in the medium term.

AUSTRALIA

Trinasolar selected for green ammonia project

Solar panel and energy storage company Trinasolar says that it has been selected to supply solar modules for the Good Earth Green Hydrogen and Ammonia (GEGHA) project near Moree, New South Wales (NSW), Australia. GEGHA is the state’s first green hydrogen and ammonia facility. The project’s 27MW solar farm will use Trinasolar’s 510W and 515W Vertex S+ modules, which incorporate a heat-strengthened dual-glass design selected for durability, weather resistance and low degradation in long-term renewable energy applications, as well as proprietary i-TOPCon technology, which helps reduce light-induced degradation, supporting stable energy yield across the project lifecycle. By supporting long-term energy generation and low degradation, the modules can contribute to lower lifecycle costs and stronger long-term project economics.



Mock-up of the new Trinasolar facility, New South Wales.

Construction is now under way. On completion, the facility is expected to produce up to 200 t/a of green hydrogen and up to 4,500 t/a of low-carbon ammonia. The project is designed to replace imported fossil fuel-based fertilisers and support emissions reductions in agriculture.

Edison Zhou, Head of Australia and New Zealand at Trinasolar said, “Projects like GEGHA demonstrate the important role solar plays in enabling emerging industries such as green hydrogen and low-carbon fertiliser production.”

“GEGHA is designed as a commercial pilot for decentralised hydrogen and fertiliser production that could be replicated across regional Australia. For a project intended to demonstrate a long-term regional model, reliable solar generation is critical. Trinasolar’s n-type dual-glass technology and experience in the Australian market were important considerations in selecting modules for the project’s solar farm,” said Joe Cumming, Senior Project Manager, Hiringa Energy.

INDIA

GAIL, RCF plan 1.27 million t/y urea plant

India’s GAIL (India) Limited and Rashtriya Chemicals and Fertilizers Limited (RCF) have signed a Memorandum of Understanding to jointly establish a gas-based urea plant in the Vidarbha region of Maharashtra, the state-owned gas transporter said in a stock-exchange filing on 29 July. The proposed facility will have capacity of 1.27 million t/y and will be built along GAIL’s Mumbai–Nagpur–Jharsuguda Natural Gas Pipeline (MNJPL). The two

companies will develop the project through a Special Purpose Vehicle.

The GAIL–RCF plant is the first project to be announced under India’s National Investment Policy for Urea-2026 (NIPU-2026), approved by the Union Cabinet on 15 July, and its 1.27 million t/y capacity matches the standard plant size envisaged under the policy. As we reported in July, NIPU-2026 aims to add 10 million t/y of new domestic urea capacity through 8–9 new gas-based plants, part of a broader fertilizer security package designed to close the gap between India’s domestic urea output – 29.33 million tonnes in 2025-26 – and consumption of about 40 million t/y.

The MoU was signed by Sanjay Agarwal, Executive Director (BD & Start-up) of GAIL and Jyoti Patil, Executive Director (Project, Corporate & Co-ordination) of RCF, in the presence of Deepak Gupta, Chairman and Managing Director of GAIL, and S. Shivakumar, Chairman and Managing Director of RCF.

“The proposed fertilizer project aligns with GAIL’s strategy of creating long-term value through natural gas utilisation and contributing to India’s energy security objectives,” said Gupta. “We are pleased to partner with RCF, a leading fertilizer company with proven expertise in the sector. This collaboration combines GAIL’s strengths in the natural gas value chain with RCF’s rich experience in fertilizer manufacturing and project execution.”

India’s CFCL starts TAN production at Gadepan

Chambal Fertilisers and Chemicals (CFCL) commenced commercial production of technical ammonium nitrate at its Gadepan complex in Kota district, Rajasthan, on 20



PHOTO: CFCL

Chambal Fertilizers' facility at Gadepan.

August, the company confirmed in a stock exchange filing. The unit produces prilled high-density ammonium nitrate (HDAN) and has a capacity of 240,000 t/a. An integrated weak nitric acid plant at the same site has a capacity of 210,000 t/a and supplies the downstream unit. Larsen & Toubro executed the works on a lump-sum turnkey basis under a technology licence from Casale, it said.

The start-up follows around eight months' delay against the January 2026 commercial production date previously indicated. CFCL is targeting industrial demand from the mining, infrastructure and quarrying sectors, reducing its exposure to agricultural cycles. The plant draws on ammonia produced on site.

CZECHIA

Agrofert forms AGF nitrogen

Czech-headquartered Agrofert Group has established a new sub-holding company, AGF Nitrogen, a.s., to coordinate the activities of its pan-European chemical division. The vehicle went live on 1 July 2026, and Agrofert said its aim is to achieve synergies through economies of scale, raise efficiency and cut operating costs. Employees, customers and business partners are not directly affected by the reorganisation.

Petr Cingr, Vice-Chairman of the Board of Directors of the Agrofert Group, becomes Chairman of the Board and Chief Executive of AGF Nitrogen. To take on the new role, Cingr resigned as Chief Executive of Germany's SKW Stickstoffwerke Piesteritz GmbH on 30 June, and will keep contact with the Piesteritz business through the position of

Chairman of the Supervisory Board. Carsten Franzke, previously Chief Operating Officer at SKW Stickstoffwerke Piesteritz, took over as Chief Executive of the Piesteritz company on 1 July. The rest of the Piesteritz management team is unchanged.

The restructure follows two significant additions to Agrofert's European nitrogen footprint. The group closed its acquisition of Borealis's fertilizer, melamine and technical nitrogen business – since rebranded LAT Nitrogen – on 5 July 2023 at an enterprise value of €10 million (\$955 million), gaining production sites in Austria, France and Bulgaria alongside its existing German assets. On 31 March 2026, Agrofert then closed the €290 million (\$342 million) purchase of OCI Ammonia Holding B.V. from Amsterdam-listed OCI Global, comprising OCI Terminal Europoort – an ammonia import and storage terminal in Rotterdam – and OCI Ammonia Distribution, OCI's third-party European distribution platform. In a separate transaction announced on 1 June 2026, OCI Global agreed to sell 50% of OCI Nitrogen, which runs the Geleen ammonia and fertilizer complex in the Netherlands, to Agrofert for half of a €110 million enterprise value, with completion expected by H₂ 2027 and put/call options over the remaining 50% exercisable from two years after closing.

"The European production of fertilizers and other nitrogen products, like almost the entire chemical industry, is in crisis. However, any crisis also represents an opportunity for future growth for us, and at Agrofert we have proven many times that we can grasp these opportunities correctly," said Cingr. "With the acquisitions of the companies of the LAT Nitrogen Group and recently

OCI Ammonia holding, the Agrofert Group has made it clear that it believes in the future of the chemical industry in Europe and that our employees, customers and business partners can rely on us. However, this future success requires organizational adjustments within the group."

ALGERIA

Work to begin on Arzew expansion

Algeria and Oman have made a final investment decision to expand fertiliser production at the Algerian-Omani Fertiliser Company (AOA) plant in Arzew, in Algeria's Oran province. The expansion is expected to increase total production capacity by 50%. The agreement was announced by Algeria's Ministry of Hydrocarbons after a meeting between Mohamed Arkab, Minister of State and Minister of Hydrocarbons, and Sheikh Saad bin Suhail Bahwan, Chairman of Suhail Bahwan Holding Group. Oman's Ambassador to Algeria, Saif bin Nasser bin Rashid Al-Badaei, Sonatrach CEO Nouredine Daoudi and senior government officials also attended the meeting.

The expansion takes the form of a third ammonia-urea train at the Arzew site. Algeria's hydrocarbons ministry has pledged to provide the required natural gas feedstock. Established in 2008, AOA is a joint venture between Oman's Suhail Bahwan Group (51%) and Algeria's Sonatrach (49%). The joint venture currently operates two ammonia-urea trains at Arzew, with a combined capacity of approximately 4,000 t/d of ammonia and 7,000 t/d of granular urea.

DENMARK

OMV takes green methanol from Kasso plant

Green methanol has begun to be shipped from Solar Park Kasso ApS, operated by a joint venture between Mitsui & Co., Ltd, with a 49% share, and renewable energy company European Energy A/S (51%). The plant, located in Kassø, southern Denmark, was inaugurated on 13 May 2025 and is based on hydrogen derived from solar electricity from the adjacent 304 MW Kassø Solar Park, which is then combined with biogenic CO₂ and distilled to 99.9% purity, suitable for combustion engines and plastics production. The plant makes 42,000 t/a of green methanol.

The initial shipment of green methanol produced by this project was supplied to Danish shipping giant AP Moller-Maersk in May 2025 for use as marine fuel. In the spring of 2026, the project also began to supply methanol for use in chemical products to the LEGO group, a leading toy manufacturer, and Novo Nordisk, a global healthcare company. The customer base has continued to expand, including the decision to supply green methanol as a

'renewable fuel of non-biological origin' (RFNBO) to leading European energy firm OMV for use as a land-based transportation fuel. Austrian energy firm OMV has begun using green methanol from Kassø as an input for fatty acid methyl ester (FAME), a component of biodiesel sold at its Burghausen refinery in Germany, claiming to be the first energy company in Germany to bring renewable e-methanol into commercial road transport.

Mitsui has designated "Global Energy Transformation 2.0" as one of its key strategic initiatives in Medium-term Management Plan 2029, with the aim of expanding the range of low-carbon energy products while building an optimised value chain in line with the external environment and customer needs, both of which are changing rapidly. Demand for green methanol is expected to expand across Europe, especially Germany, driven by policy frameworks such as the Renewable Energy Directive (RED III).

CHINA

Shanghai Electric expands green methanol plant

Chinese power conglomerate Shanghai Electric has launched phase two of its Taonan wind-powered green hydrogen-based bio-methanol plant in Jilin, targeting a scale-up to 200,000 t/a. The new phase will build on the facility's current operational capacity of 50,000 t/a, while also adding 10,000 tonnes of sustainable aviation fuel (SAF). The Taonan plant produces methanol by gasifying agricultural biomass into syngas and combining it with green hydrogen produced through electrolysis powered by 67.2 MW of wind power. It became operational in July 2025.

AUSTRALIA

SAF project to use NextChem gasification technology

NextChem, via its subsidiary MyRechemical, has been awarded a licensing, process design package (PDP) and engineering services contract by SKY Renewables Burdekin Pty Ltd, an Australian project development company focused on the production of sustainable aviation fuel (SAF), for the syngas section of Project Lion, in North Queensland. The project will gasify locally available sugarcane residues as feedstock to produce purified chemical grade syngas using of NX Circular™ gasification technology. The syngas will then be used for subsequent conversion into SAF and renewable diesel through third-party solutions. Once at full operational scale,

Project Lion has the potential to produce up to 125,000 t/a of sustainable aviation fuel.

NextChem says that by valorising sugarcane tops and trash, residual biomass that is often burned in the field, the project demonstrates how gasification can enable the transformation of agricultural residues into a valuable intermediate for low-carbon fuels, while supporting a more sustainable use of local biomass resources.

Fabio Fritelli, Managing Director of Nextchem, commented: "We are proud to contribute to a project of this kind in Australia, a geography of growing importance in the evolution of the industry and an important area for the diversification of our portfolio. By leveraging our gasification technology, we can support the conversion of locally available sugarcane residues into low-carbon fuels, combining circular carbon solutions with the decarbonization needs of aviation."

SOUTH AFRICA

Envision and Sasol study green hydrogen at Sasolburg

Chinese wind and green hydrogen group Envision Energy and South African chemicals major Sasol have agreed to run a joint design study on a potential green hydrogen system at Sasol's Sasolburg operations. The study will look at how renewable power, battery storage and electrolyzers could be integrated to produce green hydrogen, and how that hydrogen could feed into lower-carbon fuels and chemicals, including e-methanol and sustainable aviation fuel (e-SAF). Envision said the design study is expected

to complete later this year and will provide technical and commercial insights to support any future investment decision.

The collaboration was announced during a visit by South Africa's Minister of Electricity and Energy, Dr Kgosisentsho Ramokgopa, to Envision's Chifeng Hydrogen Net Zero Industrial Park in Inner Mongolia, held as part of the South Africa-China Energy Investment Conference. Sasolburg is Sasol's existing chemicals complex in Free State province.

"The design study with Envision is an important step in assessing how integrated renewables, energy storage and electrolyser technologies could support cost-competitive green hydrogen production at Sasolburg," said Danie Cronje, Sasol senior vice president for business building. "By drawing on leading global expertise, we can evaluate how these technologies may contribute to future lower-carbon fuel and chemical value chains, while building on Sasol's existing industrial capabilities."

The Sasolburg study widens Envision's green hydrogen portfolio beyond ammonia. Envision's Chifeng Net Zero Industrial Park in Inner Mongolia is already producing green ammonia at 320,000 tonnes/year, with capacity scaling to 1.5 million tonnes/year by 2028 under a long-term offtake with Marubeni of Japan.

South Africa green hydrogen fund hits first close

A new South Africa-focused green hydrogen fund has raised its first ZAR 3 billion (\$182 million), giving it the firepower to start backing large-scale projects, including

green ammonia. The SA-H2 Fund, managed by Cape Town- and Hague-based Climate Fund Managers, announced first close on 6 August. It is targeting a final size of ZAR 12 billion (\$728 million) by mid-2028. The "SA" in the fund name stands for South Africa, and both of the projects the fund has backed so far are located in the country.

SA-H2 will invest across the green hydrogen value chain, including green hydrogen production, green ammonia, green methanol, and the decarbonisation of hard-to-abate industries such as fertilizer, steel and chemicals. The fund blends public and private money. Public money goes in first to reduce risk, which then allows big institutional investors such as pension funds and insurers to commit. Backers of this first close include the European Commission through its Global Gateway strategy, Dutch state-backed Invest International, South Africa's Public Investment Corporation on behalf of the Government Employees Pension Fund, Sanlam Life, and the Industrial Development Corporation of South Africa. The Development Bank of Southern Africa is also supporting the fund.

"As the energy transition progresses, industrial decarbonisation requires solutions beyond electrification, and green hydrogen has a critical role to play," said Andrew Johnstone, chief executive of Climate Fund Managers. "This first close reflects confidence in Climate Fund Managers' blended finance model and our track record of developing and scaling infrastructure projects in emerging markets into institutional-grade assets."

SA-H2 has already signed development funding agreements with two South African projects: Green eFuels Producers, a wastewater-to-green-methanol plant in Gauteng Province, and the Hive Hydrogen Coega Green Ammonia Project, described as South Africa's first large-scale green ammonia production plant. South Africa's strong solar and wind resources, combined with export infrastructure at Coega, have made it one of the more closely watched green ammonia locations globally.

SA-H2 is one of several country funds under Climate Fund Managers' Climate Investor Three platform, which also includes a separate green hydrogen fund for Namibia (SDG Namibia One). The manager's earlier Climate Investor One and Climate Investor Two funds have, it says, together mobilised more than \$2 billion for renewable energy, water, waste and ocean infrastructure in emerging markets.

INDIA

MoU on coal gasification

Coal India Limited (CIL) says that it has executed a non-binding memorandum of understanding (MoU) with ArcelorMittal Nippon Steel India Private Limited (AMNSI), to examine the use of syngas from a gasification facility which CIL would set up next to the ArcelorMittal's Paradip pellet plant in Odisha state. The company says that it will be "exploring the possibility of utilising syngas pro-

duced from a coal gasification facility... coupled with CCUS." The focus of the MoU will initially be to assess the technical, commercial, and implementation aspects of the project and to facilitate preparation of a preliminary feasibility report for evaluating project viability.

CIL already has two gasification joint ventures, including Bharat Coal Gasification and Chemicals Limited (BCGCL), in which CIL holds 51%, which is building a coal-to-ammonium nitrate plant at Lakhanpur in Jharsuguda district, Odisha.

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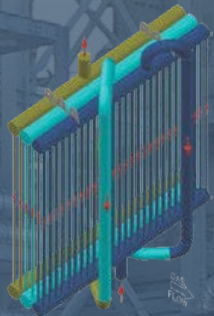
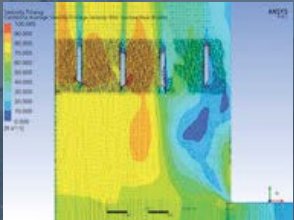
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NITROGEN+SYNGAS
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CRU

India's Public Enterprises Selection Board (PESB) has recommended **Shri Manoharan Potheri** as the new Director of Finance for state-owned Fertilisers and Chemicals Travancore Limited (FACT). Shri Potheri currently serves as Chief General Manager (Finance), Northern Region and Delhi State Office, for the Indian Oil Corporation Ltd. Since February 2026, the Director (Finance) position at FACT has been held by **Shri S. Sakthimani**, who is also Chairman and Managing Director.

India's Department of Fertilizers has also appointed **K.F. Sajo** as the Technical Director for FACT. The appointment takes effect from the date he assumes charge and will continue until his superannuation on 31 May 2028. Mr Sajo has more than 35 years of experience with FACT. He holds an M.Tech. in Project Engineering and an MBA in Marketing. Before joining the Board, he served as Chief General Manager – FEDO & FEW, leading the company's engineering, consultancy and project activities. During his career as a Process Engineer, he has implemented operational improvements across several plant sections, contributing to higher productivity, improved operational efficiency and stronger process reliability.

India's National Fertilizers Limited has appointed **Shri Mahak Singh** as an Addi-



Shri Manoharan Potheri, the new Director of Finance for Fertilisers and Chemicals Travancore Limited (FACT)

tional Director, in the capacity of a Non-official Independent Director, with effect from 14 August 2026. Singh is a businessman and public-service professional with more than 30 years of experience in business and community engagement. He has been involved in a range of grass-roots social-welfare initiatives focused on community development. He served as a Municipal Councillor (Nigam Parshad) in the Municipal Corporation of Delhi from 2007 to 2017 and was also Chairman of

the Standing Committee of the East Delhi Municipal Corporation (EDMC). His experience spans business, civic administration, public service and local community development.

Ruth Herbert has been appointed as Chief Executive Officer, EET Hydrogen & Power, effective from 1 July. She succeeds Joe Seifert, who is returning to the investment banking sector. Ruth takes on the role at EET Hydrogen & Power as it approaches Final Investment Decision (FID) on its landmark HPP1 project.

Announcing the appointment, Prashant Ruia, Chief Executive of Essar Energy Transition, said: "We are delighted that Ruth will be stepping into the role of CEO for EET Hydrogen and Power. Her track record in the sector is considerable, and she has already been instrumental in shaping our vision for a low-carbon energy hub in the northwest. Ruth is perfectly positioned to lead the business through the next phase of delivery."

