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Number 400

March | April 2026

nitrogen+syngas

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From cutting-edge technologies to strategic revamping: Casale's complete approach for a greener future

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PAGE 16
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Another price shock

> “Urea prices have jumped, in some cases by a reported $200/t...”

In just its first two months, 2026 had already managed to be a rollercoaster of a year, but at the start of March, the onset of hostilities against Iran by the US and Israel has managed to deliver another huge shock to markets, particularly commodities. Iran’s strategy of widening the conflict to neighbouring states, including by attacking Qatar’s massive LNG facility at Ras Laffan, effectively shutting it down, has sent the LNG market into chaos, and attacks on several tankers and other ships have paralysed maritime insurance markets and by default achieved the long-feared closure of the Straits of Hormuz.

At time of writing the conflict is less than two weeks old, but already oil prices have risen 35% to $90/bbl, after peaking at $120/bbl. All Gulf exports have halted, and Saudi Arabia is only able to export 5 million barrels per day via the Red Sea. Natural gas prices here in the UK have virtually doubled, as LNG cargoes are diverted away from Europe towards Asia by rising prices. Dutch TTF prices were last reported at $15/MMBtu, with some relief in Europe provided by warmer spring weather. Urea prices have jumped, in some cases by a reported $200/t, as the Straits carry almost one third of all traded product, and Iran has been a major exporter, particularly to India and China. India has invoked emergency measures to cut natural gas supplies to its fertilizer industry, forcing the sector to operate at approximately 70% of recent capacity, removing millions more tonnes from the market. Overall, around 47% of global sulphur, 43% of urea, 27% of ammonia and 24% of phosphate fertilizer trade is judged to be ‘at risk’.

For nitrogen markets, the shutdown of Qatar’s 5.6 million t/a urea complex at Mesaieed has been the first confirmed fertilizer production impact in the region. Most other sites are currently understood to be operating normally, but could mirror Qatar’s approach if the conflict persists. Duration is the key variable: CRU expects the two-week point to be pivotal for operational continuity. If disruption extends beyond two weeks, the main risk shifts to broader supply interruptions driven by constrained export routes, limited domestic offtake, and inadequate storage. With an additional two weeks potentially needed to restart idled capacity, this would imply a meaningful reduction in Middle East supply availability for March, alongside higher costs from repeated shutdown/restart cycling.

At present, CRU’s central assumption is that major shipping disruption will persist for at least three weeks, with significant ramifications for fertilizer markets heading into the spring planting season. By the end of week three of the conflict, the economic consequences may become crippling and may force a declaration of ‘victory’ or at least some form of agreement that allows some traffic through Hormuz to resume. Even so, while he has shown some signs of concern at rising oil prices feeding through to the gasoline pump in the US, president Trump has also said that the campaign may extend to five weeks or longer. For its part, the election of Mojtaba Khamenei as Ayatollah is a signal by Iran that it is in no mood for concessions, and the Islamic Revolutionary Guard Corps (IRGC) has said that it will determine when the war ends, not the US. ■

Richard Hands, Editor


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Price Trends

Ammonia sentiment was overtaken this week by the escalating Middle East conflict and the effective closure of the Strait of Hormuz, which left vessels unable to enter or exit the Arabian Gulf. With maritime trade frozen, price indications for prompt Middle East business largely stalled. In normal conditions, the sudden removal of Gulf export flows would point to sharply higher prices, particularly given the already-tight global availability and surging urea values, but participants said the absence of tradable cargoes made it difficult to pin down an indication. The immediate knock-on was felt East of Suez, where the supply shock pulled southeast Asian values back up to around $470-480/t f.o.b. Prevailing length in the market has been reportedly absorbed, with buying interest strongest from east Asia and India.

India is notably exposed to Middle East and Iranian supply. While demand is currently muted as turnaround period persists, a prolonged disruption would leave importers with few prompt alternatives once demand returns.

West of Suez was already facing tight supply and the tightness was further exacerbated by the conflict in the Middle East. Fertiglobe reported a 15,000 t sale at $750/t c.fr for mid-March delivery, $70/t higher from last week's assessed average. LAT Nitrogen reported it would reduce ammonia operating rates at sites in France and Austria, presumably linked to the sharp rise in European energy costs; Dutch TTF hub prices have surged to a three-year high.

The urea market attention has also been dominated by the fallout from US intervention in Iran and the subsequent regional conflict that has sent prices soaring and severely disrupted trade flows from the Middle East. In Iran, market visibility was lacking following an internet blackout, with no fresh transactions heard and the operational status of its producers unclear. The wider Middle East saw activity draw to a halt as Iranian threats to shipping effectively closed the Strait of Hormuz. This disruption was highlighted by QatarEnergy's decision to halt all urea production at its Mesaieed complex following strikes on its facilities, leaving several loaded vessels for destinations including India and Brazil stranded within the Arab Gulf. West of Suez, the supply shock from the Middle East sent prices spiralling upwards as traders scrambled to secure alternative tonnage. In Algeria, at least 150,000 t granular urea was sold, with AOA eventually concluding business for April loading at $680/t f.o.b., a level not seen since October 2022. Egyptian producers capped a similarly relentless week of business with Mopco eventually placing granular at $665/t f.o.b. for March shipment to Europe, a level also not seen since 2022 Q4. The bullish sentiment was mirrored in Nigeria, where Dangote sold 30,000 tonnes granular at $665/t f.o.b. for April, a jump of $210/t on business concluded in early February.

In the Americas, the NOLA market experienced a volatile week of trading. Strong demand for the upcoming spring season, coupled with global supply fears, pushed March barges to a new high of $620/st FOB before easing slightly. ■

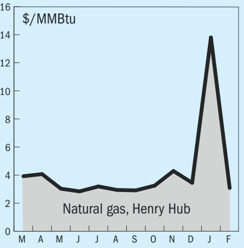
Table 1: **Price indications**

Cash equivalent	**mid-Feb**	**mid-Dec**	**mid-Oct**	**mid-Aug**
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	585	610	550	445-450
f.o.b. Arab Gulf	450-512	500-539	400-420	320-340
c.fr N.W. Europe	670-690	640-695	620-630	560-570
Urea ($/t)				
f.o.b. bulk Black Sea	460-465	345-355	380-385	460-470
f.o.b. bulk Arab Gulf*	437-455	355-395	330-410	386-515
f.o.b. NOLA barge ($/st)	432-437	360-376	375-377	420-445
f.o.b. bagged China	n.m.	390-400	389-390	445-490
DAP ($/t)				
f.o.b. bulk US Gulf	625-632	605-625	770	787-805
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	360	365	310-315	327-330

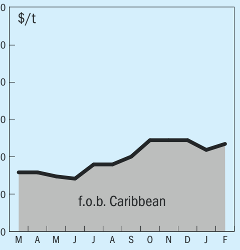
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

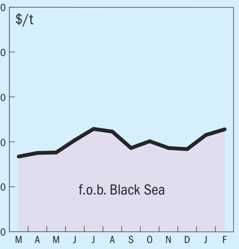
natural gas



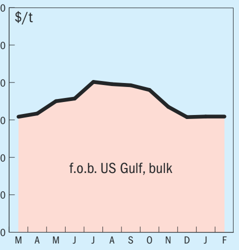
ammonia



urea

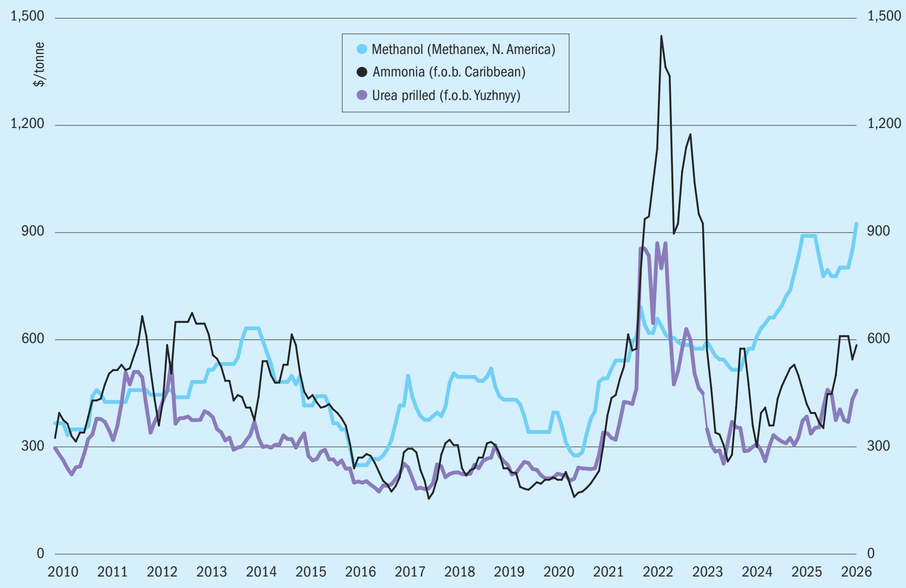


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Prices are likely to remain on an upward trajectory as long as the Strait of Hormuz remains effectively closed and Middle East export availability is constrained.
- The effect on the LNG market of a cessation of supply from Qatar and other Gulf nations is likely to increase feedstock prices in Europe and India.
- However, East Asia is relatively comfortably supplied by long-term contracts in the near term, with a steady run of scheduled arrivals continuing despite the ongoing conflict in the Middle East.
- Should the conflict in the Middle East persist, Southeast Asian producers may see further surges in demand from India. The India market is typically reliant on Iranian and Middle East supply, while this constrained Southeast Asia material remains the next best alternative.