Ruth commented: "It is a privilege to lead EET Hydrogen & Power at such a pivotal moment. Joe has built a world-class team and an incredible project pipeline. My focus will be on maintaining this momentum, working closely with our partners and the Government to deliver the low carbon hydrogen that is so vital to the UK's industrial future."

Calendar 2026/27

SEPTEMBER

29-OCTOBER 1

World Methanol Conference, ROTTERDAM, Netherlands

Contact: Chemical Market Analytics by OPIS

Email: events@chemicalmarketanalytics.com

Web: https://chemicalmarketanalytics.com/events/world-methanol-conference

OCTOBER

14-15

European Methanol Summit, VALENCIA, Spain

Contact: ACI

Tel: +44 (0)20 7981 9800

Email: luca@acieu.net

NOVEMBER

3-5

IMPCA/MMSA Methanol Conference, SINGAPORE

Contact: IMPCA

Email: meetings@impca.eu

Web: https://www.energyaspects.com/resources/events-webinars/ea-mmsa-international-methanol-conference-2026

3-5

38th AFA Technical Conference & Exhibition, AMMAN, Jordan

Contact: Arab Fertilizer Association

Tel: +202-23054464 / 67

Email: events@arabfertilizer.org

26-28

FAI Annual Seminar 2026, NEW DELHI, India

Contact: Secretary, The Fertiliser Association of India

Tel: +91-11- 46005204

Email: secy@faidelhi.org

JANUARY 2027

17-20

Fertilizer Latino Americano, RIO DE JANEIRO, Brazil

Contact: CRU Events

Tel: +44 (0) 20 7903 2444

Email: conferences@crugroup.com

MARCH

16-18

Nitrogen+Syngas Expoconference 2027, ROME, Italy

Contact: CRU Events

Tel: +44 (0) 20 7903 2444

Email: conferences@crugroup.com

Date tba

Gasification 2027, HELSINKI, Finland

Contact: ACI

Tel: +44 (0)20 7981 9800

Email: luca@acieu.net

Plant Manager+

Problem No. 79

What happens in the low-pressure carbamate condenser?

The low-pressure carbamate condenser (LPCC) in a Stamicarbon urea plant is far more than a simple condenser for ammonia and carbon dioxide vapours. It also plays a critical role in concentrating the carbamate recycle stream before it returns to the urea reactor.

Minimising water in this recycle stream is essential. Higher water content in the urea reactor reduces conversion because water shifts the overall reaction equilibrium towards the reactants. As a result, excess water in the carbamate recycle lowers reactor conversion and can significantly reduce overall urea-process efficiency.

However, the water content cannot simply be reduced indefinitely. The lower limit is determined by the crystallisation point of the carbamate solution. If the solution contains too little water, solids may form during pumping and recycle to the reactor. If it contains too much water, the plant may not achieve its maximum efficiency.

Achieving the right balance is complex. Ammonia, carbon

dioxide and water can form different products depending on their relative concentrations, each with a different crystallisation temperature. Yet operators often have only laboratory analyses showing the weight percentages of ammonia, carbon dioxide and water in the carbamate recycle stream. Consequently, crystallisation behaviour may be estimated primarily from water content, which can be imprecise.

Operators must also avoid entering a “water recycle operation mode”, in which water recirculation progressively increases throughout the plant. If this continues, plant load may eventually need to be reduced substantially to restore stable operation.

In a submerged condenser, not all vapours should condense. A residual vapour phase is needed to maintain a high heat-transfer coefficient, while inert gases must also be accommodated. The following round table discussion highlights the practical challenges associated with operating an LPCC.

Treyzztyler, a student at the University of Malaya in Malaysia, opens the discussion: Can anyone explain the operating conditions of the LP carbamate condenser? I have found values of 65°C and 3 atm. Under these conditions, ammonia and carbon dioxide would both be gases, so how can condensation occur? If condensation takes place, do all gases condense to form ammonium carbamate?

Mohamad Kamal of Abu Qir Fertilizers Company in Egypt replies: The condensation temperature depends on the N/C ratio, water content and pressure. Not all gases are condensed.

Prem Baboo, retired from Dangote Fertilizers in Nigeria, shares his operating experience: Condensation is favoured by higher pressure and lower temperature. In the low-pressure section, typical operating conditions are 39–41°C and 3.1–3.5 kg/cm² for the design N/C ratio. According to the condensation chart, maximum condensation occurs under these conditions. In the Saipem process, ammonium carbonate rather than ammonium carbamate forms.

Zadpanchal of GNFC Ltd in India adds: The vapour mixture also contains water vapour. At approximately 3–3.5 bar, water condenses first. The condensed water absorbs ammonia, forming an ammoniacal solution, which then absorbs carbon dioxide. Ultimately, condensation occurs as an ammonium carbonate solution.

Mark Brouwer of UreaKnowHow.com in the Netherlands joins the discussion: In a Stamicarbon plant, the LPCC also concentrates the carbamate recycle as much as possible to minimise water recycle to the synthesis section, thereby achieving a minimum H/C ratio.

In a Saipem plant, this function is performed in the medium-pressure carbamate condenser (MPCC).

The minimum water content depends on the N/C ratio and the margin between the condensation and crystallisation temperatures – typically around 8–10°C by design.

In a Stamicarbon LPCC, subcooling of approximately 10°C also typically occurs. Different carbamate forms may be produced at different CO₂, NH₃ and H₂O compositions. Refer to <https://vmgurea.appspot.com/> which provides crystallisation-temperature estimates based on measurement data from the 1930s.

Rajan Kher of Koch Fertilizer LLC in Wever, United States, raises an operational question: What could cause the LPCC liquid-carbamate outlet temperature to decrease by 20°F (11.1°C)? What does this indicate, and how can the temperature be restored?

Mark Brouwer suggests several areas for investigation: Is the temperature reduction continuous or temporary? Has the cooling-water duty changed? Review both the temperature difference and flow of tempered cooling water. Has LPCC pressure changed?

Rajan Kher provides further operating details: The reduction is continuous. The LPCC level-vessel temperature is stable at 175°F (79.4°C), with cooling-water temperatures of 126–128°F (52–53°C). However, I can no longer achieve 170°F (76.7°C), even with cooling water at 131°F (55°C). Operations manually set the LPCC cooling-water temperature.

Finally, **Majid Mohammadian** of Fertiglobe in Abu Dhabi summarises the likely causes: Assuming no change in the cooling-water temperature difference, a low carbamate temperature is generally caused by a low N/C ratio, high water content, or a combination of both.

The outlook for low carbon hydrogen

The scale up of low carbon hydrogen has proved slower, more selective and more geographically concentrated than the ambitious plans announced earlier in the decade had anticipated.

Woodside's Beaumont blue ammonia plant, Louisiana

Low-carbon hydrogen is progressing from a policy-led concept toward an investable industrial market. Supply is increasing and a significant group of projects has reached final investment decision or construction. However, high production costs, weak or uncontracted demand, regulatory uncertainty, constrained infrastructure and slow project maturation mean that only a fraction of the announced pipeline is likely to be operating by 2030.

The market is developing differences by region. North America is the principal centre of low-carbon hydrogen and blue-ammonia development, benefiting from comparatively low natural-gas costs, established industrial clusters, carbon-capture-and-storage infrastructure and the US 45Q tax credit. Meanwhile China is establishing itself as the low-cost leader in renewable hydrogen and electrolysis equipment, although its low-emissions market remains at an early stage. Europe, Japan and South Korea seem more likely to emerge as policy-supported demand centres and import markets than as low-cost supply hubs. The Middle East retains potential as an exporter of both blue and green derivatives, but project and trade routes are exposed to geopolitical and infrastructure risks.

Furthermore, ammonia appears to be becoming central to the hydrogen outlook, for several reasons; it is an existing commodity with established storage, handling and shipping networks, as well as being a potentially important hydrogen carrier and low-carbon fuel. However, the outlook for dedicated low-emissions ammonia demand is uncertain. CRU expects that the first substantial volumes

of low-emissions ammonia will need to compete in the conventional merchant market before large new end uses such as marine fuel and power generation are established. That risks putting pressure on ammonia prices and project economics through the end of the decade.

Rapid growth

Global hydrogen consumption remains overwhelmingly conventional and fossil-fuel (mainly natural gas) based. The International Energy Agency (IEA) estimates that total hydrogen demand was around 103 million t/a in 2025¹, while low-emissions hydrogen production was still below 1 million t/a - less than 1% of global output. Low-emissions production nevertheless increased by approximately 20% during 2025 and is expected to rise by a further 30% in 2026 to almost 1.2 million t/a.

This growth matters because it establishes industrial operating experience, supply chains and reference projects. However, it also puts the scale of the challenge into perspective. Traditional refining, ammonia and methanol production and industrial consumption still account for nearly all hydrogen demand. New end uses such as transport, power generation and hydrogen-derived fuels represented only 1.1% of hydrogen demand in 2025. Under existing policies, the IEA expects these newer sectors to account for 4.2% by 2030: rapid growth in percentage terms, but not yet a transformation of the overall hydrogen market.

On the basis of projects already operating, under construction or at final

investment decision, the IEA sees low-emissions hydrogen production reaching 4.3 million t/a by 2030. Including projects with "strong potential" raises this above 6 million t/a, which would represent about 4% of global hydrogen production by 2030. However, this is far lower than the nearly 27 million t/a of aggregate national 2030 production targets identified by the IEA. Achieving those targets would require annual production growth of around 100% through 2030. By contrast, committed projects imply approximately 40% annual growth over the remainder of the decade. The divergence illustrates a shift from broad national aspiration toward a more project-specific, commercially constrained outlook.

Project rationalisation

The announced pipeline of potential low carbon hydrogen projects remains large, but that pipeline has been considerably rationalised. The IEA has reduced its estimate of announced low-emissions hydrogen capacity for 2030 from 37 million t/a in its 2025 review to 27 million t/a in 2026, reflecting cancellations, delays beyond 2030, paused projects and projects with no reported progress for at least three years.

This rationalisation is not necessarily evidence that the sector is failing. Rather, it indicates that developers, financiers and policymakers are moving from early announcements to stricter tests of project viability. The key distinction is increasingly between announced capacity and capacity that has secured finance, permitting, infrastructure and offtake.

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According to the Hydrogen Council², global committed clean-hydrogen investment exceeded \$110 billion across 510 projects at final investment decision or later, an increase of \$35 billion over the preceding year. Around 1 million t/a of low carbon hydrogen was operational in 2025, including roughly 700,000 t/a of blue hydrogen production and 300,000 t/a of green production. Blue hydrogen capacity was particularly important in the operational base: approximately 90% came from eight legacy projects in North America. Looking forward, the Council estimates 13 million t/a of announced low-carbon capacity in the 2030 pipeline. After accounting for anticipated delays, pauses and project attrition, it considers 4–7 million t/a potentially feasible by 2030, conditional on offtake being secured. This is broadly consistent with the IEA assessment. The most important implication is that published capacity announcements should not be interpreted as expected supply without a clear view of project maturity. However, timings remain uncertain. The IEA notes that around 22 million t/a of announced projects will not be operational by 2030 if they do not reach a final investment decision by early 2027. More than 100 GW of announced electrolysis projects in the 100 MW–1 GW range face a similar risk if investment decisions are not made in 2026 or 2027. Typical construction periods are 1–4.5 years for electrolysis projects and 2–3.5 years for carbon-capture-based hydrogen projects, although delivery varies by region and project complexity.

Blue hydrogen

Low-carbon hydrogen produced from fossil fuels with carbon capture, utilisation and storage is expected to provide a significant part of near-term clean hydrogen supply. North America is the principal global hub for development. It accounts for 2.2 million t/a of committed low-carbon capacity – 85% of the global total - and could represent 70–75% of the risk-adjusted low-carbon supply projected for 2030.

North America – particularly the United States - advantage derives from an unusually favourable combination of factors, including relatively low-cost natural gas; existing industrial hydrogen and ammonia demand; available carbon-dioxide transport and storage capacity; export infrastructure on the US Gulf Coast; expe-

rienced industrial developers and engineering providers; and the US 45Q credit, worth \$85/tCO₂ for permanently sequestered carbon. These factors can make US low-carbon hydrogen and derivatives competitive, or close to competitive, with unabated alternatives in high gas price and carbon-priced markets.

The commercial importance of offtake agreements is evident in the leading projects. CF Industries’ Blue Point project in Louisiana reached final investment decision in the second quarter of 2025 and is scheduled to begin operation in 2029. It is designed to produce 1.4 million t/a of ammonia, equivalent to 246,000 t/a of hydrogen, while permanently sequestering around 2.3 million t/a of carbon dioxide. Ownership-linked offtake is allocated among CF Industries, JERA and Mitsui. Likewise, Linde and Dow’s Path2Zero development in Canada, under construction since 2024 and due in 2027, benefits from a long-term supply agreement and existing regional carbon-dioxide transport infrastructure. The broader lesson from the project pipeline is that projects are more likely to advance where carbon management, feedstock supply, engineering capability, logistics and firm demand are integrated from the outset.

Nevertheless, the strength of the US low-carbon pathway remains uncertain or limited in some areas, leaving many projects reliant on export markets. Projects also remain exposed to cost escalation, carbon-storage availability, changes in regulation, and the treatment of lifecycle emissions by importing jurisdictions. Cost escalation in particular has been an issue for US projects. CRU estimates that, prior to 2023, US ammonia projects reported capital intensity of around \$800–\$1,350 per annual tonne of ammonia capacity. However, reported costs for the Beaumont project are closer to \$2,800/annual tonne, and Blue Point may reach \$2,900/t. Beaumont is producing ammonia but the CCS section is not due online until next year and owner Woodside is conducting a strategic review of the way forward. In an interview, Woodside CEO Liz Westcott said “all options” were on the table, and that the review reflects a shift in international policy positions since it agreed to the acquisition in August 2024 and slack demand for lower carbon ammonia; “when we took an investment decision, it was a different world.”

Green hydrogen

Renewable hydrogen has grown quickly, particularly in China, but remains more expensive than conventional hydrogen in most locations. The IEA estimates fossil-based hydrogen production costs in 2025 ranged from below \$1/kg H₂ to more than \$4/kg H₂ depending mainly on fuel prices. Adding carbon capture generally increases costs by around \$0.4–1+/kg H₂. Renewable hydrogen typically remains above \$3/kg H₂ and may exceed \$10/kg H₂ where electricity, capital or financing costs are high.

The gap is driven by power costs, electrolyser capital expenditure, utilisation rates and financing. Electrolysers supplied by manufacturers outside China had installed costs of around \$1,900–2,500/kW in 2025, compared with about \$500–1,100/kW for Chinese systems installed domestically, although non-Chinese installed electrolyser costs could fall to \$1,500–1,900/kW by 2030. Still, China has the best prospect of broad renewable hydrogen cost competitiveness by 2030, supported by cheaper renewable electricity, lower-cost electrolysers and lower financing costs. In favourable northern Chinese locations, the IEA expects renewable hydrogen costs below \$2/kg H₂ by 2030. CRU believes that this outlook is over-optimistic, however, with estimated Chinese green hydrogen costs of around \$5.2/kg H₂ in 2030, declining to \$3.5/kg H₂ by 2050. CRU forecasts Middle East green ammonia levelised production costs of \$1,427/t in 2030, declining to \$644/t by 2050 in real-2024 terms. Blue ammonia costs are substantially lower, at \$375/t in 2030 and \$406/t in 2050. This suggests that, without a meaningful carbon price mandate or customer premium, green ammonia is likely to remain commercially constrained relative to blue and conventional ammonia for the foreseeable future.

Demand

The most credible near-future demand opportunities are those that build on existing hydrogen consumption: refining, ammonia, methanol, steel and other industrial applications. These sectors require less transformation of end-use equipment and are often located in established industrial clusters.

The IEA expects committed industrial projects to supply around 2 million t/a of low-emissions hydrogen by 2030, primarily to ammonia, methanol, steel and related industrial uses. Refining demand is also expected to increase, with committed projects lifting low-emissions hydrogen use from below 250 kt in 2025 to above 500 kt by 2030.

Hydrogen derivatives are especially important. More than half of low emissions hydrogen production in 2025 was used to make hydrogen-based fuels and feedstocks, notably ammonia. Nearly 60% of announced 2030 production is aimed at ammonia, methanol, synthetic methane or synthetic liquid fuels. This reflects the practical difficulty of transporting and storing pure hydrogen, as well as the relative maturity of ammonia and methanol handling infrastructure.

By contrast, power generation and transport remain less established demand sources. Hydrogen and ammonia-capable power capacity was only 520 MW at the end of 2025. Announced projects could increase this to 6.8 GW by 2030, but only 2 GW was operational, under construction or at final investment decision. Japan and South Korea are important prospective markets for ammonia co-firing, but progress has been uneven. South Korea's second clean-hydrogen auction, targeting 3,000 GWh of generation, was cancelled after securing no contracted volume. The outcome reflected tensions with the country's coal phase-out, high hydrogen and ammonia costs, and limited technology readiness.

Ammonia

Low-emissions ammonia has a pivotal role in the market outlook because it may provide a route to transport hydrogen internationally, decarbonise fertiliser production and eventually serve as a fuel in shipping and power. Yet it also illustrates the risk of developing supply before demand is established.

CRU forecasts low-carbon ammonia demand at 8 million t/a in 2030, 25 million t/a in 2035 and 63 million t/a in 2040, rising to 155 million t/a by 2050. Conventional ammonia demand remains dominated by fertilisers, which account for more than 80% of consumption. Energy-transition applications, including co-firing and ammonia as a hydrogen

carrier, are expected to remain at pilot scale through 2030.

At the same time, the project pipeline is very large. CRU identifies 267–268 million t/a of announced low-emissions ammonia capacity, of which the majority is still in pre-FEED or FEED. Only a small share is operating or at final investment decision. Low-emissions projects are expected to account for 63% of total new merchant ammonia additions through 2030. This creates a potential market imbalance. CRU expects low-emissions merchant supply to arrive before dedicated low-emissions end-use demand. Rather than immediately establishing a large premium market, some output may compete with conventional ammonia, contributing to oversupply. It forecasts global ammonia operating rates falling to around 80.6% in 2028 before recovering only modestly to 81.2% in 2030.

Shipping is a major prospective source of demand, but policy remains uncertain. The International Maritime Organization's Net-Zero Framework was approved in draft form in April 2025, but formal adoption planned for October 2025 was postponed by a year. If adopted as expected in late 2026, it could enter into force in March 2028. CRU views the delay as a setback for global demand certainty, while strengthening the relative importance of regional rules such as FuelEU Maritime. It may also mean the expansion of the LNG-fuelled fleet to offer a more immediate emissions-reduction route than ammonia.

Policy, trade and infrastructure

Policy support remains decisive because the cost premium cannot generally be absorbed by voluntary demand alone. The IEA identifies \$41 billion of public funding associated with hydrogen-policy progress since its previous review, but observes a continuing imbalance: around \$1.5 is directed to supply for every \$1 supporting demand. Offtake agreements often remain insufficient, with only around 20% of agreements signed in 2025 being firm contractual commitments.

Europe is particularly dependent on policy implementation. The combined effect of the EU Emissions Trading System, Carbon Border Adjustment Mechanism, Renewable Energy Directive III and national support mechanisms could create almost 5 million t/a of clean-hydrogen demand by 2030. But national implementation remains

incomplete, and complex eligibility criteria, permitting delays and grid constraints are delaying final investment decisions.

For ammonia, CBAM may influence trade flows. CRU expects the mechanism to encourage substitution of higher-emissions ammonia imports with lower-emissions material, especially where producers can measure, report and verify actual emissions and demonstrate permanent carbon storage. It forecasts Europe's import dependency rising from 26% in 2026 to 42% in 2030. However, CBAM does not eliminate Europe's underlying natural-gas cost disadvantage.

Infrastructure is another binding constraint. More than 40,000 km of hydrogen transmission pipelines are announced for 2035, but only 9% is operating, under construction or at final investment decision. Announced underground hydrogen storage totals around 11 TWh, with just over 7% at comparable maturity. Existing ammonia terminals – around 170 globally – provide a useful basis for early trade, but larger flows will require investment in ports, pipelines, storage, import terminals, carbon-dioxide networks and conversion facilities.

Conclusion

Low-carbon hydrogen is entering a more disciplined phase of development. Its future is increasingly likely to be shaped by projects with firm offtake, integrated infrastructure, credible carbon management, supportive policy and experienced industrial partners – not by the full scale of announced capacity. By 2030, growth should be meaningful but well below early ambitions. Low-carbon hydrogen and blue ammonia appear relatively advantaged in North America, while renewable hydrogen's clearest cost leadership is likely to be in China. Europe, Japan and South Korea may provide major demand pull if policy frameworks are implemented effectively, while ammonia will remain the principal mechanism for linking distant supply and demand centres.

The central uncertainty is not technical potential, but the conversion of policy ambition and project announcements into bankable demand. Until that demand is secured at scale, the sector is likely to remain characterised by selective project delivery, a large early-stage pipeline and a continuing premium over conventional hydrogen and ammonia.

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PHOTO: JERA



Ammonia demand in the power sector

While the power sector has been advanced as a major long term source of demand for emerging low carbon ammonia projects, the pace of development in leading proponents such as Japan and South Korea remains patchy.

The ammonia tank at the JERA co-firing demonstration plant at Hekinan, Japan

Ammonia's potential role in decarbonising power generation is being considered in several forms: as a direct fuel for co-firing in coal plants; as a fuel for dedicated turbines and engines; and as a carrier for imported hydrogen that can subsequently be cracked and consumed in power generation or industry.

However, the current demand picture still has yet to achieve the scale envisaged by numerous project announcements and policy goals. Fertilizer production continues to account for more than 80% of global ammonia consumption, while power-sector demand is largely confined to demonstration units, early procurement mechanisms and development-stage projects. Technology development is progressing, especially in Northeast Asia, but a technically successful demonstration does not automatically produce durable fuel demand. Utility-scale ammonia consumption requires a combination of reliable low-emissions supply, adapted

generation assets, emissions control, import and storage infrastructure, policy support, and a commercial framework capable of absorbing a significant fuel-cost premium, and at the moment, only a few of these conditions are met.

Demand routes

Direct ammonia use in electricity generation remains at an early stage. There are so far no cases of widespread, routine utility-scale operation in which ammonia is an established normal fuel for a major power plant. Instead, the market consists of a small number of high-profile demonstrations, test facilities, equipment-development programmes and policy-led offtake initiatives.

The leading direct-use pathway is ammonia co-firing in existing coal-fired power plants. This route has been attractive to governments and utilities, especially in east Asia, because it could

displace some coal consumption and reduce carbon dioxide output while retaining existing coal-fired power capacity, avoiding the need to build completely generation capacity before low-carbon fuel demand can emerge.

Japan

The most important technical milestone to date is JERA's Hekinan Thermal Power Station Unit 4 in Japan. In June 2024, JERA completed a large-scale demonstration run using ammonia to substitute for 20% of the fuel input at a 1 GW-class coal unit. The company reported that nitrogen-oxide emissions did not exceed the coal-only baseline in the tested configuration, while sulphur-oxide emissions declined with reduced coal consumption. JERA is developing the associated unloading, storage and pipeline infrastructure with an aim of commercial readiness in fiscal year 2029.

That demonstration is significant, but a single successful trial is not the same as large scale ongoing ammonia demand. Full commercialisation would require regular fuel deliveries, secure terminal infrastructure, consistently compliant low-emissions product, plant reliability at varied operating loads, and economics that are acceptable under the applicable power market framework.

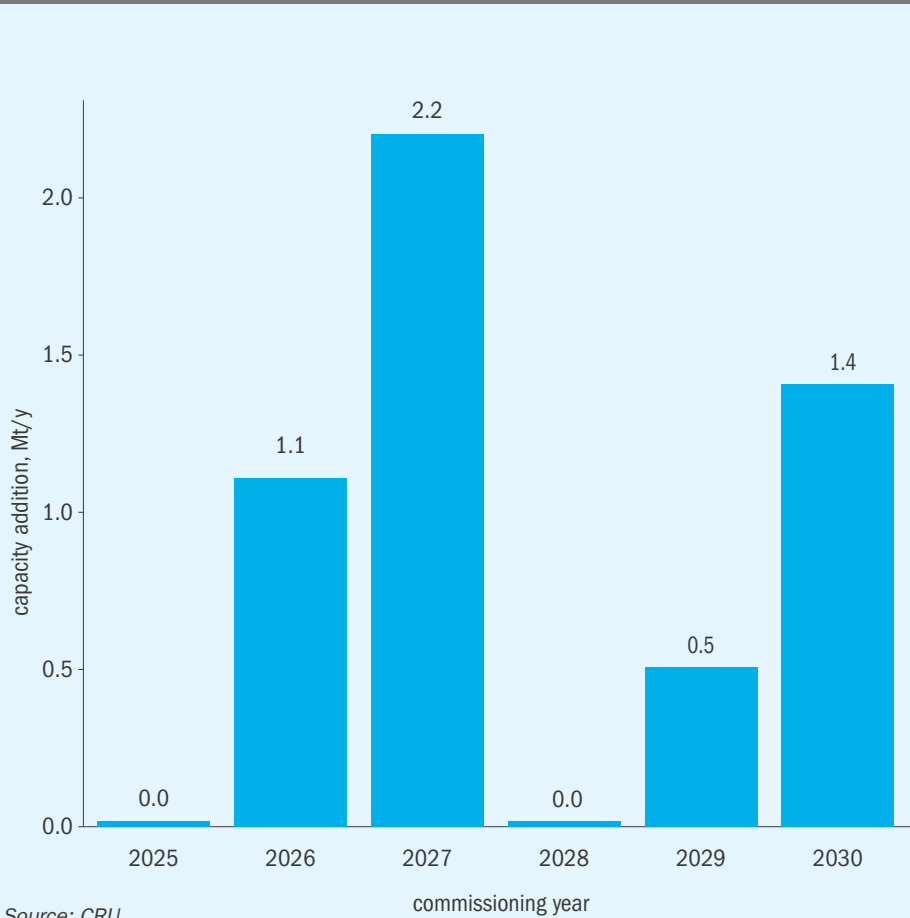
Japan is the most advanced market for ammonia as a direct power-generation fuel. Its position reflects energy-security concerns, a large thermal generating fleet, constrained domestic energy resources and coordinated policy support for hydrogen and fuel ammonia. The Japanese approach seeks to develop supply and demand in parallel. Public-sector support, including programmes associated with METI and NEDO, has encouraged work on low-emissions ammonia supply chains, power-generation equipment, higher co-firing ratios and eventual mono-fuel ammonia combustion.

The Hekinan demonstration shows that Japan has tested a commercially relevant co-firing ratio in a large, operating thermal asset. The proposed next stage is to develop the full fuel value chain. JERA has indicated plans for major ammonia-storage tanks, a dedicated unloading jetty, local transport infrastructure and supply arrangements connected with the United States. The scale of the potential investment is a reminder that ammonia power is a logistics-intensive proposition rather than simply a modification to existing plants.

Japan could become a major market if commercial co-firing proceeds after 2029, but this of course remains contingent on continued government support and the availability of low-emissions ammonia at prices that generators can absorb. The country’s policy design is attempting to address this through support for the difference between low-carbon fuel costs and conventional alternatives, but the resulting market is not yet fully established.

There is also significant uncertainty around the ultimate scale of the Japanese market. Higher co-firing rates and dedicated ammonia firing would increase potential fuel demand, but would require more extensive technical validation. Coal co-firing may also face questions over whether it constitutes a sufficiently durable decarbonisation pathway, particularly where power systems have long-term coal-reduction or coal-retirement objectives.

Fig. 1: Projected low carbon merchant ammonia capacity, 2025-2030



South Korea

South Korea has developed one of the most tangible policy mechanisms for creating ammonia demand in the power sector. But it has also supplied the clearest recent evidence of the gap between policy ambition and commercial execution. The first South Korean clean hydrogen power auction, in 2024, sought to find contracts for 6,500 GWh of generation. But it only received bids for 5,782 GWh and only awarded 750 GWh per year under 15-year contracts. Korea Southern Power was the sole successful bidder and intended to use ammonia co-firing at an existing coal-fired power plant.

The mechanism was notable because it imposed a minimum 20% co-firing blend requirement, with monthly non-compliance affecting contract pricing. This created a direct link between fuel procurement, plant performance and project revenue. It also highlighted the challenges of turning a supported power market mechanism into bankable ammonia demand. A generator unable to secure adequate ammonia volumes or maintain the required technical performance could face an economic penalty.

The following year’s auction was even more disappointing. The 2025 round targeted 3,000 GWh over 15 years but was cancelled before securing any volume. Among the factors which caused this were identify official concern over the extent to which the plans aligned with a planned 2040 phase out of coal-fired power generation in Korea. CRU’s assessment also points to high costs and limited technology readiness as more fundamental constraints.

This does not mean that ammonia co-firing has no future in South Korea. KEPCO (Korea Electric Power Company) has developed hydrogen- and ammonia- co-firing testing capability and is working on technologies for ammonia use in both circulating fluidised-bed and ultra-supercritical pulverised-coal boilers. Korea Southern Power has also undertaken procurement activity for clean ammonia intended for future co-firing. Nevertheless, the auction cancellation weakens expectations for near-term demand, and demonstrates that the creation of a dedicated power sector offtake mechanism is not sufficient by itself. Fuel cost, infrastructure, compliance risk and the strategic future of coal assets must all be resolved before substantial ammonia demand can become durable.

Other markets

Outside Japan and South Korea, direct ammonia combustion in power generation is less advanced or less transparently documented. In China, there have been ammonia co-firing trials, including a 10% ammonia test at Taishan power plant in Guangdong. China is potentially of great importance because of its large coal generation fleet, extensive engineering base and rapidly growing green-ammonia capacity. However, China has yet to become a large, established source of ammonia power demand. The end-use allocation of emerging green ammonia supply is uncertain, with shipping, chemicals, fertilizer markets and exports all competing for volumes.

In Europe, ammonia’s role is more commonly framed as part of a hydrogen-import chain. The region is developing interest in importing ammonia, cracking it back into hydrogen and using the resulting hydrogen in industry, power generation or other applications. Uniper and thyssenkrupp Uhde, for example, are progressing an ammonia-cracking demonstration in Germany. This pathway could create ammonia demand, but it differs from direct combustion. Cracking introduces further capital expenditure, energy consumption, purification requirements and conversion losses. It may be preferred where power systems or industrial users are better equipped to consume hydrogen than ammonia, but it is not yet a major source of ammonia demand in its own right.

The United States and the Middle East are more important at present as prospective suppliers than as identified direct-ammonia power markets. Large planned blue and green ammonia projects could make these regions important exporters into Asian and European energy-transition markets. There are expectations of substantial low-emissions merchant-capacity growth through 2030, but as the accompanying article in this issue notes, there have been setbacks for blue ammonia in the US in particular, as costs increase, and so far much of this supply is not linked to firm power sector demand.

Supply mismatch

One of the most important features of the present market is the risk of a mismatch between low-emissions ammonia supply ambitions and the pace of new demand creation. CRU expects low-emissions projects to account for 63% of new merchant ammonia additions through 2030. Around 7.2 million t/a of standalone merchant capacity is expected to commission over 2025–2030, materially above the scale of the 2016–2018 merchant-capacity wave. The outlook anticipates structural oversupply from 2027 if demand does not grow commensurately.

This may appear positive for ammonia-for-power projects: greater availability and weaker ammonia prices could reduce fuel-cost barriers. In practice, the relationship is more complex. First, a power plant requires not merely ammonia, but ammonia with a sufficiently low and credibly documented lifecycle carbon intensity. Second, power generators require long-term and reliable delivery arrangements, rather than opportunistic merchant supply. Third, lower ammonia prices do not necessarily close the gap with coal, natural gas, renewables or other low-carbon generation options. Finally, supply projects may sell

into conventional fertilizer markets where that offers a more established source of demand. Supply expansion is a necessary prerequisite for ammonia power demand, but not sufficient to create it. A large proportion of prospective low-emissions ammonia capacity could initially be absorbed into existing merchant channels rather than stimulating a rapid increase in utility demand.

Cost

Fuel cost is the central obstacle to significant ammonia demand in power generation. Low-emissions ammonia is generally derived from either green hydrogen or fossil-based hydrogen combined with carbon capture and storage. Both routes remain more expensive than conventional ammonia in many

circumstances. CRU expects green hydrogen to remain materially more expensive than grey and blue hydrogen through 2040. In CRU’s illustrative China case, green-hydrogen costs are around \$5.2/kg in 2030 and decline to approximately \$3.5/kg by 2050. These economics constrain the ability of green ammonia to compete in power markets without policy intervention.

The International Energy Agency has similarly assessed that low-carbon ammonia co-firing can raise generation costs significantly compared with conventional thermal generation. Its analysis of Japan suggests that the cost differential may vary by operating pattern, but that policy support remains important to bridge the gap.

For ammonia demand to grow materially, the sector will need one or more of the following: lower production costs; higher carbon prices; dedicated contracts-for-difference or similar support; capacity-market revenues that reward dispatchable low-carbon generation; or strategic energy-security policies that assign value to fuel diversification.

Certification

The environmental credibility of ammonia power also depends on the lifecycle emissions of the fuel. Direct combustion may reduce stack carbon-dioxide emissions relative to coal or gas, but it does not automatically make generation low-emissions if upstream hydrogen production, natural-gas supply or carbon capture are poorly managed. This creates a growing importance for certification, monitoring, reporting and verification. Eligibility for treatment under the European Carbon Border Adjustment Mechanism (CBAM) can differ materially between default values and verified actual emissions data, highlighting the importance of permanent carbon storage and credible reporting arrangements for CCS-based ammonia.

For the power sector, this means that a fuel procurement strategy must look beyond nominal “blue” and “green” designations. Generators and policymakers will increasingly need to specify accepted carbon-intensity thresholds, treatment of methane emissions, capture rates, storage assurance, renewable-power sourcing, certification methodology and chain-of-custody requirements. These

“One of the most important features of the present market is the risk of a mismatch between low-emissions ammonia supply ambitions and the pace of new demand creation.”

requirements can add cost and complexity but are likely to be essential if ammonia-fired power is to qualify for low-carbon support mechanisms and retain public legitimacy.

Technical challenges

The direct use of ammonia also carries meaningful technical constraints. Ammonia is a difficult combustion fuel because of its low flame speed, relatively high ignition temperature and challenging stability characteristics. In coal plants, fuel systems, burners, combustion controls, monitoring and emissions-control equipment may require modification. In turbines and engines, combustor design and operating conditions require careful optimisation.

NO_x, N₂O and ammonia slip are central considerations. Since ammonia contains nitrogen, combustion can produce nitrogen oxides, while some operating conditions can result in nitrous-oxide emissions. Ammonia slip must also be controlled for environmental, safety and operational reasons. Results from Japa-

nese demonstrations are encouraging, but they remain plant- and configuration-specific rather than a universal solution.

Logistics are equally important. Large-scale imported ammonia use requires marine receiving facilities, refrigerated or pressurised storage, pipelines or road and rail distribution, trained operators, leak detection and emergency-response capability. The recent conflict in the Arabian Gulf has also highlighted potential exposure to disruption for supplies from that region. For an ammonia-fired power plant, security of supply and adequate inventory may be as important as the underlying fuel price.

Outlook

The current status of ammonia demand in the power sector can therefore be summarised as early-stage market formation. The technology is no longer speculative: large-scale coal co-firing has been demonstrated, turbine and engine technologies are progressing, and governments have begun to create support mechanisms. But power-sector demand is still

too small to materially influence global ammonia balances.

Japan remains the principal direct-combustion market to watch, particularly as JERA develops Hekinan toward commercial readiness. South Korea remains strategically important, but its cancelled 2025 auction illustrates the fragility of emerging demand mechanisms. Europe is more likely to create demand through ammonia-to-hydrogen import chains than direct combustion, while China remains a potentially significant but less transparent market.

Over the next several years, the pace of demand growth will depend less on the existence of announced projects and more on whether the sector can solve five practical problems: delivered fuel cost, certification of lifecycle emissions, reliable supply chains, sustained technical performance, and policy frameworks that can support dispatchable low-carbon generation. Until those conditions are met, ammonia will remain a promising strategic fuel for power systems rather than a substantial source of global ammonia demand.

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Safety in digitised ammonia plants

Digitalisation brings with it a fresh set of issues as well as opportunities for safety management.

Digitalisation is changing the way ammonia plants are operated, maintained and monitored. Advanced process control, connected sensors, predictive-maintenance tools, digital twins, remote diagnostics and artificial-intelligence-enabled analytics can give operators more timely visibility of plant performance. They can help identify equipment degradation, detect abnormal conditions earlier and make operating procedures more consistent. However, the safety question is whether each new digital capability makes hazardous scenarios easier to prevent, detect, control or mitigate without creating unacceptable new dependencies.

The strongest approach is to treat digitalisation as part of the plant's overall process-safety management system. Digital tools can improve safety performance, but their implementation must preserve independent protection layers, support competent operator decision-making and account for operational-technology cybersecurity risks.