UREA

- Urea prices look set to remain supported for as long as the Strait of Hormuz remains effectively closed, with significant further increases likely over the coming weeks if no resolution to the ongoing conflict in the Middle East is found.
- The supply disruption has created a precarious situation for India. Following RCF's 18 February tender, a substantial portion of the 1.3 million tonnes of urea secured was set to be sourced from the Middle East. With several vessels now stranded, traders are scrambling to cover their positions.
- There remains significant uncertainty as to whether RCF will grant laycan extensions beyond the 31 March shipment deadline, and the potential for delayed arrivals is likely to impose further strain on India's dwindling stock levels just as many domestic plants enter seasonal maintenance.

METHANOL

- The outbreak of hostilities in the Middle East has sent a shock through oil and gas markets, and there is likely to be a significant knock-on effect on olefins and polyolefins markets.
- Prior to this, production curtailments outside of China had tightened the market slightly. Iranian plants were already mostly down due to winter gas supply restrictions, but Trinidad and Venezuela also have gas supply restrictions, and a cold snap in the US also led to a temporary shutdown of several methanol plants. While demand remains subdued in Europe, rapidly oil prices point to rising methanol prices.
- Meanwhile, China's January methanol output was the second-highest monthly level in recent years. Plant utilisation rates are above 90% while demand remains relatively weak, leaving the market oversupplied. Port inventories were up at 1.77 million tonnes ■

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Nitrogen Industry News

EUROPEAN UNION

EU to suspend import duties

The European Commission (EC) officially proposed to suspend, for one year, the most favoured nation (MFN) duties on imports of several key nitrogen-containing fertilizers and inputs for their production, including ammonia and urea, officials said 24 February. The tariff suspension will be implemented for all countries, except Russia and Belarus, through duty-free tariff rate quotas, the Commission noted. Imports beyond these quotas will be subject to standard MFN duties, it added.

"The volume of the quota corresponds to the volume of Union MFN imports of 2024, except imports from the Russian Federation and the Republic of Belarus, but increased by a top-up of 20% of the volumes imported into the Union from these two countries in 2024," the EC said.

The products included under the proposal are ammonia, urea, ammonium sulphate (AS), calcium ammonium nitrate (CAN), urea ammonium nitrate (UAN), NPKs, MAP and DAP. Quota volumes are as follows: ammonia (300,000 t), urea (890,000 t), AS (413,000 t), CAN (27,000 t), UAN (583,000 t), NPKs (360,000 t), MAP (87,000 t) and DAP (83,000 t). Import tariffs on fertilizers from most-favoured nations are 6.5%, excluding those on Russia and Belarus, which are subject to higher "staged" tariffs to end EU dependency on those origins.

For urea, CRU calculations suggest the total quota allocation for MFN imports (excluding Russia and Belarus) amount to 750,000 tonnes, against 2025 imports totalling 770,000 tonnes. Countries exempt from MFN tariff status include Egypt, Algeria and Uzbekistan. The quota set by the EC (890,000 tonnes) should allow for some price relief for as long as the MFN tariff exemption is in place through mid-2027, while there is also 120,000 tonnes worth of incremental upside import potential from MFN countries on the basis of 2025 import data. ■

UNITED STATES

CF, Trafigura and TFG Marine to collaborate on low carbon marine fuels

CF Industries has signed a memorandum of understanding with Trafigura and TFG Marine, a leading global marine fuel supplier, to facilitate the adoption of low-carbon ammonia as a marine fuel. Building on previous collaboration between CF Industries and Trafigura in the shipment of low-carbon ammonia, this agreement establishes a framework for the parties to work together on advancing low-carbon ammonia as a marine fuel, supporting the global shipping industry's emissions-reduction efforts, including market development, stakeholder engagement, and bunkering logistics planning. The collaboration will initially focus on the U.S. Gulf Coast and Northwest Europe.

CF Industries says that it will leverage its low-carbon ammonia production and export capabilities at its Donaldsonville, Louisiana, complex. Trafigura will contribute its expertise in commodity logistics and market development, while TFG Marine, a joint venture between Trafigura, Frontline and Golden Ocean Group, will leverage its global marine fuel supply network and bunkering capabilities to support last-mile delivery solutions, coordinate ammonia bunkering demand, and transport ammonia to bunkering hubs globally.

"We are pleased to collaborate with industry leaders such as Trafigura and TFG Marine to establish the supply chain necessary to meet the expected transition of the marine shipping industry to low-carbon ammonia as a fuel," said Bert Frost, Executive Vice President and Chief Commercial Officer, CF Industries.

Exxon in legal case over CO_2 pipeline access

ExxonMobil has been named by Clean Hydrogen Works as an additional defendant an in existing anti-trust suit over access to a CO_2 pipeline. Clean Hydrogen Works alleges that CO_2 enhanced oil recovery firm Denbury, now acquired by ExxonMobil, unlawfully terminated its previously agreed access to Denbury's pipeline network, threatening the proposed Ascension Clean Energy (ACE) blue ammonia project in Louisiana's Ascension Parish. ExxonMobil has its own blue hydrogen and ammonia project under development, at Baytown, Texas, although it "paused" it last year, citing weak customer demand and difficulty securing sufficient offtake agreements. ExxonMobil has not publicly commented on the lawsuit.

CF takes write-down on green ammonia project

CF Industries has reported a $51 million impairment in its most recent accounts due to the abandoning of its 20MW green hydrogen facility at the company's huge Donaldsonville, Louisiana fertilizer complex. The alkaline electrolysis unit had been planned to feed green hydrogen to produce up to 20,000 t/a of green ammonia. The company says that it will focus instead on more economically attractive blue ammonia production.

SPAIN

Casale and Paralloy sign MoU on OMEGA reformer tubes

Casale and Paralloy Group announced a strategic memorandum of understanding (MoU) at the recent CRU Nitrogen+Syngas 2026 Conference in Barcelona to jointly commercialise Paralloy's OMEGA® profiled reformer tube technology, which Casale will offer alongside its existing steam reformer process design and plant-wide optimisation capabilities. Casale CEO Federico Zardi said: "Our objective is to build a long-term relationship, combining our respective strengths to bring the best solutions to the market for syngas generation and the production of ammonia, methanol, and hydrogen."

Casale says it will combine Paralloy's tube metallurgy and geometry with its own reformer process design and plant-wide optimisation expertise, targeting higher throughput, lower fuel consumption and extended equipment lifetime in ammonia, methanol and hydrogen applications. Paralloy's Omega tubes were previously featured by Nitrogen+Syngas in March 2025, when Paralloy said the profiled internal surface "increases the internal surface area by more than 50%" to improve heat transfer and turbulence, and reported laboratory tests showing "a minimum of 10% improvement" in heat transfer coefficient versus conventional tubes.

Paralloy CEO Robert McGowan said of the new Casale partnership: "This is not just a commercial agreement — it is a commitment to deliver something truly unique to the market".

PHOTO: CASALE

Paralloy CEO Robert McGowan (L) and Casale CEO Federico Zardi (R) at CRU's Nitrogen+Syngas 2026 Conference in Barcelona.

Avalon seeking permits for hydrogen plant

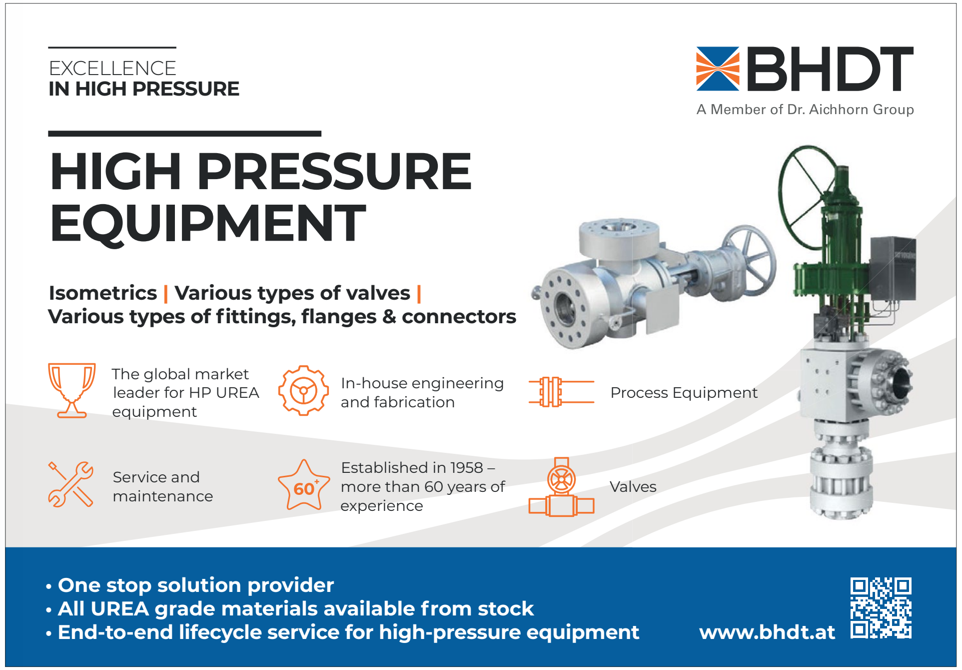
Avalon Renovables says that it has begun the administrative process to obtain environmental permits for the company's planned Arquillo green hydrogen plant at Jerez de la Frontera. The plant is one of eight green hydrogen plans planned as part of the Bays of Algeciras and Cádiz Project (PBAC), with pipeline tie-ins to the future green ammonia plant in Campo de Gibraltar. The plant will include a 47 MW solar voltaic power plant called Arquillo, feeding 35 MW of electrolysis capacity, with an estimated output of 4,900 t/a of hydrogen.

Avalon has also begun the permitting process for other plants in the project, including those in Villamartín and Puerto Serrano, which will add up to 350 MW of power and have already obtained 37.4 million euros in European funding, as well as the Los Barrios plant, whose construction is scheduled for 2027 and where it will transform hydrogen into up to 800,000 t/a of green ammonia.

MOROCCO

Agreement signed with green ammonia developer

The government of Morocco has signed an agreement with the ORNX consortium to advance a $4.5 billion green ammonia project in the southern city of Laayoune, as part of Morocco's ambitions to become a global hub for green hydrogen and



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derivatives. The development combine wind and solar electricity generation with hydrogen from electrolysis to feed green ammonia production. Under the terms of the agreement, more than 2 GW of renewable energy capacity will be installed, feeding 900 MW of electrolysers producing green hydrogen. To ensure operational stability and continuous output, the facility will also incorporate battery energy storage systems. In addition, a seawater desalination plant will be constructed to provide the purified water required for hydrogen production, addressing resource constraints in the arid coastal region. During its initial phase, the complex is expected to generate around 100,000 t/a of green hydrogen, which will allow the production of 560,000 t/a of green ammonia. The ammonia will be used both domestically in ammonium phosphate production as well as being exported internationally.

INDIA

Madras seeking approval for greenfield urea plant

Madras Fertilizers Limited (MFL) has submitted a proposal for a new $1.1 billion greenfield ammonia-urea manufacturing project in Chennai, aimed at strengthening domestic fertiliser production and reducing import dependence. The company says that the project is aligned with the government's broader push for self-reliance in critical agri-inputs and improved food security. The proposed plant will have a capacity of 1.3 million t/a of urea and is currently at the feasibility study stage, but MFL says that its existing 1970s vintage plant is already running at 120% of nameplate capacity, and that a new larger scale facility would see significant improvements in output and operating efficiency.

PAKISTAN

Government moving forward with coal-based urea plant

The government of Pakistan has published a 'strategic roadmap' for the country's major Coal-to-Fertiliser (C2F) initiative. The project is being executed by the publicly-owned Fauji Fertiliser Company (FFC), and will use local coal reserves at Thar as feedstock for the ammonia plant, which will in turn feed 720,000 t/a of urea capacity. The $1.1 billion project aims to strengthen the country's fertiliser security as well as add value to local resources. A bankable feasibility study was completed in November 2025, and the project is now in the Front-End Engineering Design (FEED) and project agreements phase. Under the proposed timeline, financial closure is expected between late 2026 and 2027, while commercial operations are targeted to commence in January 2031.


PHOTO: KBR

JGC's green ammonia demonstrator plant, Japan.

JAPAN

Start-up for green ammonia demonstrator plant

Asahi Kasei Corp says that it has begun operations at a demonstration plant using green ammonia production technology in January 2026, using hydrogen manufactured by Asahi Kasei. The plant, built by JGC, and using KBR's K-GreeN® ammonia production technology, is part of Japan's NEDO (New Energy and Industrial Technology Development Organisation) Green Innovation Fund project. The hydrogen feedstock comes from a 10MW alkaline water electrolysis system at the adjacent Fukushima Hydrogen Energy Research facility, which Asahi Kasei has operated since 2020. Leading the design and construction of the ammonia plant, JGC will conduct the demonstration operation during the fiscal year 2026 to advance process optimisation and commercialisation studies.

"We believe that ammonia production using hydrogen made with renewable energy is an important technology for realizing a decarbonized society, offering potential as an energy storage and transport medium as well as supplying carbon-free ammonia, which has a wide range of applications as a chemical feedstock," commented Masami Takenaka, Lead Executive Officer and Senior General Manager of Asahi Kasei's Green Solution Project. "By leveraging the expertise gained through this demonstration, including coordination with chemical plants to maintain stable hydrogen supply, we will help advance future commercialisation and build a sustainable society powered by clean hydrogen."

SAUDI ARABIA

Topsoe technology selected for ACWA green ammonia plant

Topsoe says that it has been selected as the ammonia technology licensor for ACWA's Yanbu Green Hydrogen Project in the Kingdom of Saudi Arabia. The process will enable green hydrogen from the Yanbu Project to be converted into ammonia. Topsoe will also deliver engineering, proprietary equipment and catalysts to Sinopec and Tecnicas Reunidas, who have jointly been awarded the front-end engineering design (FEED) contract.

Yassir Ghiyati, CCO at Topsoe, said: "We are happy to expand our collaboration with ACWA on their impressive project. Green ammonia plays a critical role in reducing emissions from energy-intensive industries and long-distance transportation. We need to deploy decarbonisation solutions on a global scale, and ACWA's project will be able to deliver a strong contribution."

The Yanbu Green Ammonia Project is a large-scale development for gigawatt-scale green hydrogen. The licensing agreement covers the first mega-scale green ammonia units in Yanbu, with a capacity of 2,700 t/d (890,000 t/a), as well as an interest to replicate the scheme in subsequent units. Topsoe says that its dynamic ammonia process will enable the ramping up/down of ammonia production bidirectionally at a rate of at least 3% per minute in response to the fluctuating supply of hydrogen to the ammonia plant, as well as a significant reduction in capital expenditure and operational expenditure since hydrogen storage systems can be reduced substantially, or otherwise eliminated.

INDONESIA

Ammonia plant revamp for Kaltim

PT Pupuk Kalimantan Timur (Pupuk Kaltim) says that it has begun work on a revamp to its number 2 ammonia plant. The plant, which was originally constructed in 1984, has a capacity of around 1,500 t/d of ammonia. The revamp, which is being carried out internally by Pupuk Kaltim, aims to improve energy efficiency at the ageing plant and reduce carbon emissions, according to the company. The revamp is expected to extend the plant's operational life, improve production reliability, and support Indonesia's long-term fertilizer supply amid rising domestic demand.

RUSSIA

Drone strike on Dorogobuzh

A Ukrainian drone attack hit the Dorogobuzh nitrogen fertilizer plant, around 140 km east of the border with Belarus in the western Smolensk region, according to local press reports. At least seven people were killed and another 10 injured, according to Russian authorities. It appears that the nitric acid and ammonium nitrate plants were targeted, as well as facilities involved in the storage and transportation of ammonium nitrate, leading to extensive damage. The strike is part of an ongoing campaign by Ukraine against Russia's oil, gas and chemical facilities.

UNITED KINGDOM

Honeywell and JM amend terms of Catalyst takeover

Honeywell and Johnson Matthey have agreed to amend the agreement for Honeywell's purchase of JM's Catalyst Technologies business segment. Honeywell's payment for the business has been reduced from £1.8 billion ($2.43 billion) to £1.325 billion ($1.8 billion), and the completion date for the transaction has been extended to July 21, 2026, with a possible extension to August 21st if any of the regulatory approvals are not satisfied by then.

Honeywell says that the acquisition of JM's Catalyst Technologies business synergises with its own Process Technologies and Process Automation businesses, and will: "unlock strategic growth by increasing Honeywell's installed base and creating a more integrated offering across energy and process technologies; expand Honeywell UOP's capabilities with the addition of a significant installed base across refining, petrochemical and renewable fuels; and enhance Honeywell's existing catalyst portfolio with complementary offerings and growth in renewable fuels capabilities."

UNITED ARAB EMIRATES

Memorandum of understanding on strategic ammonia collaboration

Polymer manufacturer Covestro has signed a memorandum of understanding with ammonia and urea exporter Fertiglobe and chemical producer TA'ZIZ to explore collaboration across the ammonia and nitric acid value chains. The MoU reflects the parties' shared interest in assessing


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both near-term supply solutions and longer-term opportunities supporting the transition toward lower-carbon production pathways. The agreement was signed during the visit of German Chancellor Friedrich Merz to the UAE.

Under the terms of the agreement, Covestro and Fertiglobe intend to explore short-term ammonia supply opportunities from Fertiglobe's facilities to Covestro's sites in China and the United States. In parallel, they will assess longer-term supply options to sites in Europe, China and the United States, based on low-carbon ammonia produced using carbon capture technologies, as well as green ammonia from renewable sources, including projects developed by Fertiglobe. Ammonia is a key raw material for Covestro's production of MDI (diphenylmethane diisocyanate) and TDI (toluene diisocyanate).

"The potential strategic supply arrangement with Fertiglobe could strengthen our access to a critical raw material while supporting the gradual transition towards lower-carbon production pathways," said Dr. Markus Steilemann, CEO of Covestro. "Reliable low-carbon ammonia supply enhances operational flexibility across our sites and helps manage long-term cost and availability risks. At the same time, the agreement is a first concrete step in translating our partnership with XRG into tangible business impact."