Ammonia plants

Ammonia's toxicity means that storage, transfer, refrigeration and loading systems all require effective detection, containment, isolation and emergency-response arrangements. The production process also introduces additional risks. Conventional ammonia plants typically involve natural-gas reforming, hydrogen production, nitrogen separation, compression and high-pressure synthesis. These stages can involve flammable gases, elevated temperatures and pressures, and equipment such as compressors, furnaces, reactors, heat exchangers and relief systems. Equipment malfunction or control failure can develop into a wider process upset if safeguards do not perform as intended. These hazards establish the baseline against which digital systems should be assessed.



PHOTO: PEN SANGRAKSAWONG/ISTOCK

Safety improvement

Connected instrumentation and continuous monitoring can enhance awareness of process conditions. Fixed gas-detection systems, for example, can provide rapid indication of abnormal ammonia concentrations. When sensors are correctly selected, positioned, calibrated and maintained, they can support alarm systems, ventilation controls, isolation actions and emergency response. Digital platforms can also make detection data easier to trend, helping operations teams identify recurring problems or weak signals before they become more serious.

Condition-monitoring systems offer another potential benefit. Compressors, pumps, turbines, valves and other critical equipment can be monitored using vibration, temperature, pressure, acoustic or electrical data. Analytical tools may help identify abnormal patterns that would be difficult to see through periodic inspection alone. For ammonia plants, this can support maintenance

planning and reduce the likelihood that an unrecognised mechanical problem develops into a process interruption or loss-of-containment event.

Advanced process control can also help reduce operating variability. A stable process is generally easier to manage than one repeatedly moving close to operating constraints. Better control of pressure, temperature, flow and composition may help operators keep equipment within defined limits and identify deviations sooner. Yet the role of advanced control should be clearly bounded: it is an operational aid, not a replacement for safety-instrumented functions, pressure-relief systems or emergency shutdown arrangements.

Digital twins can support both engineering and operations. A well-maintained model of a plant or process unit can be used to test operating scenarios, examine process interactions, improve training and evaluate planned changes before implementation. Simulator-based training may be particularly valuable

where operators need to practise abnormal and emergency scenarios that cannot safely be recreated in a live facility. Research on digital twins and process-safety methods indicates potential for these tools to supplement hazard studies and operational decision support, though plant-specific validation remains essential.

New risks

Every additional connection, software interface and data stream can create a new failure mode. A sensor may drift or fail. A data historian may be unavailable. A model may be based on incomplete or unrepresentative data. A remote dashboard may present a simplified view that obscures local operating context. These are not arguments against digital systems, but they are reasons to design them for uncertainty and failure.

One concern is automation bias: the risk that people place excessive confidence in a recommendation generated by an algorithm or automated system. Operators must understand what a digital tool can and cannot infer. A predictive-maintenance model can flag potential degradation, but it cannot remove the need for engineering judgement, inspection and an appropriate maintenance response. Similarly, anomaly-detection tools may identify unusual process behaviour, but the underlying cause must still be investigated.

The availability and quality of data are central. An analytics system may appear sophisticated while relying on poorly maintained field instruments or inconsistent operating data. If a sensor is miscalibrated, an automated system may generate false alarms, miss a genuine event or recommend an inappropriate action. Data validation, calibration, maintenance and clear ownership of data quality should therefore be treated as safety-critical disciplines where the information supports a protective decision.

The same principle applies to remote operations. Centralised expertise and remote diagnostics can help a site access specialist support more quickly. But local operators must retain sufficient situational awareness, authority and capability to manage an abnormal event. Digital systems should be designed so that critical actions remain possible when external connectivity, cloud services or remote support are unavailable.

Independent layers of protection

A facility should not depend on one connected platform to control the process, issue alarms, advise the operator and execute protective shutdown. If a common failure affects that platform, the plant could lose multiple defences at the same time. Independent layers may include the basic process control system, alarms and operator intervention, safety-instrumented functions, emergency shutdown systems, pressure-relief devices, physical containment and emergency-response arrangements.

For a digital project, this means asking practical questions at the design stage:

- Does the new system affect a safety-critical control loop, alarm or shutdown function?
- Is it sufficiently independent from the systems it monitors or supports?
- What happens if it becomes unavailable, provides incorrect information or is compromised?
- Can operators continue to operate the plant safely in a degraded mode?
- Has the modification been assessed through formal management of change?

Alarm management

More data does not automatically mean better decisions. A digitised facility can generate a much larger volume of notifications, alarms and performance indicators than a conventional plant. If these are poorly designed, operators may face alarm floods during upset conditions, making it harder to identify the few warnings that require immediate action.

Alarm systems should therefore have a defined philosophy, rationalisation process and ongoing performance review. Alarms need a clear purpose, a realistic response time and an identified operator action. Critical warnings should remain visible and comprehensible during high-workload events. Digitalisation may provide richer visualisation and prioritisation, but it should not conceal important alarms behind complex interfaces or excessive filtering.

The human-factors implications become more pronounced where monitoring is remote or where automation performs routine decisions. Operators need training not only in how to use new interfaces, but also in how to recognise their limitations. They should practise managing situations involving unavailable data, communication loss, instrument failure and conflicting recommendations.

Cybersecurity

In a digitised ammonia plant, cybersecurity is inseparable from physical safety. A cyber incident can affect operator visibility, change configuration settings, interrupt communications, disable access to data or interfere with control-system availability. The consequence is not simply loss of information; it may be reduced ability to detect, control or respond to a hazardous situation.

A proportionate operational-technology security programme should include an accurate asset inventory, network segmentation, tightly controlled remote access, identity management, monitoring, secure configuration, tested back-up arrangements and incident-response procedures. Vendor access and third-party connections require particular scrutiny because they may provide paths into operational networks.

Importantly, cyber incident exercises should involve operations, engineering, maintenance, safety and information-security teams. A response plan should cover scenarios such as loss of historian access, unavailable remote support, compromised workstations and loss of communications between systems. Safe manual or local operating arrangements should be clear, current and practised.

Reinforcing resilience

The objective should not be maximum connectivity. It should be resilient, understandable and safe operation. A useful digital system makes weak signals easier to identify, supports better maintenance decisions, reduces avoidable variability or improves emergency preparedness. It remains effective – or fails safely – when data, communications or software do not perform as expected.

For ammonia producers, the most credible digital-safety strategy combines technology with established process-safety disciplines: hazard identification, functional safety, management of change, mechanical integrity, alarm management, operator competence, emergency preparedness and cybersecurity. Digital tools can strengthen each of these areas, but they should be evaluated on their real contribution to risk control rather than their novelty.

In that sense, the central message is straightforward. Digitised ammonia plants can be safer plants, but only where digital capability is engineered into a wider system of independent safeguards, capable people and robust operational resilience. ■

A standard without a practical test

Graham Roeber, CEO, Orono Spectral Solutions, looks at how to test the oil content limit in anhydrous ammonia specifications.

Oil content sits in almost every anhydrous ammonia specification; metallurgical grade: 2 parts per million maximum; refrigeration grade: 3 ppm; commercial grade: 5 ppm. Those numbers are printed on product data sheets, written into supply contracts and copied onto certificates of analysis that travel with the cargo. Ask how routinely those numbers are actually measured, however, and the picture gets less clear. In my experience a significant share of plants do not routinely measure oil at all. That is not carelessness – it is a reasonable response to what the reference method asks of them.

ISO 7106

The international reference is ISO 7106, the determination of oil content in liquefied anhydrous ammonia for industrial use. A sample of liquid ammonia is evaporated off, the residue is taken up in solvent, and the oil is either weighed or measured by infrared absorbance near 3.4 microns. Written down it sounds ordinary. Run at the scale the method requires, it is not.

To recover enough residue to work with, you evaporate on the order of a litre of liquid ammonia. At a liquid density of about 0.68 g/ml, that is roughly a cubic meter of ammonia vapour to be safely handled or discharged per test. Supplier literature is candid about it: Tanner Industries' storage and handling guide tells customers that, where quality control testing is deemed necessary, an analysis can be made using an evaporation method, then adds that analysing anhydrous ammonia by this method "is difficult and hazardous and the procedure should not be attempted

by unskilled personnel." That is striking language for a routine quality check.

The hazard is not the worst of it; the arithmetic is. Oil limits are quoted in parts per million by mass, and 1 ppm by mass is 1 milligram per kilogram, so limit and method compare directly. A litre of liquid ammonia weighs about 682 grams. At a 5 ppm limit, the oil to be recovered and weighed from that entire litre comes to 3.4 milligrams. At the 2 ppm metallurgical limit, 1.4 mg. ISO 7106 states that its gravimetric determination applies to products with an oil content of 10 mg/kg or more. In that same litre, that is 6.8 mg.

Put those figures side by side. The gravimetric route in the reference method is declared applicable only above a concentration roughly twice the commercial specification limit, and five times the metallurgical one. A plant running that route against a 5 ppm limit is working below the range that the method claims for itself. The infra-red finish in the same standard reaches lower, to about 1 mg/kg, and is the appropriate choice at these concentrations, but it still needs the same litre of ammonia and the same extraction to get there.

Solvent

That brings up the solvent. ISO 7106 specifies carbon tetrachloride. Under modern health, environmental and regulatory controls, including the US Environmental Protection Agency's 2024 risk management rule under the Toxic Substances Control Act, it has become increasingly difficult for a laboratory to justify holding or using routinely. In practice, some laboratories substitute solvents such as hexane. That may

well be sound chemistry. I have not found a published equivalence study behind it, and without one the substitution lacks a common, independently documented basis for comparison with the reference method.

The paperwork underneath is thin. ISO 7106 dates from 1985 and was reviewed and confirmed as current in 2025, so a method built around a solvent now under regulatory restriction remains the international reference for another cycle. In the United States, Federal Specification O-A-445 was cancelled without replacement more than a decade ago, and it continues to appear in supplier and industry documentation.

None of this is a failure of any one plant or laboratory. It is drift. The limits written into ammonia specifications and the framework meant to demonstrate compliance with them have moved apart, in concentration range and in what a laboratory can reasonably keep on the shelf. The predictable consequence is less routine measurement, and trend data that is rarely discussed in public. Oil introduced into an ammonia system can accumulate, coat heat-transfer surfaces and gradually degrade performance. That decline can be slow enough to be absorbed as normal equipment ageing rather than investigated as contamination.

Solutions

My suggestion is unglamorous. Start measuring, and start trending, before the standards question is settled. For trend monitoring, repeatability may matter as much as absolute agreement with a reference method. A consistent quarterly measurement can reveal accumulation long before an occasional reference test provides useful history.

There are candidates. The infrared finish already inside ISO 7106 is the obvious starting point, because it is part of the standard and reaches the concentrations being specified. Extraction, chromatographic, infrared and online techniques all deserve evaluation against this matrix, and I would not prejudge which earns the job. What the industry can usefully agree with first is what a modern method must achieve: the range it covers, the sample handling it demands, and the reproducibility it shows between laboratories.

Answer that with data, and there is something concrete to take to ISO/TC 47: a measured gap between the written method and modern laboratory practice, with evidence for what should replace it. Until then, the problem is real, but the case for changing the standard remains incomplete. ■



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Catching the early warning signs

A major nitrogen producer put an AI troubleshooting system to work in a world-scale ammonia plant. In the first six months of deployment it flagged a failed bearing temperature sensor before it could mask an overheating bearing, warned that a degrading compressor bearing would not make its next turnaround, surfaced a worn control valve that had escaped every alarm, and caught the signature of a reformer tube leak roughly twelve hours ahead of shutdown. That first deployment was the opening move of a wider multi-plant rollout, now live at four more sites.

Ammonia plants almost always show warning signs before they fail. The problem is that the signs are subtle and easy to miss: the reformer, the synthesis loop, the big rotating machines on refrigeration and CO₂ compression all degrade in ways that show up first as a change in the relationship between dozens of tags, long before any one of them crosses an alarm limit. By the time an alarm fires, the cushion to act has often gone. A modern plant streams thousands of tags into its historian every second, yet most monitoring still waits for a fixed threshold to be crossed. The data is all there; the early warning is what is missing.

That is the gap a major nitrogen producer set out to close, beginning with one of its ammonia plants as the first site in a planned, fleet-wide rollout. It is one of the world's largest nitrogen producers,

turning out more than 5 million tonnes of urea and nearly 2 million tonnes of ammonia per year. ControlRooms deployed its AI troubleshooting agent on top of the plant's existing data infrastructure, with no change to control logic or hardware. Within weeks it was surfacing the early signs the plant's alarms were never able to catch.

Two models, one job: catch it before it becomes a problem

Harmony Models lay the foundation

For each area of the plant, ControlRooms builds a single Harmony Model, a multi-variate model that learns how all the relevant tags in that area normally behave in concert. These models are not trained on a library of known failure patterns. They learn what normal looks like and flag departures from it, allowing them to

catch problems the plant never thought to watch for: a group of variables drifting out of their usual harmony while all individual readings still look fine. A handful of them covers an entire plant within weeks. Catching the unknown unknowns, the problems no one thought to watch for, is exactly what Harmony Models are built for.

Predictive models add the scaffolding

Alongside that broad coverage, smaller asset-level models tackle known failures and pivotal performance-improvement areas: a bearing with a failure history, an analyser prone to drift, a control valve that wears, a heat exchanger that fouls, a pump losing suction, a compressor stage running hot. A Harmony Model watches a whole area at once; a predictive model zeroes in on one asset and the specific way it tends to fail.

Catches from the first six months

A blind spot on a critical bearing

A Harmony Model flagged a subtle anomaly on a combustion air fan journal bearing in the reforming and heat recovery area. The cause turned out to be the bearing's temperature sensor, which had failed. A dead sensor on a critical bearing is dangerous precisely because it is quiet: it leaves the bearing's real temperature invisible and can mask an overheating event entirely. Because the alert put it in front of the team, they took the machine down to fix it rather than keep running blind. A senior process engineer at the site, who had watched the signature build over the preceding days, was direct about the value: "These alerts are very useful. As soon as something happens we get informed. Never had this functionality in the past. If you guys are catching that signature, that's a great sign".

A compressor tracked toward its turnaround

A predictive model on a large ammonia refrigeration compressor flagged slowly rising journal-bearing vibration. Rather than a single alarm, this became a months-long watch: reviewing it week by week, the team correlated the vibration with falling lube-oil temperature and the anti-surge valve position at reduced rates. The bearing was tracked intelligently with a predictive model right up to the planned turnaround, instead of failing between turnaround cycles. This is the kind of slow, interconnected degradation that no single alarm could ever explain.

A worn valve no one could see

A Harmony Model on the synthesis area picked up a developing oscillation across the ammonia flash-drum and cold-exchanger levels. The cause was a level control valve whose plug and seat had worn, quietly forcing operators onto a bypass to hold level. Nothing had alarmed. The same engineer put plainly why whole-system monitoring earns its keep: "I would not have known about this defect if I didn't have the visibility via ControlRooms.ai".

A signature that pointed at fatigue

The model surfaced temperature fluctuations on the wall of the ammonia synthesis reactor that tracked pressure cycling in the synthesis loop. That is not a nuisance reading: pressure cycling drives cyclic fatigue, and a sister facility had previously suffered a through-wall crack on the reactor's outlet cone. Catching it at the temperature-fluctuation stage gives

the engineering team the data to investigate the fatigue risk early, instead of finding the damage at an inspection.

Twelve hours of warning on a reformer tube leak

A focused oxygen model on the primary reformer, run against data from a past tube-leak event, flagged a clear deviation roughly twelve hours before the unit came down, with measured oxygen falling below the model's prediction in step with the onset of the leak. That is a whole shift of warning on one of the most expensive failures an ammonia plant can have.

Cleaner data and sharper operations

Some of the earliest flags were not process failures at all. The models surfaced bad tags, incorrect tag metadata and poorly set alarm limits. These are the subtler operational-excellence gains that come with real visibility into the process: cleaner data, better-tuned alarms and a more trustworthy picture of the plant, whether or not any given flag turns out to be a failure. One of the site's engineers put it directly: "Not only is ControlRooms.ai detecting anomalies in the measured values but also pointing out errors from when the historian was set up".

Beyond the data itself, the catches kept coming across the plant: a CO₂ compressor signal loss the engineer learned about from the alert before anywhere else, a failed desuperheater starved of boiler feedwater, a reformer running with burner cocks closed. Different equipment, same pattern: the system saw it first.

Where the value compounds

Early detection only pays off if someone acts on it, and that is what this deployment was built around. Alerts were routed into the team's existing collaboration channel, not a new dashboard to remember to open. Each one arrived as a short, readable message naming the area and tags, with a trend and a one-click link straight into a view of the anomaly inside the app.

An engineer could open the alert, pull related tags into the same view, and share a link that put anyone else into the exact view they were looking at, instead of trading screenshots and stale reports. Investigations that used to take days closed out in a single shift, thanks to those streamlined troubleshooting features. The channel became a living record of what the plant was doing and why, with each engineer and operator's explanation attached to the

alert that prompted the investigation. Even alerts that proved benign or already known were not wasted: each added context or prompted a slight model tuning, and a standing weekly review kept improving the system. The result was a plant that ran better, with teams troubleshooting together instead of in isolation, fewer surprises, and more work shifting from reactive firefighting to preventive intervention.

The impact

The operator's own before-and-after captures both the depth and the breadth of the value the system delivers. Earlier, an undetected temperature excursion driven by a control-valve failure had taken a unit down for the better part of two days, with several thousand tons of lost production. Later in the same year, when a positioner began to fail on a cold exchanger, AI anomaly detection flagged the developing oscillation early enough for a planned, targeted intervention. The unit kept running and the event closed out with no downtime at all.

That contrast, undetected and costly versus seen early and contained, is now something the operator points to in its own performance reporting, and it factors AI-based anomaly detection into its multi-year value-creation targets. None of it required new instruments or changes to the control system. It came from catching developing problems hours, sometimes days, earlier than the alarms could. Across the first six months, catches like these added up to thousands of tons of saved production.