"We see strong potential in combining our ammonia production portfolio with Covestro's industrial expertise and global footprint," said Ahmed El-Hoshy, CEO of Fertiglobe. "The Memorandum of Understanding creates a structured basis to assess concrete projects and opportunities - from supply and infrastructure to downstream applications."

NORWAY

Cancellation for green ammonia project

Hy2Gen has been forced to end plans for a green ammonia plant in Norway, following the withdrawal of an electricity supply agreement by the main energy provider. Iverson eFuels, co-owned by Hy2Gen and Copenhagen Infrastructure Partners, had been planning to build a 200,000 t/a green ammonia plant at Birkeland in Sauda, using 240 MW of electrolysis capacity. However, the plant's operational schedule has been pushed back from an original launch date of 2027 to 2031, prompting Norwegian electrical grid operator Statnett to withdraw the 270 MW of previously allocated grid capacity at the end of December, saying that it could only offer the extra capacity once upgrades to the grid had been completed in the period 2033-35. Following several weeks of discussions, Iverson eFuels said in a statement that: "such an unresolved situation related to the completion of new network capacity is not compatible with further development of the project. On this basis, Iverson has decided to terminate the project concerning green ammonia production in Sauda. The company regrets the decision, thanks its partners, and will now consider the possibility of establishing a data centre to create new activity in Sauda."

AFRICA

NextChem to supply equipment for nitrogen plants

NextChem says that its subsidiaries Stamicarbon and KT Tech have been awarded licensing, process design package (PDP) and critical equipment supply contracts for the development of three world-scale complexes, two of them dedicated to granular urea production, and one integrating ammonia and methanol co-production, for an undisclosed "major client in West Africa". The contracts are all based on proprietary technologies.

The overall package is worth €485 million, of which €10 million related to engineering activities already started will be recognised in the pre-FID phase, and the remaining part at Final Investment Decision. The two large-scale nitrogen fertilizers plants will consist of four hydrogen units based on NX AdWinHydrogen® technology, four ammonia units based on NX STAMI™ Ammonia technology, four urea-melt trains and six urea-granulation units based on NX STAMI™ Urea technology for an overall urea production above 3 million tonnes per annum. NX AdWinHydrogen® autothermal reforming (ATR) produces syngas at the scale needed for the downstream plants. NX STAMI™ Urea technology is aimed at reducing steam consumption and improving energy efficiency while producing high-quality urea granules.

The third plant combines 900,000 t/a of ammonia capacity and 600,000 t/a of methanol capacity co-production, using NextChem's autothermal reforming-based NX AdWin® Combined technology; a large-scale high-pressure ATR technology for sequential/parallel methanol and ammonia production. NX AdWinHydrogen® and NX AdWin® Combined were both developed by GasConTec, NextChem's subsidiary dedicated to low-carbon hydrogen and methanol solutions.

Fabio Fritelli, Managing Director of NextChem, commented: "This is a landmark award, which leverages NextChem's integrated expertise across the hydrogen, ammonia, urea, and methanol value chains. It reinforces our position as a leading technology partner for large, integrated industrial projects, demonstrating the scalability and complementarity of our proprietary technologies."

AUSTRALIA

Pilbara Ports Signs Ammonia Bunkering MoU

Pilbara Ports has signed a memorandum of understanding (MoU) with Yara Pilbara for low carbon ammonia bunkering. The companies have agreed to collaborate on government and stakeholder advocacy, develop a training program for safe ammonia handling, and are planning the necessary fuelling infrastructure at Dampier and Port Hedland ports as part of the Pilbara Clean Fuel Bunkering Initiative.

Pilbara Ports Chief Executive Officer Samuel McSkimming said: "We're pleased to work alongside Yara Pilbara to promote the production of clean marine fuels in the Pilbara, and on ensuring Western Australia plays a leading role in the global transition to low-emission shipping. The green iron corridor between the Pilbara and East Asia has the scale, stable demand, port infrastructure, and risk management experience to support the significant investment that maritime decarbonisation requires, while the Pilbara has the renewable energy resources, carbon capture and storage potential, and ammonia-based industry to lead in green fuel production."

Currently, ships do not generally bunker in the Pilbara, instead taking on heavy fuel oil elsewhere for their entire outward-bound and return voyages. Launched last year, the Pilbara Clean Fuel Bunkering Hub outlines a strategic approach to establish a clean fuel bunkering hub in the region, enabling the use of alternative fuels such as ammonia. One successful bunkering trial has already taken place and another is set to occur in the Port of Port Hedland later this year. ■

Syngas News

MEXICO

FID expected soon on blue methanol project

Transition Industries has signed a long-term firm natural gas supply contract for the Pacifico Mexinol project in Topolobampo, Sinaloa state with CFEnergía. CFEnergia has agreed to supply about 1.6 bcm/year of natural gas for the project, which it aims to buy in the US and supply it at market competitive prices by optimising the use of existing infrastructure. Financing is coming from the World Bank's International Finance Corporation, and Australian investment bank Macquarie, as well as support from the government of Sinaloa state.

The Pacifico Mexinol project envisages the construction of a large scale $3.3 billion methanol plant to produce approximately 1.8 million t/a of blue methanol and 350,000 t/a of green methanol at a site on the west coast of Mexico to feed the Pacific market (mainly Japan), and to "catalyse the development of derivative industries in Mexico and ensure additional domestic consumption of methanol" according to the CEO of Transition Industries. Japan's MGC has contracted to take 50% of the plant offtake.

"The contract signing with CFEnergía represents the final outstanding commercial milestone, enabling the start of the construction phase, and confirming the timeline for Mexinol's operational readiness in late 2029 to early 2030," Transition Industries said in a statement. "With the gas supply contract secured, Mexinol enters the execution phase, solidifying its position as a key project in the transition to net-zero emissions and establishing itself as a strategic industrial platform for innovation in Mexico."

The current timescale for the plant envisages completion and operation by 2030. ■

FINLAND

Tax credit for green methanol project

ETFuels has been awarded €118.6m ($139.8m) in tax credits over 19 years under Business Finland's Clean Transition program to develop a green hydrogen-based methanol project in Lapland. The credits will go towards the company's Ranua facility, which is designed to produce 110,000 t/a of green methanol. According to ETFuels, the project, which is currently in early engineering stages, will use 300MW of renewable wind energy alongside battery storage facilities. The Ranua project is being developed in collaboration with Finnish energy firm Neova.

INDIA

ACME looking at green methanol

Indian renewables developer ACME says that it will partner with the Industrial Promotion and Investment Corporation of Odisha Ltd (IPICOL) to set up a green methanol plant in Kendrapada, Odisha state. He

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proposal is for a 200,000 t/a plant, with ACME taking a stake via its ACME Akaysha Energy subsidiary, part of its green hydrogen business. ACME says that the project forms part of its plans to develop multiple low carbon hydrogen plants and downstream chemical production. The company is planning a large green ammonia facility in Gopalpur through a joint venture with Japan-based IHI Corporation. It is also developing a 2,200 t/d green ammonia project in Paradip with cooperation from the Solar Energy Corporation of India. The output of the facilities will be used both for domestic applications and for export.

"Odisha, with a strong green energy ecosystem and deep industrial and port infrastructure, is fast emerging as an important centre for manufacturing green molecules, including green methanol," said Anil Kumar Taparia, chief operating officer of ACME Green Hydrogen.

SPAIN

Green hydrogen for Bilbao refinery

Repsol says that it is planning a 100MW green hydrogen plant to supply its Petronor refinery near Bilbao. From 2029, the plant will supply the refinery with 15,000 t/a of green hydrogen. Repsol says that the installation could prevent up to 167,000 tonnes of carbon dioxide emissions per year. The €292m ($346m) project has already secured €160m ($190m) in NextGenerationEU funds from the Spanish Recovery, Transformation, and Resilience Plan, after being recognised as a Project of Common European Interest by the European Commission.

NETHERLANDS

Equinor backs out of blue hydrogen project

Norwegian oil and gas major Equinor says that it is no longer pursuing its planned H2M Eemshaven blue hydrogen project in the Netherlands, citing policy uncertainty and insufficient funding. The project was a joint venture between Equinor and Linde, and would have produced hydrogen from natural gas piped from Norway, with a capacity of 210,000 t/a of hydrogen beginning in 2029. Around 95% of the carbon dioxide produced would then be piped back to offshore storage sites near the Norwegian coast. Equinor had received a grant of €162 million for the project from the European Innovation Fund last summer. However, uncertainties over whether the project would receive carbon credits under the EU's RED III directive, and a lack of local hydrogen infrastructure at Eemshaven meant that the project was unable to secure offtake agreements.

NEW ZEALAND

Kapuni project reaches financial close in Taranaki

Ballance Agri-Nutrients and its partners say that the Kapuni Project has reached financial closure, unlocking an integrated renewable electricity and green hydrogen development in South Taranaki, New Zealand. The consortium includes Ballance, Hiringa Energy, Todd, Parininihi ki Waitōtara (PKW) and the New Zealand Ministry of Business, Innovation and Employment (MBIE).

The project integrates four 6.4 MW wind turbines (25.6 MW installed) with a 5 MW hydrogen electrolyser linked to Ballance's Kapuni plant. The partners say that the wind farm is expected to generate around 100 GWh per year, with power used to supply Ballance's site operations, produce hydrogen for transport via Hiringa's refuelling operations, and export electricity to the national grid to support Hiringa and Ballance's operations and supply the Todd network. They also say green hydrogen can augment some of the natural gas feedstock at the Kapuni plant. Hiringa is due to start construction in early March 2026, beginning with civil enabling works, with first renewable electricity and green hydrogen production expected in 2027. The project is backed by non-recourse project financing from Westpac.

The move follows Ballance's wider repositioning over the past year, after the co-operative entered consultation in 2025 on a proposal to cease sulphuric acid and single superphosphate (SSP) manufacturing at its Mount Maunganui site, while retaining nutrient storage and distribution and continuing urea production at Kapuni.

DENMARK

Worley to build hydrogen pipeline

Worley has been awarded a five-year engineering, procurement and construction management (EPCM) services contract by Energinet Brint A/S to support Phase 1 of the Danish Hydrogen Backbone pipeline. Danish Hydrogen Backbone 1 will establish a national hydrogen transmission network for Denmark, linking large scale green hydrogen production from wind and solar to Germany and wider European markets, supporting Europe's energy supply.

Under the contract, Worley will provide EPCM services for approximately 41 km of new hydrogen pipeline and the conversion of approximately 89 km of existing natural gas pipeline, together with adjacent infrastructure supporting Denmark's future hydrogen network. Commissioning of the Danish Hydrogen Backbone 1 is currently expected by late 2030.

INDIA

BHEL to supply syngas purification plant

Bharat Heavy Electricals Ltd says that it has secured a $305 million contract from Bharat Coal Gasification and Chemicals Ltd (BCGCL) for a syngas purification plant at Lakhanpur, Odisha. The lump sum turnkey package includes design, engineering, equipment supply, civil works, commissioning and 60-month operation and maintenance services. The project, part of BCGCL's planned 2,000 t/d ammonium nitrate facility, has a 42-month execution timeline. BCGCL is a joint venture between Coal India Ltd, with a 51% stake and BHEL with a 49% shareholding.

BHEL says that the contract reinforces its position in the coal gasification and chemical processing sector, and contributes to India's domestic manufacturing capabilities in chemical production. "The Lakhanpur facility represents a significant investment in Odisha's industrial infrastructure, supporting regional economic development and employment generation", the company said in a press release.

GIZ and thyssenkrupp to support green hydrogen and power-to-X developments in India

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and thyssenkrupp nucera have entered into a new agreement to accelerate the development of green hydrogen and Power-to-X markets in India. Announced at India Energy Week in Goa, the partnership brings together international development cooperation and private-sector technological expertise to unlock opportunities along the country's hydrogen value chain.

The partnership falls under Germany's International Hydrogen Ramp-Up (H2Uppp) programme,w ith support from the German Federal Ministry for Economic Affairs and Energy (BMWE), via GIZ, a state company specialising in international cooperation for sustainable development, and using technology developed by thyssenkrupp nucera, a global leader in electrolysis technology and hydrogen markets. ■

People

Grupa Azoty has dismissed its CEO **Andrzej Skolmowski**. He had been in the job less than one year, having originally been appointed in June 2025. Skolmowski was removed from his role as president of the company's management board on 12 February, along with vice presidents Paweł Bielski and Andrzej Dawidowski. Grupa Azoty's vice-chair, **Aleksandra Machowicz-Jaworska**, will now act as temporary president of the management board for up to three months until a replacement CEO is found.

The senior level dismissals come after Grupa Azoty agreed extensions to its financing deals with 12 banks and the European Investment Bank in late January, keeping funding lines in place until 31 March 2026. The extensions were conditional on the chemicals and fertilizer group meeting certain requirements by 27 February 2026, as it works on a longer-term restructuring plan.

Dangote Industries has appointed the CEO of MTN Group, **Ralph Mupita**, to the board of its fertiliser business as it prepares to expand and list the operation in the Nigerian Stock Exchange. The company says that it is aiming for an initial public offering (IPO) this year, which aligns with Mupita's experience in the listing of MTN's unit in Nigeria in 2019 – South Africa based MTN is Africa's largest mobile telephone network provider. Dangote Fertiliser produces about 3 million t/a of granulated urea, and plans to expand its complex in Lagos and build a facility in Ethiopia this year to become the largest maker globally by 2028.

Chris Reynolds, Nutrien.

PHOTO: NUTRIEN

Nutrien has appointed **Chris Reynolds** as Executive Vice President, Global Sales, to unify leadership across its wholesale and retail sales organisations. The company says that the appointment follows a planned leadership transition as **Jeff Tarsi**, who led Nutrien's global retail business through a period of significant growth and transformation, steps into an advisory role.

"Chris' experience, vision, and leadership will guide our global sales organization through its next phase of growth," said Ken Seitz, President and Chief Executive Officer of Nutrien Ltd. "His track record of delivering results across our international operations makes him the right leader to deliver greater value for our customers worldwide, strengthen our teams, capture efficiency, and enhance our execution."

Reynolds has over 25 years of experience in the global fertilizer industry, including 22 years at Nutrien, where he has held senior leadership roles across domestic and international sales, supply chain, potash operations, and commercial functions. Most recently, he served as Executive Vice President and Chief Commercial Officer for the company. He has also held leadership roles with the International Fertilizer Association (IFA) and The Fertilizer Institute (TFI) and currently serves on the Board of Canpotex Limited.

Seitz also had warm words for Jeff Tarsi; "I want to sincerely thank Jeff for his leadership and the lasting impact he has had on Nutrien over his tenure," said Seitz. "By keeping safety and customers at the center of everything we do, Jeff has played a central role in building and scaling our global retail platform, positioning us as a leading provider of crop inputs and services. We're grateful he will continue to support Nutrien in an advisory capacity, and we will continue to benefit from his experience and counsel."

"It has been a privilege to serve Nutrien and work alongside such a talented team," said Tarsi. "I'm confident in Chris' leadership and the direction of the business, and I look forward to supporting the team in an advisory role as Nutrien continues to deliver for its customers." ■

Calendar 2026

MARCH

10-11

Clean Ammonia Storage Conference, ROTTERDAM, Netherlands
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25-26

Gasification 2026, BERLIN, Germany
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APRIL

21-23

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IMPCA European Methanol Mini-Conference, VIENNA, Austria
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Email: meetings@impca.eu
Web: https://impca.eu/events/36th-impca-european-mini-conference/

AUGUST

30 – SEPTEMBER 3

70th Annual Safety in Ammonia Plants and Related Facilities Symposium, MONTREAL, Canada
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Email: micma@aiche.org
Tel: +1 203 702 7660
Web: www.aiche.org/conferences/annual-safety-ammonia-plants-and-related-facilities-symposium/2026

SEPTEMBER

6-11

Ammonium nitrate/nitric acid conference, BOLOGNA, Italy
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Plant Manager+

Incident No. 8 RT 125 - Pressure instrument related failure at a urea plant

Diaphragm seals are applied when pressure or level transmitters need to be protected against harsh conditions like the corrosive ammonium carbamate in urea plants. The process pressure is transmitted via the flexible diaphragm and transmission fluid to the measuring instrument as shown in Fig. 1 below.

In urea plants it is best practice to apply extended seals for the pressure and level diaphragm instruments. This reduces the risks of condensation and crystallisation in the dead end part of the nozzle. ■

The incident

The DCS operator notices that a pressure transmitter in the high pressure urea synthesis section has failed. Two operators go to the pressure transmitter and see leaking fluid (ammonium carbamate) coming out of the insulation. In order to further assess the size of the leak, they remove the insulation. The transmission fluid capillary breaks off. Hot fluid releases and causes injuries to two operators…

The causes

The material of construction of the diaphragm was 316L stainless steel. This material experiences relatively high corrosion rates and is sensitive to, for example, condensation corrosion. This caused a leak in the diaphragm on the extended body. The leak source was the capillary, which was corroded due to the corrosion of the diaphragm, creating an open connection with the hot process media under high pressure. The corrosion of the capillary is a result of the corrosive ammonium carbamate.

The consequences

Health and safety: Two operators were injured, a QHSE investigation was performed and a QHSE report prepared with lessons learned and knowledge sharing.

Operational and technical costs: There was an unplanned shutdown for seven days: three days to do the maintenance and four days to start up the urea plant once again.

Production loss: Production loss 14,000 t of urea corresponding to some EUR 5 million loss of revenue.

Other: The incident caused organisational stress, because of the urgency to get the plant back on-line.

Lessons learned

To minimise the risk of a failed diaphragm it is recommended to upgrade to a higher grade material. Also, it is recommended to improve the maintenance instructions to operators to insure that they are aware of the risk of corrosion of capillaries.

Badotherm has developed a full-body EXT-FSO diaphragm-seal system made from Zirconium 702; it has been in operation for over ten years.

Since its installation in 2014, the zirconium diaphragm seal has consistently operated without failures or unplanned maintenance. An in-service calibration conducted in 2017 verified that neither degradation nor measurement drift had occurred during operation. By 2026, the seal will have achieved over 12 years of uninterrupted service, establishing a new standard for on-stream performance in diaphragm seal applications within urea synthesis processes

Zirconium material became the internal standard seal material at this site, after the accident: More than 25 units of zirconium seals. Maintenance procedures were reviewed and improved.