From an initial deployment to a fleet

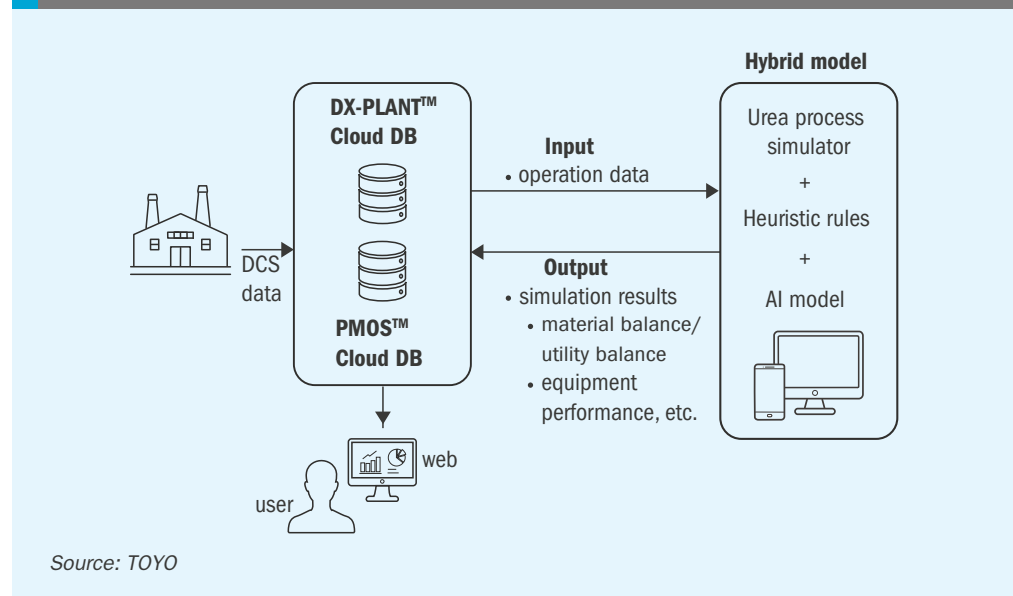
This was the first site in a planned, fleet-wide rollout, and the early wins here are what carried it forward. Six months of incremental catches built the case: real coverage across the plant, a team that reviewed proactive AI alerts, and a range of findings from a worn valve to a fan bearing to a reformer tube leak. With that foundation the producer rolled the system out to four more production sites, where it is live today.

The takeaway applies to any continuous process. The plant did not lack data and it did not lack alarms. What it gained was the few hours of warning between a pattern starting to drift and a limit being crossed, delivered to the people who could act, via an intuitive interface. On an ammonia complex, those few hours are the difference between proactive intervention and a multi-day shutdown. ■

Digital twins and AI support for urea plants

Toyo Engineering Corporation is advancing urea plant support by combining its PMOS™ digital twin platform with AI-assisted reporting and knowledge utilisation. **Motonori Hirose** of TOYO explains how by integrating plant data, process simulation, and accumulated engineering expertise, these tools help engineers assess operating conditions more efficiently, identify emerging issues, and strengthen technical advisory services.

Fig. 1: PMOS™ digital twin concept for urea plant monitoring and performance evaluation



Over the past decade, the role of digital technologies in process industries has evolved considerably. What began with data collection, remote monitoring, and visualisation has developed into digital twin technologies that provide deeper insight into plant performance and operating conditions. Since 2016, Toyo Engineering Corporation (TOYO) has developed DX-PLANT™, a digital transformation platform for industrial plants. Through this platform, TOYO has introduced digital solutions supporting engineering, operations, maintenance, and business functions. For urea plants, these solutions include process

performance monitoring, anomaly visualisation, and simulator-based operational analysis, drawing on TOYO's process engineering expertise.

TOYO's DX-PLANT™ platform and related digital solutions have been presented in previous issues of Nitrogen+Syngas, including the November–December 2020 issue, which outlined the development of TOYO's digital services.¹

A core technology within this framework is PMOS™ (Plant Monitoring & Optimisation System), TOYO's digital twin solution for urea plants. By combining real plant operating data with plant-wide process simulation, PMOS™ delivers engineering insight into

plant performance and operating conditions. More recently, TOYO has extended the practical application of these technologies through technical advisory services for operating urea plants. Since August 2024, TOYO has provided technical advisory services for the urea plant operated by Yacimientos Petrolíferos Fiscales Bolivianos (YPFB) using DX-PLANT™. This service combines digital technologies with TOYO's expertise as a urea process licensor, creating an environment in which operational data, simulation results, performance indicators, and engineering evaluations are continuously generated and accumulated. As digital twin applications produce growing volumes of plant data, simulation results, performance indicators, and technical reports, the next challenge is to use this information more effectively.

At the same time, advances in artificial intelligence (AI), particularly generative AI, are creating new opportunities to support information summarisation, report preparation, and the application of accumulated engineering knowledge. Building on its digital twin platform, TOYO has begun applying AI technologies to enhance technical advisory services and operational evaluation activities.

This article describes TOYO's progression from digital twin-based monitoring to AI-assisted operational support for urea plants, and considers future opportunities to integrate digital twin technologies, engineering expertise, and AI-enabled information utilisation.

PMOS™ as a digital twin for urea plants

PMOS™ is TOYO’s digital twin solution for urea plants, integrating real plant operating data with a plant-wide process simulation model. As described in a previous publication,¹ the system continuously replicates plant operating conditions and estimates process information that cannot be obtained directly from conventional distributed control system (DCS) measurements (Fig. 1). By combining operating data with process simulation, PMOS™ provides engineering information including:

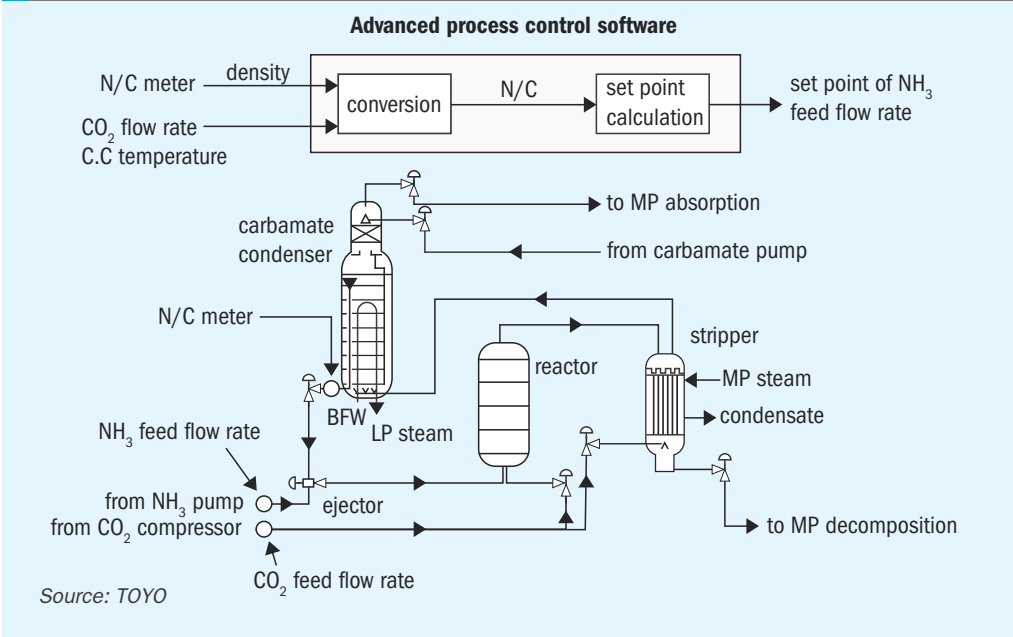
- material balances;
- stream compositions;
- process conversion;
- utility consumption;
- equipment-performance indicators.

These outputs allow both plant owners and TOYO engineers to assess plant conditions from a process-engineering perspective, rather than relying solely on measured operating variables. The availability of this information supports a more comprehensive understanding of plant performance and operating conditions. Operational data, simulation results, performance indicators, and engineering evaluations are continuously generated and accumulated, creating a digital representation of plant operation. This digital twin environment provides a foundation for advanced operational analysis and future digital applications.

From digital twin monitoring to future optimisation

Although PMOS™ was initially developed as a digital twin platform for monitoring and performance assessment, the information it generates may also support future operational optimisation. TOYO has previously developed advanced process control (APC) applications for urea plants. APC uses key process indicators, such as the N/C ratio (NH₃/CO₂ molar ratio), together with process measurements including pressure, temperature, and flow rate. Based on optimisation calculations, the system determines appropriate control actions to maintain optimal operating conditions and improve overall plant efficiency (Fig. 2). TOYO is studying how the process variables and performance indicators generated by PMOS™ can be used more effectively

Fig. 2: Concept of advanced process control (APC) for urea plant operation

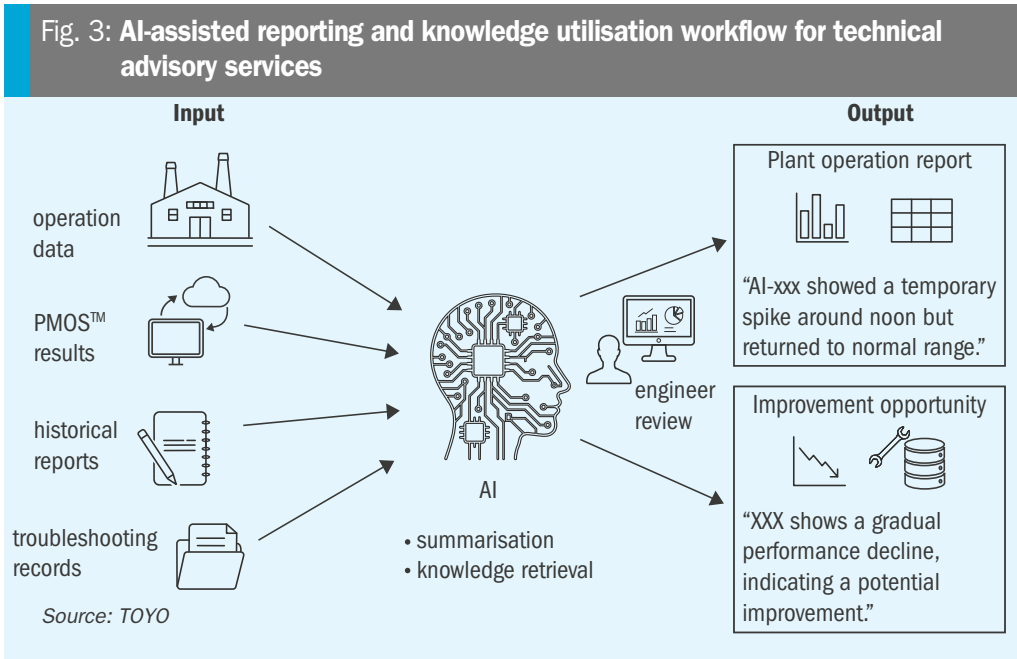


in future operational-support applications. One potential approach is to integrate PMOS™ outputs with APC. Conventional APC applications are primarily based on direct process measurements. While these variables are effective in maintaining stable operation, they may not always provide a complete view of overall process performance. PMOS™ supplements these measurements with engineering information on process conditions and material balances in areas where direct measurement is unavailable. It also provides plant-wide indicators, including process conversion, utility consumption, and equipment-performance trends. This broader process perspective could complement the conventional measurements used by APC. In turn, APC may be able to identify changes in process performance at an earlier stage and support control actions that reflect overall plant condition, rather than individual measurements in isolation. Further development and validation are required. However, combining digital twin technologies with advanced-control approaches such as APC may create new opportunities to improve plant stability, reduce energy consumption, and further optimise urea plant operations.

AI-assisted reporting and knowledge utilisation

As digital twin monitoring and technical advisory activities continue, substantial volumes of operational data, simulation results, plant-event records, and

engineering evaluations accumulate over time. Using this information efficiently has become an increasingly important challenge. While digital twin technologies offer detailed insight into plant conditions, the growing volume of operational and engineering information can increase the time required for review, interpretation, and reporting. Building on TOYO’s previous work in AI-assisted reporting, generative AI has now been applied in technical advisory services for operating urea plants. In the technical advisory service for YPFB’s urea plant, operational information accumulated through daily reports is automatically summarised to support the preparation of weekly technical reports. AI assists engineers by organising operating information, identifying key changes, and preparing report drafts for engineering review. This enables engineers to devote less time to routine information processing and more time to technical evaluation and engineering analysis. Practical experience has also demonstrated benefits beyond report preparation. AI-assisted analysis can rapidly identify historical operating records associated with non-routine conditions that may warrant attention from a stress corrosion cracking (SCC) risk perspective. Identifying such conditions traditionally requires experienced process engineers to review large volumes of daily reports and operational records – an increasingly demanding task as information volumes grow. By automatically extracting and highlighting potentially relevant events, AI helps



engineers focus on issues requiring further technical evaluation. Rather than replacing engineering judgement, AI acts as a productivity tool that supports faster and more consistent review of operational information.

AI can also assist with trend identification by linking operational events with PMOS™ performance indicators and historical engineering knowledge. This can help engineers evaluate plant conditions more efficiently and identify emerging operational issues at an earlier stage.

In parallel, TOYO is developing retrieval-augmented generation (RAG)-based solutions. In this approach, AI retrieves relevant technical information before generating responses or draft comments, combining operational information, PMOS™ analysis results, and accumulated engineering knowledge.

Over many years of urea process licensing, plant design, commissioning support, technical services, operational reviews, troubleshooting, and improvement studies, TOYO has accumulated extensive knowledge assets. RAG-based AI can retrieve relevant information from technical reports, troubleshooting records, operating manuals, and previous advisory activities, helping engineers prepare technically grounded recommendations and advisory comments.

This capability can reduce the time required to locate relevant historical information and support more consistent use of knowledge accumulated across previous projects and operating experience. It therefore has the potential to improve the consistency of technical support and strengthen the use of organisational

knowledge across advisory activities.

Fig. 3 illustrates the concept of AI-assisted reporting and knowledge utilisation. Operational data, PMOS™ results, historical reports, and troubleshooting records are processed by AI to support summarisation and knowledge retrieval. The resulting outputs are reviewed by engineers and used to support technical reporting and the identification of improvement opportunities.

The combination of AI-assisted reporting and knowledge utilisation represents an important step in the evolution of technical advisory services. Through this approach, TOYO aims to enhance both the efficiency and quality of technical support while enabling faster identification of operational risks and improvement opportunities. These developments illustrate how AI can function as a practical engineering-support tool in plant advisory activities, complementing rather than replacing the knowledge and judgement of experienced process engineers.

Future perspective: From monitoring to optimisation

TOYO’s digitalisation strategy for urea plants can be viewed as a stepwise progression from data collection and monitoring to operational visibility enabled by digital twin technologies, AI-assisted engineering and operational support, and ultimately more integrated operational intelligence.

Today, digital twin technologies such as PMOS™ provide process-oriented information that improves visibility of plant

conditions. At the same time, AI technologies help engineers organise operational information, use accumulated knowledge, and prepare technical recommendations more efficiently.

Looking ahead, TOYO aims to expand the integration of plant operating data, PMOS™ analysis results, AI-assisted information utilisation, and accumulated process expertise. This integration can support more advanced technical advisory services, including more systematic reviews of operating conditions, improved use of historical knowledge, and more effective identification of improvement opportunities.

Over the longer term, the combination of digital twin technology, AI-assisted information utilisation, and advanced-control technologies such as APC could create further opportunities for operational optimisation. Together, these technologies can contribute to more stable, efficient, and optimised urea plant operation.

Conclusion

This article has described TOYO’s evolution from digital twin-based monitoring to AI-assisted operational support for urea plants.

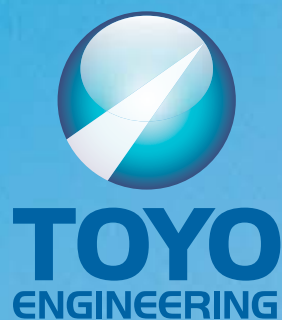
PMOS™ provides the digital twin foundation by combining real operating data with plant-wide process simulation, improving visibility of plant conditions and performance. The engineering information generated by PMOS™ supports plant evaluation and may create opportunities for future integration with advanced operational-support and optimisation technologies.

Building on this foundation, TOYO is applying generative AI in technical advisory services to support reporting, operational-information review, and knowledge utilisation. In the technical advisory service for YPFB’s urea plant, AI-assisted summarisation of daily operational information supports preparation of weekly technical reports.

By integrating digital twin technologies, AI-assisted engineering support, accumulated process expertise, and future optimisation technologies, TOYO aims to further enhance the safety, reliability, and efficiency of urea plant operation.

Reference

“TOYO adds new services and digital solutions to DX-PLANT,” Nitrogen+Syngas, No. 368, pp. 55–57 (Nov–Dec 2020).



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<<< Ammonia and urea plant in Nigeria

Sustainable ammonia production

Low-carbon ammonia is emerging as a dual-purpose molecule: essential for fertiliser production and increasingly important as a hydrogen carrier and potential fuel in the energy transition. **Deepak Shetty, Rolf Postma, and Nikolay Ketov** of Stamicarbon (Nextchem) outline how proven blue and green ammonia technologies, together with process integration, can help deliver scalable, lower-carbon production for both agriculture and new energy applications.



Computer-generated 3D model of a Stamicarbon green ammonia plant.

Ammonia is vital to global food security through nitrogen fertilizers and supports a wide range of downstream chemical value chains. Beyond its established role in agriculture, ammonia is increasingly seen as an enabler of the energy transition, serving as a hydrogen carrier and potential fuel. It can support hard-to-electrify sectors, including maritime transport, heavy industry, and power generation.

To make ammonia a key element in the energy transition, the industry does not need

to create an entirely new supply chain; it can build on a century-old platform and scale it for new low-carbon applications.

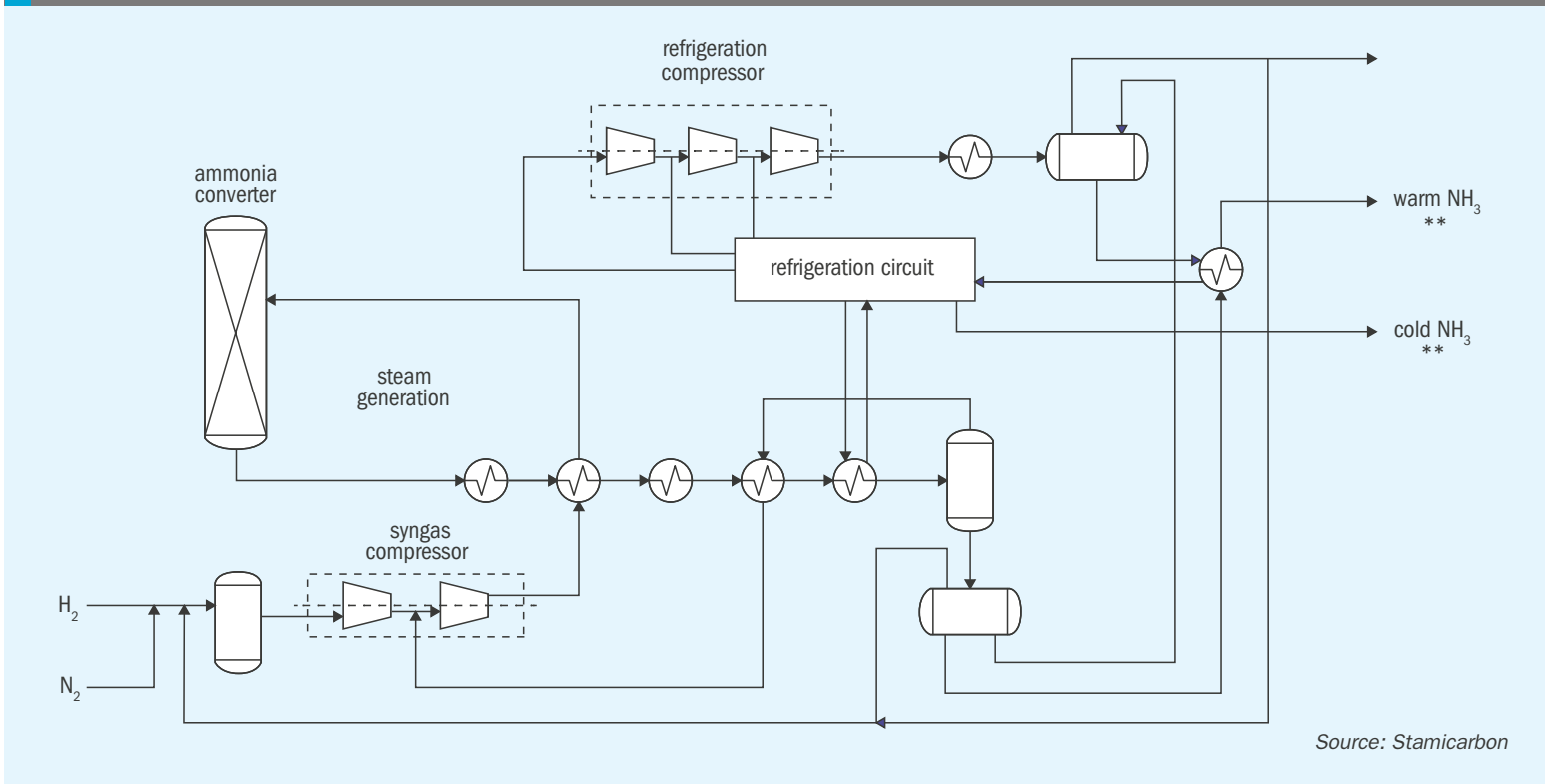
At the same time, nitrogen fertilizers remain a strong conventional demand driver. Ammonia production is expected to rise substantially by mid-century, driven mainly by population and economic growth. The key question is not whether ammonia volumes will grow, but how quickly demand from emerging energy applications will materialise and how the industry can support that growth.

Decarbonisation challenge

Traditional ammonia production combines nitrogen from air with hydrogen that is typically derived from fossil fuels (commonly natural gas via steam methane reforming), followed by synthesis in the Haber-Bosch loop. This conventional route delivers highly reliable, world-scale production, but comes with significant CO₂ emissions as byproducts of hydrogen generation and process energy use.

To tackle this challenge, blue ammonia at scale through carbon capture and

Fig. 1: NX STAMI™ Ammonia medium-pressure design process diagram



storage (CCS) integration and green ammonia from renewable electricity are gaining industrial traction. Large-capacity facilities are increasingly being designed around high-capture configurations where CO₂ is dehydrated, compressed, and sent for utilisation or permanent storage. In parallel, green ammonia projects are advancing, with renewable resources, grid conditions, and policy frameworks supporting competitive electrolytic hydrogen. Here, hydrogen is produced by water electrolysis powered by wind, solar, hydro, or geothermal energy, combined with nitrogen from air separation, and synthesised in the Haber-Bosch loop, producing ammonia with a substantially lower greenhouse-gas footprint.

In this landscape, technology is the practical bridge between ambition and bankable projects. Decarbonisation at industrial scale is not only a question of selecting a “route,” but of executing it efficiently and reliably: optimising heat integration and synthesis loop performance, minimising energy losses across compression and refrigeration, and designing plants for stable operation. Technology must address challenges like variable renewable power on the green pathway or CO₂ capture and handling on the blue pathway. Integration becomes even more powerful when ammonia is viewed as part of a fertilizer value chain, where steam balance, CO₂ utilisation (for

downstream products such as urea), and energy efficiency can be optimised as one system rather than isolated units.

World-scale blue ammonia

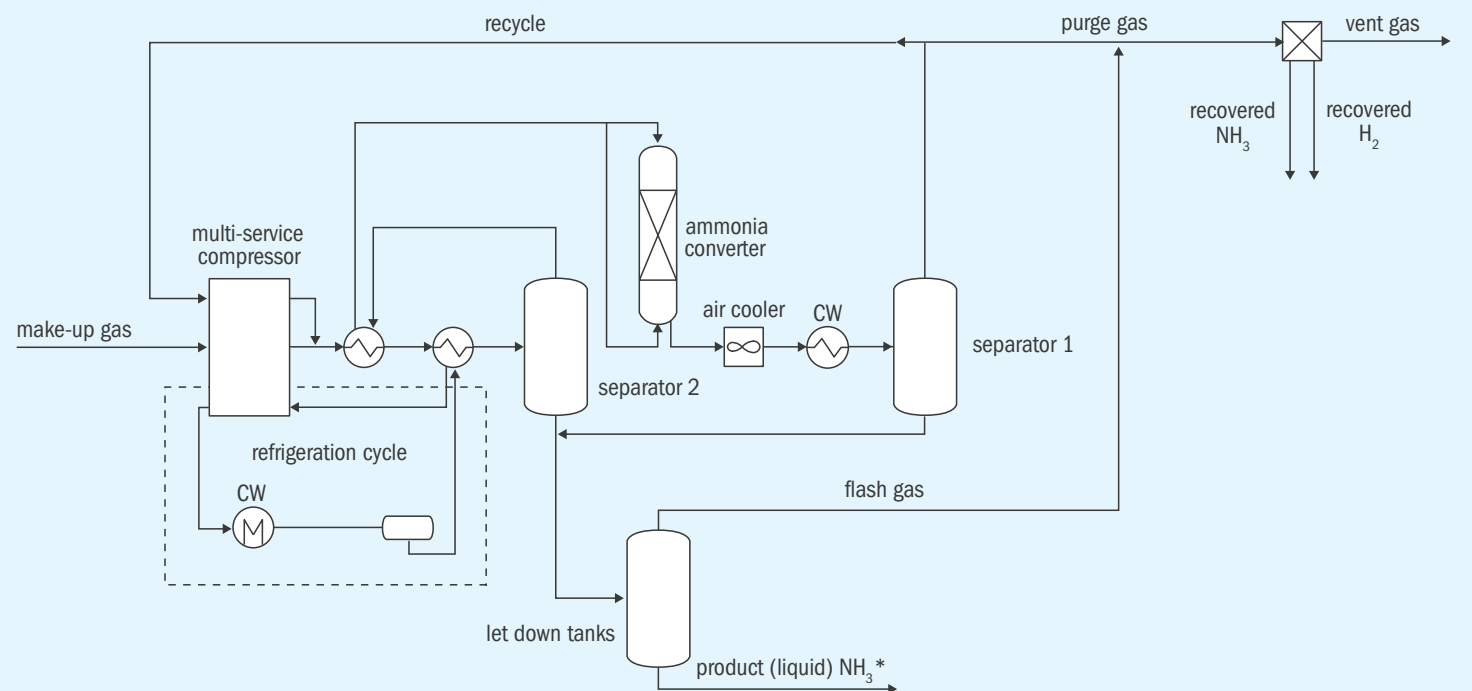
To meet the rising demand for low-cost, high-efficiency ammonia production on world scale, Nextchem (MAIRE Group) offers the NX STAMI™ Ammonia medium-pressure design via its nitrogen technology licensor Stamicarbon. This is an optimised Haber-Bosch process, adjusted for capacities from 50 up to 3,500 tonnes/day. It is ideally suited for large ammonia plants using natural gas or other feedstocks. It can be efficiently paired with front-end solutions like steam methane reforming (SMR) or autothermal reforming (ATR) and carbon capture solutions. With over 45 industrial references from small to large scales, the medium-pressure design is a proven, cost-effective solution for reliability and scale.

In Nextchem’s medium-pressure design (Fig. 1), ammonia synthesis is carried out in a multi-bed radial-flow reactor configuration that minimises pressure drop. This design maximises the per-pass conversion of hydrogen and nitrogen with the smallest possible catalyst volume. 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 tailoring key operating parameters (pressure, flow rates, recycle ratios) to a client’s needs, the design can be modified for optimal performance in different scenarios.

A conventional large-scale ammonia plant using this design can be made significantly more sustainable by integrating carbon capture into the front-end. Nextchem can also provide an advanced ATR technology that is particularly advantageous for “blue ammonia” projects. ATR yields a high-pressure syngas stream with a high concentration of CO₂, which makes downstream carbon capture far more efficient. ATR-based ammonia production can enable carbon capture rates higher than 98% achieved with 40% less solvent circulation compared to a conventional amine-based solvent technology. Nextchem’s ATR operates at a high pressure (60+ barg), reducing the compression duty needed in the ammonia synthesis loop compared to conventional reforming at lower pressures and reducing the reactor size compared to conventional ATR. This translates to lower capital cost profile and lower operating costs. Moreover, the ATR route uses robust, well-proven equipment and a simplified process scheme that improves overall energy efficiency rates. When coupled with CCUS, an ATR-based ammonia plant can deliver world-scale output with a significantly smaller carbon footprint – delivering “big blue” ammonia at competitive economics.

Fig. 2: NX STAMI™ Ammonia high-pressure design process diagram



Source: Stamicarbon

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

Scalable green ammonia

Meeting the demand for smaller capacities, Nextchem's NX STAMI™ Ammonia high-pressure design (Fig. 2) is a green ammonia technology for plants ranging from 50 up to 500 t/d. This process is engineered to maximise efficiency and simplicity in plants powered by renewable energy. It features a high-pressure synthesis loop (operating at over 300 bar) that drives the ammonia formation reaction to a high conversion per pass. By elevating the loop pressure, the need for extensive recycle compression and refrigeration is greatly reduced – an important advantage in smaller plants where simplicity and energy efficiency compensate for the lack of economy of scale. High pressure in the loop allows ammonia to condense with cooling water in a single stage, eliminating the need for a costly refrigeration compressor. This significantly lowers equipment count and contributes to an estimated 25–30% reduction in capital expenditures for the synthesis section alone.

The high-pressure design is characterised by 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. 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 (both fresh make-up gas and recycle gas) is handled by a single, electrically driven reciprocating compressor, which supplies all services. This not only minimises the number of compressors required but also improves reliability and cuts maintenance costs. Nextchem's high-pressure green ammonia design is ideal for distributed, smaller-scale projects that can be scaled up as renewable infrastructure grows.

NX STAMI™ Ammonia high-pressure technology has four operating references, giving the strongest reference list in the sub-500 t/d. By leveraging this proven technology, early movers in the green ammonia space are achieving their decarbonisation goals while positioning themselves for future expansion as electrolyser and renewable capacity grow.

Achieving operational efficiency through integration

Significant synergies can be gained by integrating green ammonia plants with downstream units. For example, green

ammonia can feed directly into a urea plant to produce low-carbon urea fertilizer, cutting the overall carbon footprint per ton of product. Alternatively, ammonia can be converted to nitric acid and ammonium nitrate, which in some cases offers even greater greenhouse gas reduction potential for fertilizer production. In an integrated low-carbon fertilizer complex, shared streams, like the oxygen from water electrolysis, can boost efficiency. These integrations save energy, reduce emissions, and achieve savings in capital and operating costs by leveraging shared resources.

Conclusion

While medium-pressure and high-pressure ammonia technologies are typically associated with different capacity ranges, they are not feedstock-dependent. Medium-pressure technology can be effectively paired with electrolyser-based hydrogen, while high-pressure designs can provide a competitive solution for fossil-based and blue ammonia production, particularly when combined with front-end technologies such as NX CPO or e-SMR. By connecting these ammonia production technologies with downstream processes such as urea and nitrates at early stages, Nextchem can design fully integrated, future-proof fertilizer complexes. ■

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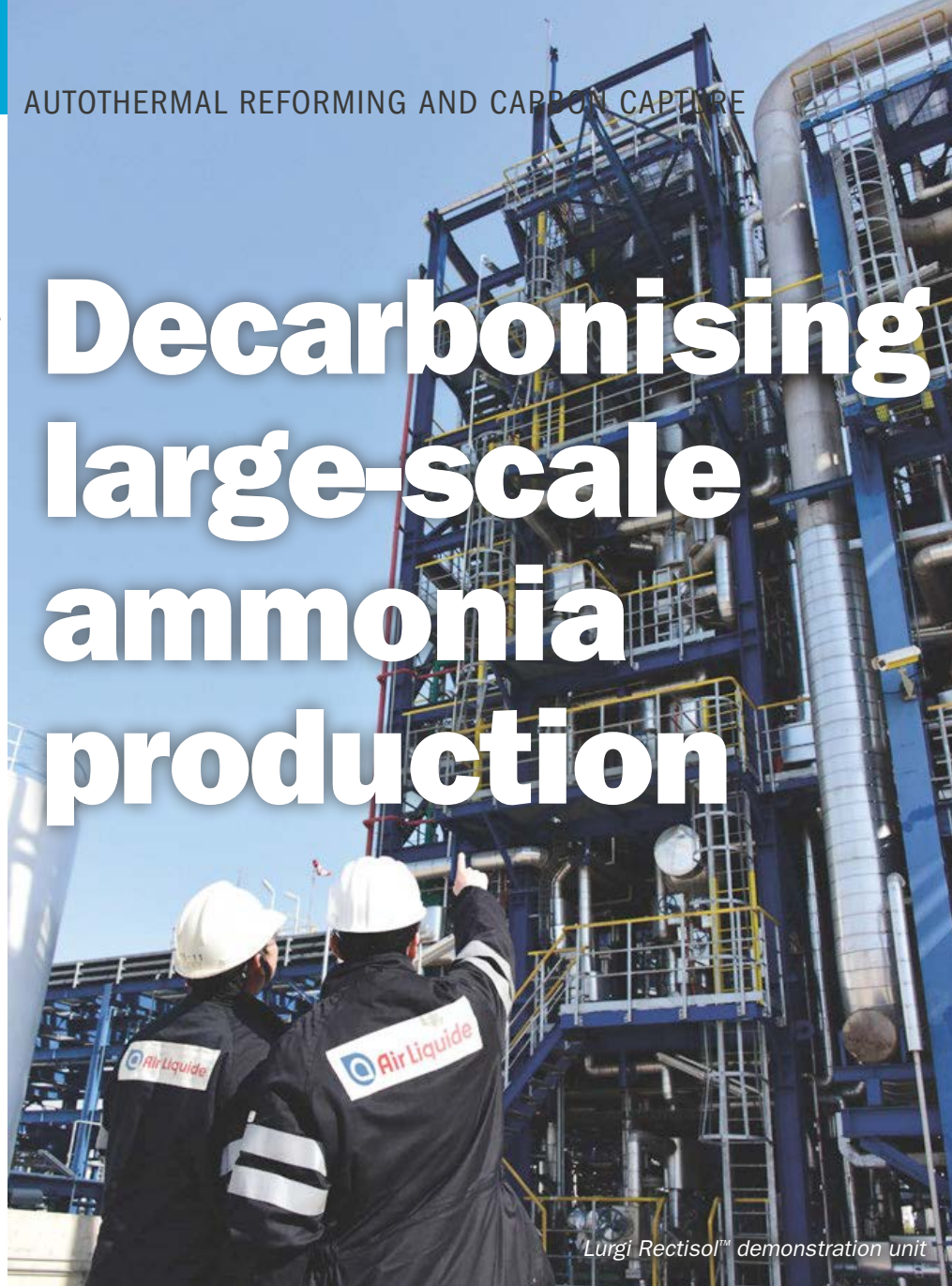


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Decarbonising large-scale ammonia production



Lurgi Rectisol™ demonstration unit

Decarbonising ammonia at world scale requires carbon capture solutions that offer a robust, scalable and cost-effective route to substantial emissions reductions. Air Liquide's Lurgi™ ATR technology, paired with its Recticap™ carbon capture process, targets dedicated low-carbon ammonia plants. **Sophia Schmidt** and **Matthias Linicus** of Air Liquide examine Recticap™'s design, compare it with alternative physical-absorption technologies, and assess its role in creating scalable, economically viable ammonia production while supporting the emerging hydrogen value chain and lowering industrial emissions at substantial scale.

Hydrogen and ammonia are central to the decarbonisation of industrial processes, in refineries, chemical plants and for transport. Air Liquide provides low-carbon production and ammonia-cracking technologies across this value chain. Developing an economically viable hydrogen supply chain will require low-carbon ammonia production at very large scale.

Autothermal reforming (ATR) is a key route to high-capacity, low-carbon ammonia production. However, ATR synthesis gas presents specific carbon capture challenges: high operating pressures, high carbon dioxide (CO₂) concentrations and very large gas flow rates. These conditions demand specialised capture solutions.

Air Liquide addresses these requirements through a proprietary technology portfolio that includes Cryocap™, Lurgi Rectisol™, Recticap™ and amine wash technologies. This portfolio enables the selection and optimisation of the most appropriate carbon capture solution for each project.

When combined with carbon capture, Air Liquide's Lurgi™ ATR technology

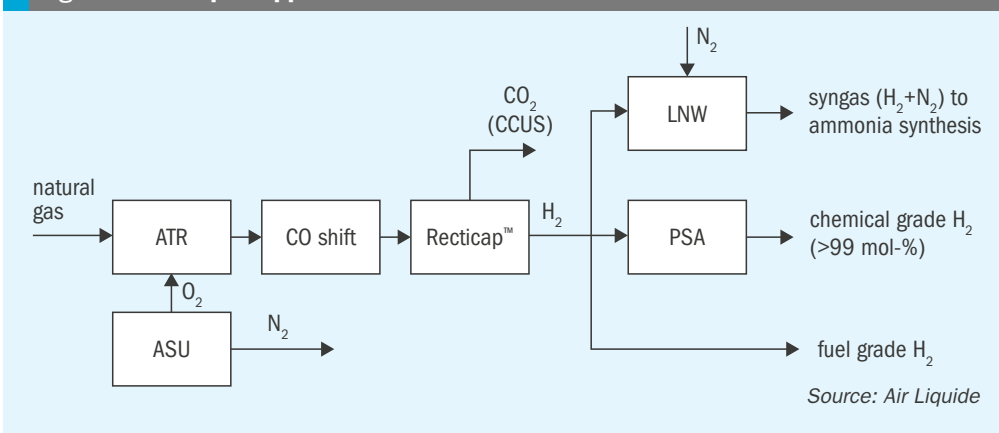
offers different optimisation pathways according to a plant's production objectives. For facilities designed to flexibly co-produce hydrogen and ammonia, Cryocap™ H₂ technology can maximise hydrogen yield while maintaining low carbon intensity. For projects focused exclusively on dedicated, large-scale low-carbon ammonia production, the combination of Recticap™ carbon capture and Lurgi™ ATR provides a streamlined and economically viable solution.