Badotherm Is a leading manufacturer of with almost 70 years of experience in the production of highly specialised mechanical pressure measurement instruments. They specialise in the design, manufacturing and assembly of diaphragm seal to pressure transmitters. ■

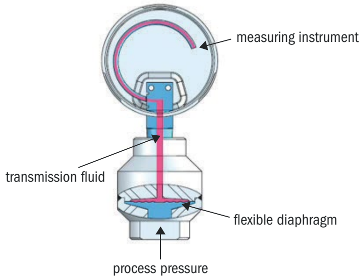

Fig. 1: Diaphragm pressure gauge

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Where will new urea capacity be built?

PHOTO: PERDAMAN

Changing markets for feedstock, shifts in demand, carbon pricing and geopolitics all help dictate the location of new urea capacity.

Perdaman's new Project Ceres urea plant under construction in Australia

Urea remains the nitrogen fertilizer of choice for much of the world, and the global traded market for urea stood at 57 million t/a in 2025, almost 30% of all production. Total production capacity worldwide was an estimated 240 million t/a that year, with 85% of this operational. New plant construction continues to stand at several million tonnes per year, with 40 million t/a of net capacity due to be added between 2025-2030.

Urea demand

Urea demand falls broadly into two categories; agricultural demand as a fertilizer, and chemical or so-called 'technical' uses. Technical urea covers demand for urea-formaldehyde resins and melamine for construction, cyanuric acid, diesel exhaust fluid to break down nitrogen oxides in exhausts, an animal feed additive, and a variety of other smaller uses. These represent about 20% of demand, concentrated mainly in China and east Asia, with other notable demand centres in industrialised regions such as Europe and North America.

Agricultural uses dominate urea demand, with the major consuming countries being China, India, Brazil and the United States, in that order – these four countries collectively represent 62% of all agricultural demand. Other major consumers include Pakistan, Iran, Turkey, Indonesia, Argentina, Canada, Nigeria, Bangladesh, Thailand and Vietnam. Urea has become the major nitrogen fertilizer of choice for most of the world because of its high nitrogen content (46%), making it the most economical way to transport nitrogen. Its use is less prevalent in more northerly latitudes, where shorter growing seasons favour the use of ammonium nitrate or AN variants such as CAN or UAN, as the nitrogen in these fertilizers is more readily available to plants as they grow, not needing to be first hydrolysed to nitrate in the same way as urea.

As Table 1 shows, the combination of technical and agricultural demand makes China the largest overall consumer by some way, dominating the total demand figure for East Asia (China represents 98% of this total), while South Asia is the other demand hotspot, 80% of this accounted for by India. Brazil, the US and the combination of Indonesia, Vietnam and Thailand make South America, North America and Southeast Asia significant secondary markets.

Table 1: **Urea supply and demand, 2025, million t/a**

Region	Production	Demand – ag	Demand – techn	Total demand	Surplus
Europe	6.2	7.4	5.5	12.9	-6.7
Russia/C. Asia	14.7	2.7	1.2	3.9	+10.8
Africa	13.7	6.6	0.1	6.7	+7.0
North America	9.6	11.0	3.7	14.7	-5.1
Central/S America	2.9	14.8	0.8	15.6	-12.7
Middle East	25.1	6.0	1.3	7.3	+17.8
South Asia	37.4	47.5	0.5	48.0	-10.6
East Asia	72.4	45.7	22.5	68.2	+4.2
Southeast Asia	13.5	12.6	1.3	13.9	-0.4
Oceania	0.2	3.9	0.3	4.2	-4.0
Total	**195.7**	**158.1**	**37.0**	**195.1**	

Source: Various

Production

Urea production is via the conversion of two ammonia molecules into an ammonium carbamate molecule with the addition of carbon dioxide as a bridge, and its subsequent dehydration to urea. While there is some standalone urea capacity, most urea plants are therefore co-located with ammonia plants. It generally makes economic sense to site urea plants where ammonia production is cheapest and then transport urea to market, as solid urea is much more easily and safely and hence cheaply transported than liquid ammonia. This is why 30% of urea is traded across international boundaries but less than 10% of ammonia.

Early ammonia production tended to come from gasification of coal, and hence was clustered in major industrial regions, especially Europe and the United States. However, beginning around the 1960s, natural gas-based ammonia production came to predominate, as it did not need the solid handling and gasification section, greatly reducing capital costs. In the absence of a global natural gas market, natural gas was often 'stranded' in remote locations away from demand centres, and ammonia/urea production became a viable way of monetising this gas. In this way, new clusters of urea production grew up in, e.g. the Middle East, Southeast Asia and central Asia/Russia, aimed at export to major consuming regions.

However, the switch towards natural gas as the major source of power generation in the late 20th century and the gradual evolution of first regional gas markets, via pipeline, and eventually global gas markets, via shipping of liquefied natural gas (LNG) altered the economics of gas-based ammonia/urea production. LNG plants were often more profitable than urea production, and gas prices began to rise as demand increased. Freight rates became important in the profitability of remote production, and this led to some switching away from gas-based production and back towards coal gasification. Meanwhile, some major consumers with little or no domestic gas reserves sought greater control over availability of urea, rather than depending on international markets, and developed almost exclusively coal-based ammonia-urea production, as was seen predominantly in China, but also Vietnam.

> **"For some years now, China has sought to manage domestic demand and production via the imposition of export controls..."**

The production situation seen in Table 1 is the result of all of these streams of urea market development. Production in China/East Asia is roughly balanced, as it has been government policy to develop sufficient domestic capacity to feed domestic demand. The Middle East and Russia/Central Asia remain major exporting regions due to their large reserves of natural gas (the other is Central Asia), and Brazil and India, and to a lesser extent the US, remain major importing regions. Notable is the build up of export capacity in Africa, one of the few regions of the world that still has large, untapped and to a significant extent still 'stranded' gas reserves. Nigeria and Egypt, and to a lesser extent Algeria have become the dominant producers and exporters here. These three represent almost all African production.

Policy and regulatory drivers

While the availability of low cost feedstock has been a major factor in developing ammonia-urea capacity over the past few decades, government policy decisions have also loomed large and distorted the market to a greater or lesser degree. The most major impacts have come from China, India and Europe. In the wake of the terrible famines of 1959-61, China set itself on a policy course of total self-sufficiency in food production, and self-sufficiency in fertilizer production was seen as the best guarantor of this. The Chinese urea industry kept up with rapidly rising demand, and was even allowed to outpace domestic demand for the first two decades of the 21st century, turning the country into a major exporter, before policy changes to pollution control and a clampdown on over-use of nitrate and other fertilizers led to a rationalisation of the industry in the 2010s. For some years now, China has sought to manage domestic demand and production via the imposition of

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export controls which effectively shut down exports on a seasonal basis. China continues to build new urea capacity, and around 26 million t/a of new urea capacity has or is expected to be commissioned between 2025 and 2030.

India also sought self-sufficiency in urea production, but poor quality Indian coal meant that the coal-gasification based capacity that China developed did not flourish in India, where the only two coal-based plants suffered many technical issues and low operating rates, and were eventually converted to gas-based production. India's relatively low domestic gas reserves however had to compete with power demand, and by the 1990s, there was effectively a moratorium on new urea plant construction, leading to a widening demand gap which was filled by imports. The Modi government has attempted to close this gap by importing large quantities of LNG to feed new domestic urea production, and, somewhat less successfully, to use coalbed methane and coal gasification to supplement this. But while India continues to build new urea capacity, it has not kept pace with rising demand, and the country remains a major importer.

Europe has set strict environmental standards for its domestic industries, which has placed a relatively heavy burden on fertilizer production. Gas and electricity prices have been high, and in the wake of the Russian invasion of Ukraine gas prices have made domestic ammonia production prohibitively expensive on occasion. The impact of the gas restrictions from Russia can be seen in the very low operating rate of urea production in eastern Europe (Table 2). The recent inception of the Carbon Border Adjustment Mechanism (CBAM), a tax on the carbon content of fertilizers imported from overseas, has helped redress the balance to an extent, but may open Europe up to a wave of imported 'blue' ammonia from the United States over the next few years, and Table 2 also shows that western European production remains disadvantaged.

Table 2: **Urea operating rates, 2025, percent**

Region	Operating rate
West Europe	69%
East Europe	25%
Russia/Central Asia	86%
Africa	74%
North America	74%
Central/South America	33%
Middle East	90%
South Asia	93%
East Asia	96%
Southeast Asia	82%
Oceania	88%

Source: Various

The sanctions imposed on Russia, meanwhile, have crimped exports to Europe, though Russian urea has found other outlets. More devastating has been a recent wave of attacks by Ukraine on Russian production facilities which have reduced output.

Table 2 also shows very low operating rates in central and southern America. Most Brazilian capacity has closed for a variety of reasons. Some of this has been economic, or to do with lack of feedstock availability, but a series of scandals that forced a restructuring of state oil and gas giant Petrobras have also played their part. While Brazil remains a large urea importer, it has actually turned increasingly to cheap Chinese ammonium sulphate in the past couple of years to make up nitrogen deficits in a more affordable way.