Recticap™ technology

Recticap™ is Air Liquide's proprietary carbon capture technology, developed from the widely referenced Lurgi Rectisol™ gas purification process. It draws on more than 75 years of experience in physical absorption using cold methanol to remove a broad range of impurities.

Recticap™ has been specifically streamlined for CO₂ capture downstream of autothermal reforming, particularly

Fig. 1: Recticap™ applications



in large-scale ammonia and hydrogen production facilities.

Potential applications (Fig. 1) include:

- ammonia synthesis gas preparation;
- hydrogen production for fuel-grade and chemical-grade applications;
- methanol synthesis gas production;
- Fischer-Tropsch synthesis gas production.

In the process, shown in Fig. 2, synthesis gas from the ATR is first cooled before entering an absorber column. There, it comes into contact with chilled methanol solvent, which selectively absorbs CO_2 .

The CO_2 -lean synthesis gas exits the top of the absorber with a residual CO_2 concentration ranging from 1–2 vol-% down to less than 10 ppmv, meeting stringent purity requirements for downstream applications.

The CO_2 -rich solvent is subsequently regenerated through a series of flash stages. During this process, most of the absorbed CO_2 is released in gaseous form, while the solvent is cooled down by the evaporation of the desorbed CO_2 .

Because the flash stages operate at different pressure levels, the CO_2 product can be released at pressures ranging from below 1 bar to 6 bar. This reduces the power required for multi-stage CO_2 compression. Where required, residual CO_2 can be removed from the methanol in a distillation column through heat input.

As Recticap™ operates at sub-zero temperatures, the lean solvent must be re-cooled before returning to the absorber. Efficient heat integration is therefore essential to recover heat of absorption under sub-zero conditions and to provide refrigeration duty that compensates for unavoidable heat losses.

The process can produce a high-purity CO_2 stream of more than 99 mol-%, suitable for pipeline transport, permanent storage or utilisation.

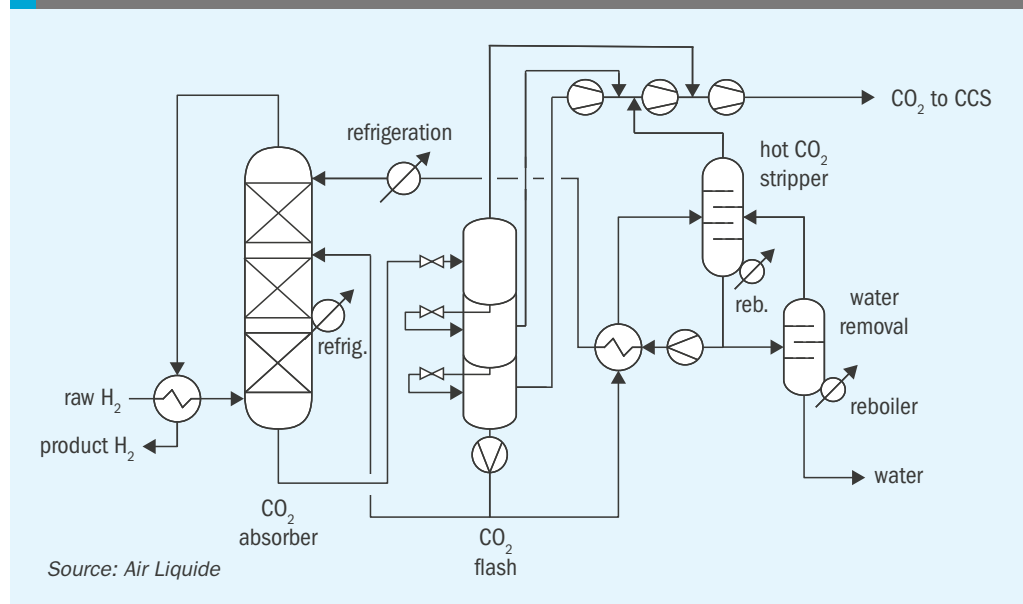
Comparing carbon capture solvents

Several solvents can be used for CO_2 absorption. They are generally classified as either chemical or physical solvents.

Chemical solvents, such as amines, bind CO_2 through a reversible chemical reaction. Physical solvents, including methanol, absorb CO_2 according to its physical solubility in the solvent.

The appropriate solvent depends on several project-specific factors, including:

Fig. 2: Recticap™ flowsheet



- plant capacity;
- CO_2 partial pressure;
- heat and power availability and cost;
- required CO_2 product conditions;
- downstream process requirements.

For large-scale low-carbon ammonia production based on ATR technology, physical solvents offer valuable advantages. This reflects the distinct characteristics of ATR synthesis gas compared with conventional ammonia production routes based on steam methane reforming (SMR) combined with air-blown ATR.

The ATR route produces synthesis gas at higher pressure and with higher CO_2 content. It can also involve significantly larger gas volumes as plant capacities increase. These conditions require a different approach to carbon capture.

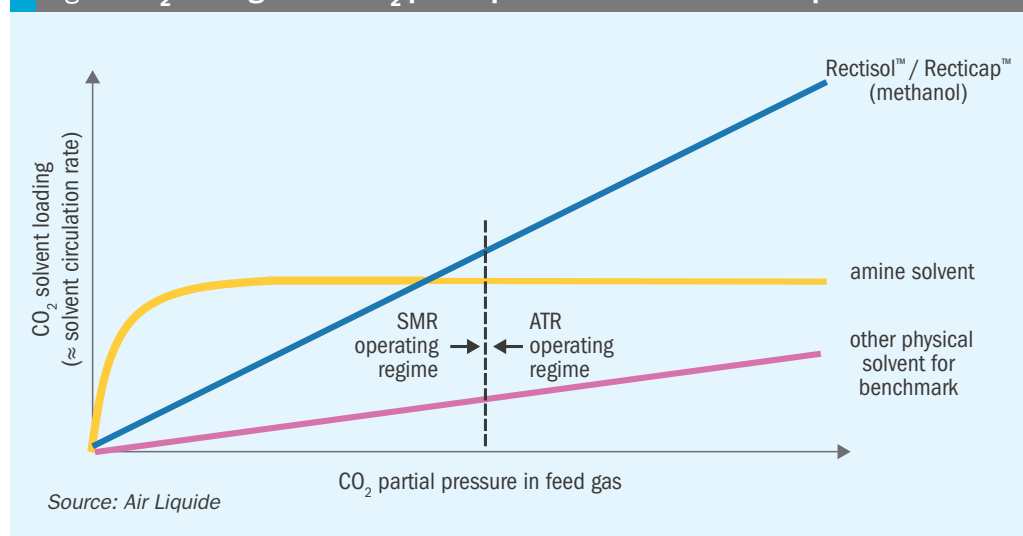
With physical solvents, CO_2 loading increases approximately in proportion to

CO_2 partial pressure. By contrast, loading in chemical solvents is constrained by chemical equilibrium (see Fig. 3). At higher CO_2 partial pressures, the greater loading capacity of physical solvents reduces solvent-circulation requirements. This can result in smaller equipment, lower pumping duties and reduced regeneration energy consumption.

Physical solvents are principally regenerated through pressure reduction, or flashing. Chemical solvents, by comparison, typically require substantial heat input to release the absorbed CO_2 . This results in higher energy consumption for regeneration of chemical solvents and may necessitate multiple process trains for very large gas capacities.

Among physical solvents, methanol – used in Recticap™ and Rectisol™ technology – offers favourable properties for CO_2 removal. Its high CO_2 solubility at low

Fig. 3: CO_2 loading versus CO_2 partial pressure for selected absorption solvents



temperatures and low freezing point of approximately -92°C enable operation at cold temperatures, maximising absorption efficiency. In addition, methanol’s low viscosity at cold operating conditions supports effective fluid handling and mass transfer.

Table 1 compares the properties of methanol with those of other physical solvents commonly used for industrial gas purification.

Given these characteristics, Recticap™ is well suited to energy transition applications. It offers energy-efficiency and cost advantages at high feed gas pressures – starting at approximately 25 bar – and large capacities, beginning at around 300 kNm³/h of hydrogen or 3,000 t/d ammonia.

Low-carbon ammonia at scale

For low-carbon ammonia projects, Recticap™ offers several distinctive advantages.

Proven technology

Recticap™ is a streamlined version of Air Liquide’s established Lurgi Rectisol™ technology. With more than 110 Rectisol™ references worldwide, including 40 commissioned in the past 20 years, Air Liquide offers extensive design and operational experience.

This includes experience operating two large-scale units in Asia, supporting high availability and reliable performance.

Large capacity

A key advantage of Recticap™ is its ability to process exceptionally large gas volumes. A single train can treat more than 1 million Nm³/h of synthesis gas, making it well suited to world-scale low-carbon ammonia projects.

Recticap™ and Rectisol™ are carbon capture technologies with commercial references at synthesis gas capacities exceeding those required for a 6,000 t/d ammonia plant. The largest operating Lurgi Rectisol™ facility treats 1.1 million Nm³/h of synthesis gas in each of its four trains.

High CO2 capture rate and low energy consumption

Recticap™ can capture up to 99.7% of CO2 while requiring as little as 0.25 GJ/t CO2, excluding compression. Its energy demand comprises both electrical and thermal components.

The relatively low thermal-energy requirement is advantageous for large-

Table 1: Comparison of different physical absorption solvents from “A comparison of physical solvents for acid gas removal”, Burr et al., 2008

Solvent property	Dimethyl ether of polyethylene glycol (DEPG)	Propylene carbonate (PC)	Methanol: Recticap™, Rectisol™
Viscosity @ 25 °C, cP	5.8	3	1.2 (@ -25 °C)
Freezing point, °C	-28	-48	-92
CO2 solubility @ 1 atm, vol. gas / vol. Solvent	3.63 (25 °C)	3.41 (25 °C)	~13 (@ -25 °C)

Source: Air Liquide

scale low-carbon ammonia projects. Waste heat from the front end can be used effectively, leaving more heat available to optimise the overall plant energy balance. Where renewable electricity is available, further Scope 2 emissions reductions may also be achieved.

Integration of Recticap™ with Air Liquide’s liquid nitrogen wash unit can further improve energy efficiency and hydrogen recovery, while producing an inert-free synthesis gas stream for ammonia synthesis.

Compact design

Drawing on Air Liquide’s expertise in column design and structured packing, developed through its Rectisol™ demonstration unit, Recticap™ absorber columns are designed to be compact. This can reduce shell volume and associated investment costs by approximately 30%.

Single-train Recticap™ units are feasible for 6,000 t/d ammonia facilities, with equipment dimensions designed to remain

within typical transport limits for remote project locations.

Cost-effectiveness

As a streamlined form of Rectisol™, Recticap™ reduces equipment requirements and capital expenditure. For a typical 6,000 t/d low-carbon ammonia plant, it can provide an efficient total cost of ownership through lower capital investment and optimised operating expenditure.

Conclusion

Recticap™ provides a proven, efficient and scalable carbon capture solution for large-scale industrial applications, particularly low-carbon ammonia production. Its ability to accommodate high-pressure, CO2-rich ATR synthesis gas at world-scale capacities makes it a strong option for projects seeking substantial emissions reductions while maintaining operational efficiency and economic competitiveness.



Steam and power balance in low-carbon ammonia and methanol plants

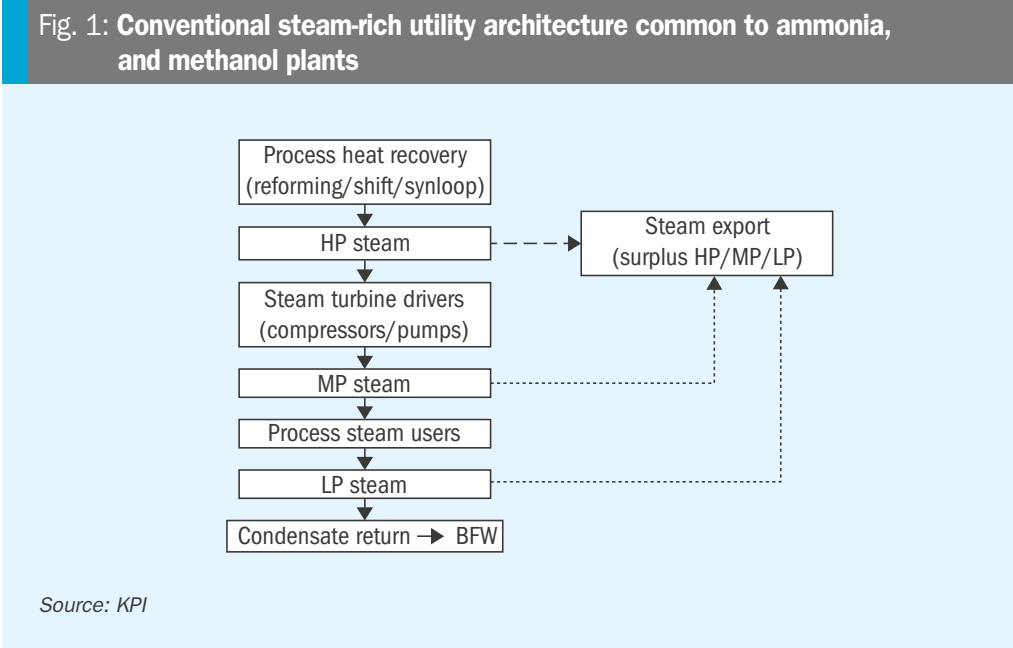
Decarbonisation is disrupting steam and electrical power balances in ammonia and methanol plants, making steam generation, driver selection, power import and operating flexibility critical constraints on low-carbon project feasibility and execution. **VK Arora** of Kinetics Process Improvements (KPI) examines the steam-system implications of low-carbon ammonia and methanol pathways and explains why steam and power balances should be assessed during pre-FEED, rather than treated as downstream utility issues.

Steam systems are not secondary utilities in ammonia and methanol plants. They form part of the process architecture: recovering heat, generating high-pressure steam, supplying process users, driving major compressors and pumps, supporting condensate recovery and determining the site steam and electrical power balance.

Conventional plants were designed around a stable, steam-rich utility model. In ammonia plants, steam generation is closely linked to primary reformer heat recovery, secondary reformer effluent cooling, shift conversion cooling, synthesis-loop recovery and boiler-feedwater heating. Large steam turbines for process air, synthesis gas and refrigeration compressors are central to energy recovery and steam-header control.

Methanol plants follow a similar but generally less steam-intensive model. Steam generation is associated with reformer waste heat recovery, ATR effluent cooling, downstream syngas cooling, synthesis-loop recovery and boiler-feedwater preheating.

Low-carbon projects are altering this foundation. ATR and partial oxidation shift steam generation away from the primary reformer. Carbon capture can introduce



new medium- or low-pressure steam demand. Imported or electrolytic hydrogen can remove major reformer-derived steam sources. Motor-drive conversion reduces turbine steam demand but increases dependence on imported power and changes steam-header control.

The critical questions are therefore: where steam is generated; at which pressure levels; how much turbine load remains;

whether carbon capture introduces new steam demand; and whether the plant can operate reliably during start-up, turndown, and other off-design conditions. These issues are particularly important in brown-field projects, where existing facilities were designed around specific relationships between process heat recovery, compressor drivers, steam headers, letdown systems and condensate return.

Conventional steam system architecture

Conventional ammonia and methanol plants were designed around a steam-rich utility model. The objective was to recover process heat as high-pressure steam, use that steam to drive major turbines and maintain a stable site steam balance, often with surplus steam available for export or power recovery. Fig. 1 illustrates this conventional architecture.

In ammonia plants, high-pressure steam generation is closely linked to reformer waste-heat recovery, secondary reformer effluent cooling, shift-conversion cooling and synthesis-loop heat recovery. Large turbine-driven compressor services are integral to the overall steam balance.

In methanol plants, steam generation is less intensive but remains closely tied to syngas generation and heat recovery. Reformer waste heat, ATR effluent cooling, downstream syngas cooling, synthesis-loop recovery and boiler-feedwater preheating all influence the steam balance. These systems work effectively because heat recovery, turbine steam demand, pressure letdown and condensate return are relatively predictable.

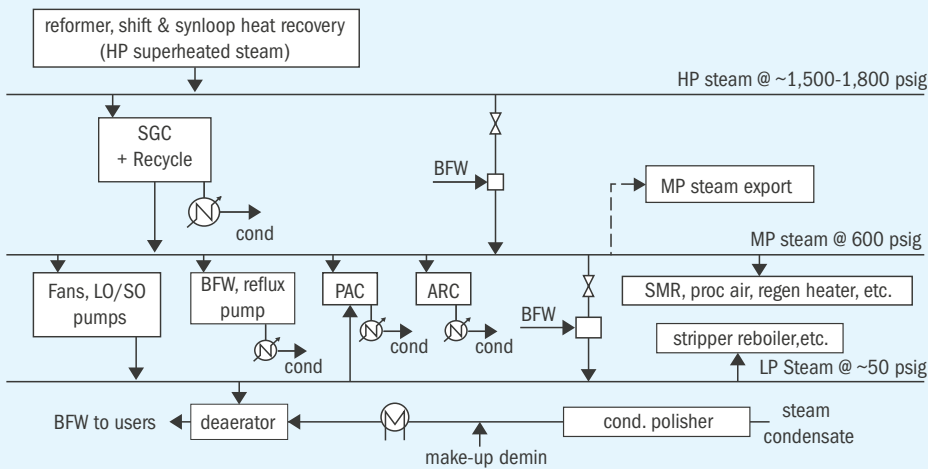
How decarbonisation reshapes steam systems

Decarbonisation changes steam systems in ways that extend well beyond fuel substitution. The key impact is not simply the total quantity of steam generated, but its location, pressure level, timing and end use.

In ammonia and methanol plants, ATR and partial oxidation relocate major heat recovery away from the primary reformer. Significant steam may still be produced, but the steam source, pressure profile and integration points change. This can affect steam headers, turbine extraction, boiler-feedwater heating and start-up operations.