New capacity

Table 3 lists new urea capacity under construction or under development around the world. These are projects judged to be firm or probable over that time scale, but omit a number of more speculative projects or those which might not be completed by 2030. However, the conclusions appear to be clear – new urea capacity continues to centre in China, where rising domestic availability is likely to lead to increased exports over the period. Chinese coal costs remain relatively manageable for producers as power generation continues to switch towards renewables and away from coal-fired power, leaving more domestic coal available for chemical production. Outside of China, the main additions are likely to come from relatively 'stranded' gas in Africa, Central Asia and Australia, together with some additional coal-based capacity in India. ■

Table 3: **New urea capacity, 2026-2030, million t/a**

Company	Location	Capacity	Onstream date
Africa			
Amufert	Angola	1.3	2030
El Nasr	Ain Sokhna, Egypt	0.4	2028
Indorama	Eleme, Nigeria	1.3	2026
Dangote	Lekki, Nigeria	Up to 5.6	2029
North America			
Petroquimico	Topolobampo, Mexico	0.7	2026
East Asia			
Various	China	15.8	2026-2030
Middle East			
Qafco	Mesaieed, Qatar	1.6	2030
Hengam Petrochemical	Hengam, Iran	1.1	2027
South/Southeast Asia			
Pupuk Pusri	Indonesia	+0.2	2028
Talcher Fertilizer	Talcher, India	1.3	2028
Central Asia/CIS			
KazAzot	Aktau, Kazakhstan	0.8	2029
Ferkensco	Yangier, Uzbekistan	0.6	2028
Acron	Novgorod, Russia	0.4	2026
EuroChem	Kingisepp, Russia	1.3	2027
Oceania			
Perdaman	Karratha, Australia	2.0	2027

Source: Various

Chemical demand for methanol

Methanol's phenomenal growth in the early years of the century was based on its uptake into fuel uses and its ability to bridge coal reserves with plastics production in China. However, with these sectors maturing, traditional chemical end uses are becoming the main growth sector once again.

PHOTO: CIMC

The CIMC biomethanol plant at Zhanjiang, China.

The world market for methanol was around 115 million t/a in 2025, or just over half the size of the market for ammonia, making it the second most important syngas derivative. Demand is split into three major categories. The fist is traditional chemical uses, mostly formaldehyde and acetic acid, as well as methyl methacrylate (MMA), methyl chlorides and similar solvents – all told, about 40% of all methanol demand is accounted for by these uses. The second is fuel and energy uses, either as a blendstock into gasoline, as a marine fuel, or via derivatives such as methyl t-butyl ether (MTBE) or TAME as oxygenate additives into gasoline, as well as dimethyl ether for LPG blending, and methanol is also used in esterification of organic oils to form biodiesel. These collectively represent around 30% of all methanol demand. The final 30% is accounted for by conversion into olefins – propylene or ethylene, and via them into longer chain molecules as part of the plastics industry.

Since the first decade or so of the 21st century, the methanol market has effectively devolved into two separate markets; China and the rest of the world. China has been where almost all incremental demand growth has occurred, as methanol based on coal gasification provided China with a way of turning its extensive coal reserves into badly needed chemicals, fuels and plastics, reducing the need for imports from overseas. In this way, China has come to represent more than half of all methanol demand, and it accounts for all methanol to olefins (MTO) demand and most fuel use demand. China actually has about 60% of global methanol capacity, though operating rates can vary.

MTO demand

As Table 1 shows, Chinese MTO demand is around 30-33 million t/a. However, the operating rate of MTO plants is very much determined by the economics of production as compared to the rival naphtha cracking route, and this in turn depends on the relative costs of coal and crude oil. The balance between naphtha and coal-based olefins production can be a fine one. In general over the past few years, coal-based methanol costs have run slightly above naphtha route economics, but Chinse coal prices have come down from a high point around 2022-23, and while oil prices had also been sluggish due to oversupply in the global oil market, the current tensions in the Middle East have seen prices rise again to favour methanol routes to olefins. There is still new MTO plant construction in China - Guangxi Huayi Energy Chemical is building a 1 million t/a plant – but the era of very rapid production growth seen in the 2010s appears to be decisively over.

Outside of China, there has been occasional interest in MTO production, but no major projects have reached completion as yet. The most advanced is Uzbekistan's Gas Chemical Complex, which aims to produce 1.1 million t/a of polymers. A 200,000 t/a MTO plant was also recently announced for Rotterdam by Blue Circle Olefins, though the project remains at an early stage.

Fuels demand

It is a similar story for fuel uses for methanol. China began blending methanol into gasoline in some of the major methanol producing regions in the 1990s, and also rapidly expanded DME capacity to blend into LPG. Methanol penetration of the gasoline market reached around 10%, but this is about as much as can be blended before specialised engines are required, and hence the fuel blending market has become essentially saturated and there has been no growth over the past few years. Israel and some other countries have also experimented with methanol fuel blending, but nowhere has come close to the level of demand achieved by China.

As far as energy uses by methanol derivatives go, biodiesel became popular in Europe, but EU regulations on where the organic oil was being sourced from have served to slow the development of that market, and biofuel uptake in countries such as the US and Brazil have focused on ethanol from plant sources instead. Even so, biodiesel demand is estimated to have risen from 45 billion litres in 2020 to 50 billion litres in 2025, according to the IEA.

Use of esters as fuel oxygenates to burn more cleanly such as MTBE and FAME continue to increase, particularly in China and India.

The largest potential growth area for methanol as a fuel is as an alternative to

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Table 1: **Methanol demand by sector, 2010-2024, million t/a**

	2010	2015	2020	2024
Chemicals				
Formaldehyde	14.3	21.7	23.8	26.1
Acetic acid	5.1	6.1	7.2	8.2
Methylamine	1.7	1.6	1.6	1.8
MMA	1.0	1.5	1.8	1.8
DMT	0.6	0.5	0.5	0.4
Solvents	2.2	2.6	2.8	3.2
Other	5.2	3.7	3.9	4.0
Total chemical	30.1 (65%)	37.7 (48%)	41.6 (41%)	45.5 (41%)
Olefins				
MTO/MTP	1.1 (2%)	12.9 (17%)	31.2 (31%)	33.7 (30%)
Fuels				
MTBE/TAME	5.6	10.1	10.4	12.7
Dimethyl ether	2.9	3.9	2.9	3.3
Biodiesel	n.a.	1.8	3.0	3.9
Direct fuel use	6.9	11.9	13.1	13.0
Total fuels	15.4 (33%)	27.7 (35%)	29.4 (29%)	32.9 (29%)
Total	46.5	78.3	102.2	112.1

Source: Various

fuel oil in the marine sector. However, this is predicated on the methanol coming from low carbon sources, as discussed later.

Chemical demand

Table 1 shows that of around 10 million t/a of incremental methanol demand increase form 2020-2024, about 2.5 million t/a came from MTO, 3.5 million t/a from fuel uses, and 4 million t/a from chemicals uses, mostly formaldehyde and acetic acid. These have traditionally been the major uses for methanol, with formaldehyde going into resin production for, e.g. fibreboard manufacture, and acetic acid being used to make vinyl acetate monomer (VAM) as an intermediate for coatings, adhesives, and construction uses. Methyl methacrylate (MMA) is mainly in the construction (building panels), automotive (lightweighting), and electronics (display panels) sectors. All of these uses are thus effectively contingent on new construction, particularly of housing and vehicles, and so demand growth tends to be closely tied to GDP growth. This led to chemicals uses lagging the rapid growth in fuels and MTO use for methanol during the 2000s-2010s, but as those uses mature, so chemical demand is beginning to take the lead again.

Methanol as a bunker fuel

The IMO has set a target of the shipping sector reaching 'net zero' carbon emissions by 2050, and a 20-30% reduction in carbon emissions in 2030 compared to a 2008 baseline. Shipping companies have been racing to find alternatives to traditional heavy fuel oil as a marine fuel as a result. Low carbon methanol is one of the leading candidates, alongside LNG, low carbon ammonia, biodiesel, hydrogen, and electricity as power sources. LNG has been the preferred candidate in the short term, and now powers around 7% of the world's merchant fleet. However, while considerably lower carbon than fuel oil, it is nevertheless a fossil fuel, and production of biomethane or low carbon synthetic methane tend to be smaller scale and expensive. Ammonia is developing rapidly as a proof of concept, but methanol engines for ships are already a proven technology, and the main barrier to methanol's wider adoption as a marine fuel is production of sufficient low carbon methanol. There are 60 methanol powered (or potentially methanol powered – many are 'dual fuel' engined vessels) ships in service and another 300 under construction.

Blue and green methanol

Supply is the main issue now for methanol as a shipping fuel. Most methanol (ca 60%) is produced using natural gas, and around 40%, mainly in China, is based on coal as a feedstock. Low carbon methanol only represents about 1% of production at present. While there has been considerable interest in low carbon methanol production, many projects have been only at pilot scale, and final investment decisions hard to come by. In August 2024 Orsted scrapped development of its 55,000 t/a FlagshipONE green methanol project in Sweden, citing slower than expected development of the market for low carbon methanol and lack of an offtake agreement. OCI sold its blue ammonia development to Woodside and two idled biomethanol plants to Methanex.

The Methanol Institute currently calculates that there is 56 million t/a of low carbon methanol capacity under development, split between biomethanol (23 million t/a) – mostly in China and Europe – green or 'e-methanol' (22 million t/a), mostly in Europe, and blue methanol projects (11 million t/a), mostly in North America. Chinese biomethanol capacity seems to have the most projects actually under construction, with CIMC Green Energy Low Carbon Technology Co completing its 50,000 t/a plant at Zhanjiang in Guangdong in December 2025. Goldwind is building two 250,000 t/a plants, both using biomass gasification, like the CIMC plant. All of the low carbon methanol is being targeted at marine fuel use.