Carbon capture introduces further complexity. Solvent-based capture systems can create substantial medium- or low-pressure steam demand for solvent regeneration, while carbon dioxide compression adds electrical load. In retrofit applications, this additional demand may not align with the original utility design, potentially requiring auxiliary boilers, modified steam letdown arrangements, driver changes, or reduced steam export.

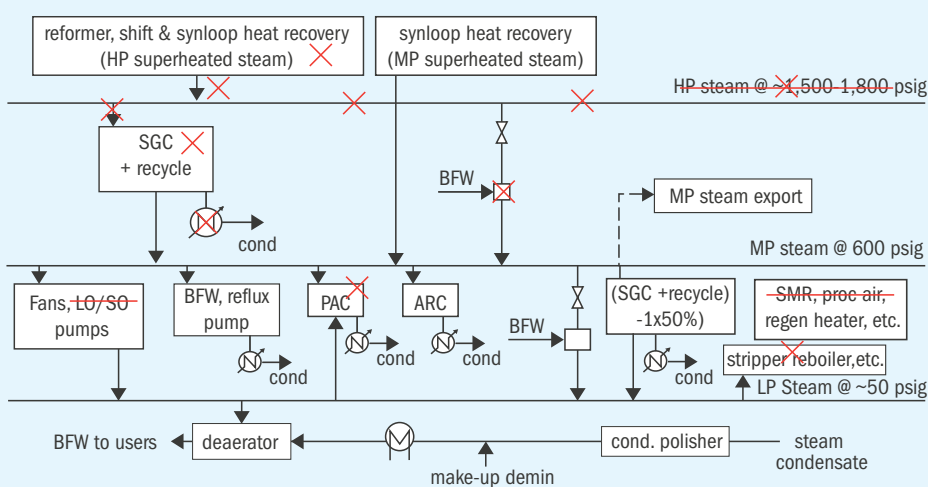
Fig. 2: Steam system for a conventional ammonia plant



SGC- Syngas Compressor; PAC- Process Air Compressor; ARC- Ammonia Refrigeration Compressor; LO/SO- Lube Oil/Seal Oil
Note: The steam system shown is typical. Start-up Aux- Boiler could be a part of SMR convection section or a stand-alone

Source: KPI

Fig. 3: Steam system with conversion to a clean ammonia plant



SGC- Syngas Compressor-1x50% new on motor drive; PAC- Process Air Compressor; ARC- Ammonia Refrigeration Compressor
Note: For conversion of an existing ammonia plant to clean ammonia, reformer- and shift-derived HP steam generation is eliminated. The major changes/deletions in the steam system are marked up

Source: KPI

Clean-ammonia concepts using imported hydrogen and nitrogen create a different challenge. Reformer- and shift-derived high-pressure steam generation can largely disappear, leaving synthesis-loop recovery and limited utility steam sources. Such configurations may become strongly dependent on imported power and electrically driven compression.

Across all pathways, the steam system becomes more dynamic and less self-balancing. Steam generation, carbon capture, driver selection, auxiliary boilers, condensate return and power imports must therefore be assessed as an integrated system. A low-carbon configuration that appears attractive on carbon intensity may nevertheless be constrained by steam-system operability.

Ammonia plant steam system impacts

Ammonia plants experience the most direct impact because the steam balance is closely linked to syngas generation. In a conventional SMR-based plant, high-pressure steam is generated through reformer heat recovery, shift cooling and synthesis-loop recovery, while major compressors are commonly steam-turbine-driven. Fig. 2 shows a conventional ammonia steam system.

Clean-ammonia conversion using imported hydrogen and nitrogen produces a fundamentally different utility balance. The reforming, shift, and carbon dioxide-removal sections are removed or bypassed, eliminating reformer- and shift-

derived high-pressure steam generation. Synthesis-loop heat recovery may remain, but the plant becomes more dependent on imported power and electrically driven compression. This configuration is illustrated in Fig. 3.

When comparing the conventional SMR-based ammonia steam system with a clean-ammonia conversion case, the practical issue is not only the removal of process equipment, but the loss of steam-generation sources that historically supported turbine operation and steam-header balance.

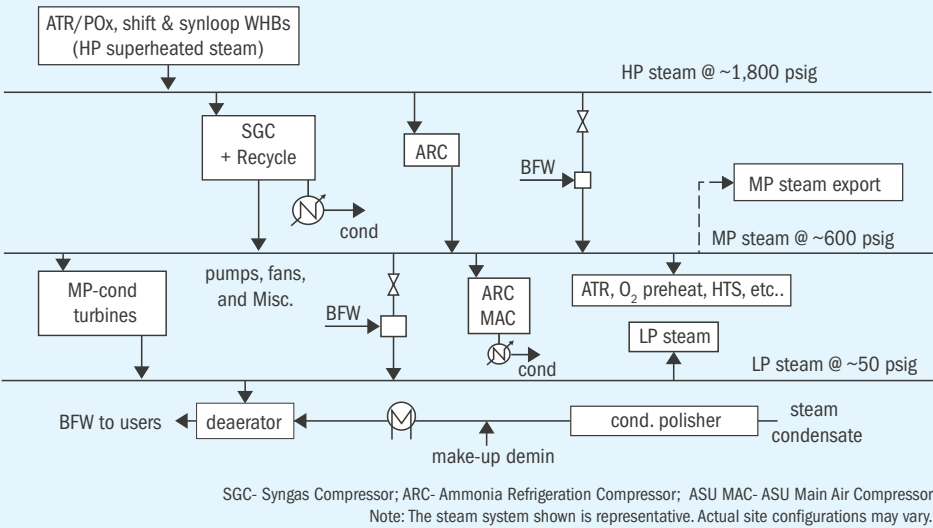
ATR-based blue ammonia follows a different path. These plants can remain significant steam producers, but the principal front-end steam-generation source shifts from primary-reformer heat recovery to ATR or POx waste-heat recovery. This changes the location of steam generation, pressure-level integration, driver selection and the utility requirements of carbon capture. A representative ATR-based blue-ammonia steam system is shown in Fig. 4.

The choice of a low-carbon ammonia configuration cannot be separated from steam and power integration. Clean, blue and green pathways may share similar carbon-reduction objectives, but their steam-system consequences differ substantially, as summarised in Table 1.

Methanol plant steam system impacts

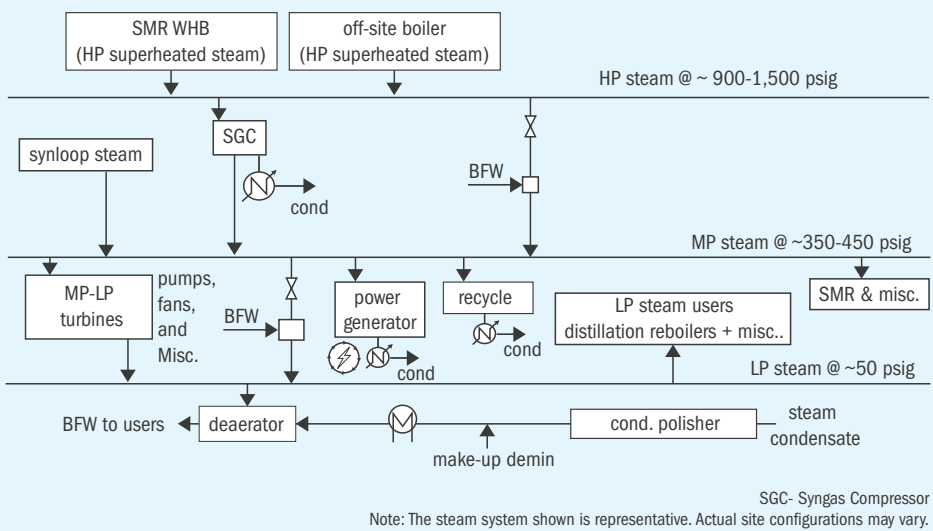
Methanol plants are generally less steam-intensive than ammonia plants, but steam integration remains central to process economics and operability. Conventional SMR-based plants generate steam primarily from reformer and synthesis-loop heat recovery, with steam turbines supporting

Fig. 4: Steam system of a next generation ATR-based ammonia plant



Source: KPI

Fig. 5: Steam system of a conventional methanol plant (SMR only)



Source: KPI

Table 1: Evolution of steam system philosophy in ammonia plants

Steam system attribute	Conventional SMR	Clean ammonia retrofit	ATR blue ammonia	Green ammonia
Primary steam source	Reformer WHB and process heat recovery	Synthesis-loop heat recovery	ATR/POx WHB and synthesis loop	Synthesis-loop heat recovery
Relative steam availability	High	Low	Moderate to high	Low to moderate
Main driver philosophy	Steam turbines	Mixed	Mixed	Mixed
Power import dependence	Low	High	Moderate	Very high
Steam export potential	High	Low	Moderate	Project specific
CCS integration	Limited	Not required	Integral to design	Not required
Utility integration focus	Steam optimisation	Steam deficit management	Steam and CCS integration	Power and steam optimisation

Source: KPI

syngas compression and auxiliary services. A representative conventional SMR-based methanol steam system is shown in Fig 5.

Large methanol plants increasingly use combined SMR and ATR configurations to support capacity, syngas-ratio control and energy integration. In these designs, steam generation is distributed across SMR heat recovery, ATR effluent cooling, downstream syngas cooling and synthesis-loop recovery. The resulting steam system is configuration-specific and depends on licensor design choices. A representative SMR-ATR configuration is shown in fig. 6.

Low-carbon methanol concepts place greater emphasis on ATR-based syngas generation, pre-combustion CCS, qualified carbon dioxide supply and renewable or low-carbon hydrogen. In these cases, steam generation becomes more closely linked to ATR heat recovery, carbon dioxide management and power imports. A representative ATR-based low-carbon methanol configuration with pre-combustion CCS is shown in fig. 7.

Decarbonisation shifts the methanol steam system from a reformer-centred utility network to a wider syngas, carbon-management and power-integration system. Table 2 summarises the progression, showing the shift from high steam intensity and export potential in SMR-based plants towards lower steam intensity, higher power dependence and greater CCS readiness in ATR-dominant configurations.

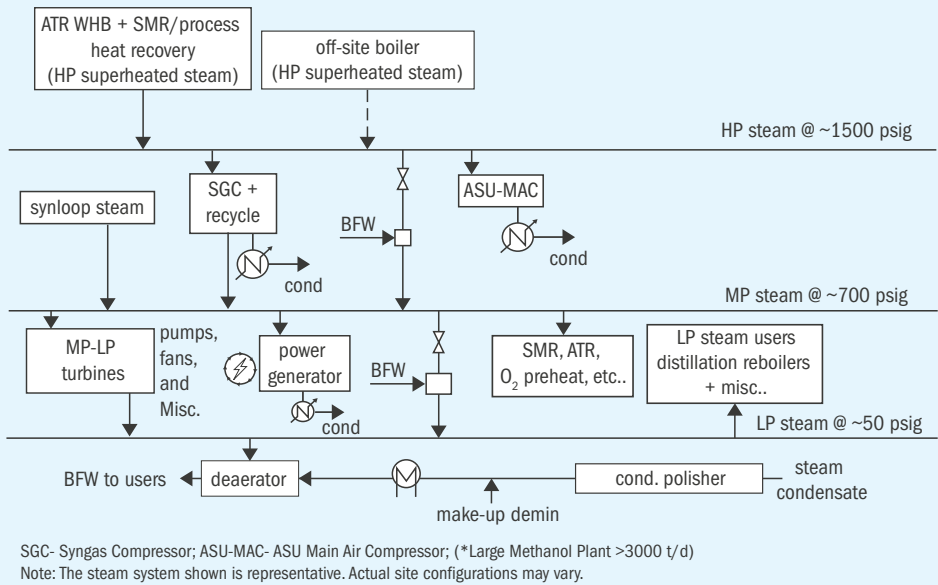
Emerging steam system challenges

Four common steam-system challenges are emerging across ammonia and methanol plants, regardless of the specific low-carbon pathway pursued.

First, the location of steam generation is changing. In conventional plants, high-pressure steam is closely associated with primary reformer heat recovery. In lower-carbon configurations, it may shift towards ATR or POx systems, synthesis-loop recovery, carbon-capture integration, or auxiliary steam generation.

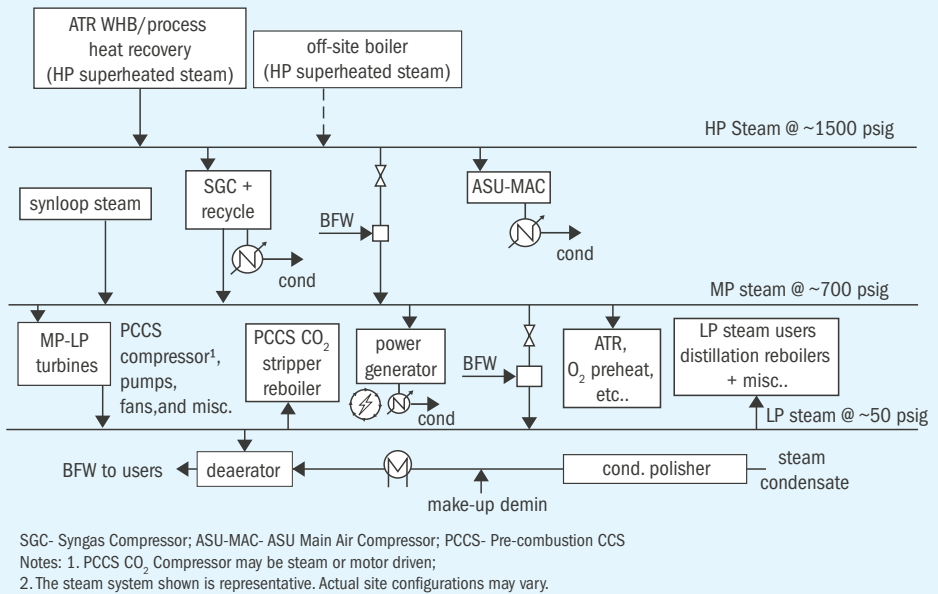
Second, steam-header balance is becoming more complex. Carbon capture can introduce new medium- or low-pressure steam demand, while motor-drive conversion can reduce turbine steam consumption. This affects extraction flows, letdown requirements, condensate recovery, auxiliary boiler operation, and steam-export potential.

Fig. 6: Steam system of a large methanol plant (SMR + ATR)



Source: KPI

Fig. 7: Steam system of a low CI methanol plant (ATR + PCCS)



Source: KPI

Third, steam and electrical systems are becoming increasingly interdependent. Low-carbon projects may require electrolyser capacity, air separation units, carbon-dioxide compression, electric motor drives, variable-frequency drives, transformers and additional imported power. This shifts part of the project risk from the steam system to electrical infrastructure and power availability.

Fourth, operating flexibility is becoming more important. Low-carbon configurations may depend on carbon-capture availability,

external hydrogen supply, renewable power, imported carbon dioxide or auxiliary steam. Steam systems originally designed for stable baseload operation may require wider control ranges and revised strategies for start-up, turndown and off-design operation.

The most successful projects will be those that maintain a workable balance among steam generation, power consumption, flexibility and long-term economics, rather than those that maximise carbon reduction in isolation.

Table 2: Steam system evolution in methanol production

Parameter	SMR	SMR + ATR	ATR dominant
Main steam source	Reformer	Reformer + ATR	ATR + synthesis loop
Relative steam system intensity	High	Medium	Lower
Steam export potential	Higher	Medium	Lower
Turbine utilisation	High	Medium	Lower
Power dependence	Lower	Medium	Higher
CCS readiness	Moderate	Good	High
Decarbonisation readiness	Moderate	Good	High
Primary decarbonisation pathway	CCS retrofit	ATR + CCS	ATR + CCS

Source: KPI

Steam turbines, motor drives and hybrid configurations

Conventional ammonia and methanol plants were designed around abundant internally generated steam, making steam turbines a natural choice for major drivers. Turbines recovered steam energy, supported steam-header balance and reduced dependence on imported electricity.

Decarbonisation changes that logic. Where steam availability is reduced, or where steam demand is redirected to carbon capture, large steam turbines may become less attractive. Electric motor drives can improve flexibility and reduce steam dependency, but they increase power import requirements and demand adequate electrical infrastructure. Hybrid arrangements may offer a practical compromise where steam remains available but is less predictable.

Driver selection should therefore be site-specific:

- Steam turbines remain attractive where the steam balance is strong and base-load operation is stable.
- Motor drives may be preferable where low-carbon power is available, start-up flexibility is important or steam is constrained.
- Hybrid configurations can provide flexibility across multiple operating modes.

For very large compressor services, double-ended motor arrangements may also be considered. A double-ended motor has shaft extensions on both sides, allowing driven equipment to be arranged on either side of the motor. This can divide transmitted torque between the two shaft ends,

improve train layout, reduce plot-space constraints, and provide mechanical integration flexibility.

Such motors are already used commercially in several large process applications, including ammonia syngas-compression service. However, each arrangement requires detailed assessment of torsional behaviour, rotor dynamics, couplings, protection systems, variable-frequency-drive requirements and maintenance access.

In brownfield projects, driver replacement also presents an execution challenge. Foundation reuse, compressor interfaces, lube-oil systems, substation capacity, cable routing, VFD cooling, harmonic studies, outage duration and commissioning risk can determine whether motor-drive conversion is practical within a particular project window.

Driver selection should not be treated as an isolated rotating-equipment decision. It must be evaluated as part of the full steam, power, condensate and carbon-management strategy, beginning in pre-FEED rather than during detailed engineering.

Conclusions

Steam systems remain central to ammonia and methanol plant integration, but their role is changing. Low-carbon pathways do not merely replace fuel or add capture units; they reshape steam generation, steam demand, turbine utilisation, power import and utility-system flexibility.

In ammonia plants, clean, blue and green pathways create very different steam

balances. Clean-ammonia conversion can eliminate reformer- and shift-derived high-pressure steam generation, while ATR-based blue ammonia can remain steam-producing but with a fundamentally different heat-recovery profile. In methanol plants, ATR-based syngas generation, carbon capture and qualified carbon dioxide supply make steam integration an integral part of carbon-management strategy.

No single low-carbon configuration is suitable for every site. Steam-system impacts depend on the process route, pressure levels, steam users, compressor drivers, condensate return arrangements, auxiliary boilers, electrical infrastructure and operating philosophy.

The practical implication is clear: steam and power integration should be assessed during pre-FEED. A decarbonisation concept that appears attractive on carbon intensity may still be constrained by steam balance, driver selection, start-up flexibility or brownfield execution. In many low-carbon ammonia and methanol projects, the steam system will be the hidden constraint determining whether the final design is operable, flexible and economically viable.

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