In the US, Lake Charles Methanol II, with 1.2 million t/a of capacity, is at the front end engineering design phase, while further southwest, Mexico's Pacifico Mexinol is still on course to become the largest blue methanol plant in production, with the aim of generating 350,000 t/a of green methanol and 1.8 million t/a of blue methanol from 2028, with construction reported to be due to start in the next few months.

While some of the optimism that was attached to low carbon methanol as a bunker fuel has dissipated, it does appear that the first concrete steps are now being taken, and while chemical uses may dominate growth in the methanol market in the next couple of years, by the end of the century fuel uses may be swinging back towards prominence again. ■

Nitrogen+Syngas Expoconference 2026

A review of papers presented at CRU's Nitrogen+Syngas 2026 Expoconference, held in Barcelona from February 10th-12th 2026.

CRU's Nitrogen+Syngas Expoconference returned to a slightly grey Barcelona this year, with an expanded programme including more than 70 papers in up to three parallel streams, as well as technical showcases and, on the first day, operator training workshops on urea plant upsets, plant revamping and decarbonisation opportunities, and safety.

The conference began with a tribute to Dr Umberto Zardi by Norbert Ringer of Clariant and Lisa Connock, Managing Editor of Nitrogen+Syngas magazine. Dr Zardi, whose obituary we carried in issue 398, was an inspirational figure in the industry, whose stewardship of Casale saw it return to its position as one of the major plant licensors, expanding from urea and ammonia to methanol and eventually nitric acid and plant construction. In her introduction, Lisa also discussed the challenges that the industry faces, balancing new low carbon technologies against finance and policy frameworks.

PHOTO: CRU

CRU's Alex Tuckett delivers the economic overview.

Market outlook

The nitrogen markets paper was presented by Charlie Stephen of CRU. He noted that high nitrogen process following the Russian invasion of Ukraine and European gas price crisis had given way to lower prices, but urea prices had been elevated in the past year or so dur to strong demand. Fertilizer affordability has been impacted by these higher prices and lower crop prices.

On the consuming side, China remains both the largest producer and consumer of urea. Over the past few years it had exported 4-5 million t/a, but this dropped in 2024 to almost nothing due to export restrictions designed to keep domestic prices lower. Exports had been opened back up in 2025 to the tune of 5.5 million t/a without unduly affecting domestic Chinese prices, so the expectation is that this year exports will be allowed again, and may reach 6 million t/a. Brazil also continues to show strong demand for urea, with imports reaching 8 million t/a, but it is also now importing huge quantities of cheap Chinese ammonium sulphate, which is competing with urea on a volume basis and to an extent placing a cap on Brazilian urea imports. India, historically the largest importer of urea, added 5.5 million t/a of domestic urea capacity from 2021-23, but demand has continue to grow at the same time, and still reached 9.4 million t/a in 2025.

Meanwhile, on the supply side, the US has a lot of new merchant ammonia capacity under development, and is likely to become a net exporter in the next couple of years. The flip side has been lower exports from Trinidad over the past few years due to restrictions on gas supply. Capital costs for projects have escalated in the US, although some of this may not be as serious as reported.

Europe has instituted its Carbon Border Adjustment Mechanism (CBAM). Urea has been relatively less affected, with imports from Algeria, Russia and Egypt not being unduly penalised, but costs will rise going forward. Meanwhile nitrates may bear the brunt of CBAM costs – European producers have by and large invested in N_2O reduction technology, but exporters to the EU, including Trinidad, the US and Russia, have not. CBAM does incentivise low carbon ammonia production outside the EU, especially for blue ammonia, but anomalously high charges on the US may impact trade flows in the short term.

A broader look at the regulatory outlook and its impact was presented by Alex Tuckett, CRU's head of economics. Tariffs seem to have stabilised, albeit at much higher levels, he said, but major uncertainties remain, especially over the political situation in Iran. The continuing intensification of the Russian-Ukrainian war and seizures of so-called 'shadow

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fleet' tankers pose risks for the oil market, and US foreign policy remains a key source of uncertainties. In the EU, CBAM has its own uncertainties, particularly over calculation of carbon intensity, but overall it is expected that CBAM will push costs up over time. The EU still faces difficult choices as it tries to balance energy security, decarbonisation and growth and maintenance of its industrial base. At the same time, a US push for deregulation will increase the gap in regulatory costs between the US and Europe.

Low carbon project development

Following the coffee break, there was an industry keynote panel discussion on major trends, which naturally converged around low carbon project development. Led by Charlie Stephen of CRU, the panel included Ignacio Fernandez Santiago of FertigHy, Torsten Brezin of the GIZ Nitric Action Climate Action Group (NACAG), Narayanan Valayaputtur of the Egyptian Basic Industries Corporation, Syed Aamir Abbas of Fauji Fertilizers, and Achim Schaadt of the Frauenhofer Institute for Solar Energy Systems.

FertigHy is developing a low carbon 500,000 t/a CAN plant in northern France using 170,000 t/a of green ammonia, with investment from the food and beverage industry, including Heineken, who are keen to reduce their Scope 3 emissions by using low carbon fertilizer to grow the barley they use for making beer. NACAG, meanwhile, has assisted with the reduction of 2.6 million t/a of CO_2 equivalent emissions via N_2O abatement technology, including 1.0 million t/a in Uzbekistan, and advocated a public-private partnership approach to emissions reduction. Achim Schaadt also pointed out that infrastructure issues remain for lower carbon production, including development of CO_2 pipelines to carry sequestered carbon dioxide.

Narayanan Valayaputtur noted that CBAM has changed EBIC's perspective, and turned CO_2 reduction into a key performance indicator. However, he advocated for an efficiency approach to begin with, arguing that if the whole industry increased its efficiency of ammonia production by 10%, this would be a larger carbon saving than all green and blue ammonia capacity that has reached a final investment decision.

PHOTO: CRU

A busy refreshment break at the exhibition.

Low carbon capacity

Paul Butterworth of CRU argued that the EU's Green Hydrogen Programme had been based on erroneous pricing for low carbon hydrogen of less than \$1/kg, whereas in fact a lower bound of around \$5/kg is more likely. The lowest possible cost for solar hydrogen varies from around \$6/kg closer to the equator in the Middle East or North Africa to \$12/kg in Spain and higher still in northern Europe. However, coupling it with wind tends to smooth the curve and bring the lowest cost to around \$5/kg in the Middle East and only \$6.2/kg for Spain and \$7.6/kg in Germany. Given that the estimated cost of converting low carbon hydrogen to ammonia, shipping it to Europe and then cracking it back to hydrogen could cost around \$3.1/kg, Paul saw little future for ammonia cracking technology, but producing low cost ammonia or direct reduction iron (DRI) outside Europe using green hydrogen and then shipping the products to Europe for use as ammonia or DRI could bring the encapsulated hydrogen cost down to \$0.7-1.1/kg and seemed the most sensible way of importing low carbon hydrogen.

Rebecca Ruan of CRU added that of a total capacity of 274 million t/a of announcements of green and blue hydrogen capacity, only 6% had so far made it to a final investment decision (FID), with blue ammonia projects far more likely to make it than green, even though more green projects had been announced. Much of the blue ammonia capacity moving forward is in North America, while China is the location for much of the green capacity. As for the emergence of demand, marine fuel seemed the most promising demand pathway, particularly in Europe, with increasing penalties on carbin equivalent cost, although at a global level the IMO has delayed implementation of its net zero framework in the short term, pushing shipping towards LNG for the time being, though ammonia remains a strong contender from the 2030s.

Uzbekistan

Bakhtiyor Sultankhodjaev's history of the nitrogen industry of Uzbekistan gave an overview of the development of capacity in that country. This began in the 1940s, with what would now be described as 'green' ammonia produced via water electrolysis using hydroelectric power at Chirchik – the first such site in the Soviet Union. However, electricity demand for other uses led to the plant being used mainly for balancing the grid, with little to no production during winter. By the 1950s the plant had switched to a coal gasification feed and then, as Uzbekistan's gas industry developed during the 1960s, it switched to a gas-based feed at the same time that new plants were developed at Navoi and Fergana. In the 1980s, new plants were built at all three sites based on modified Kellogg technology. Chirchik continued to have a hybrid electrolysis/gas fed until the 1990s. More recently, a 3,000 t/a green ammonia pilot plant has been developed at Chirchik in partnership with Saudi company ACWA Power using local wind power. Uzbeikstan is now targeting a 50% renewable share in power production by 2030, offering further options for future green projects. The renewable share reached 22% in 2025, more than doubling since 2021. A 200,000 t/a green ammonia project is now under development in the Navoi region using a mix of solar and wind power, though this will be used for local green fertilizer production for export rather than export of green ammonia itself. Longer term, if this is successful, further green/grey hybrid production is planned.

Project profiles

Phil Ingram of Johnson Matthey discussed his company's partnership with EET on the Hydrogen Production Partnership 1 at the Stanlow refinery near Liverpool. The project uses JM's Leading Concept for Hydrogen (LCH) and it, along with two other similar projects in the UK, will capture 2.1 million t/a of CO_2. The Stanlow project will sequester emissions in ageing gas fields in the Irish Sea.

The project required a guaranteed hydrogen offtake for investment, which it solves by coupling the offtake the hydrogen feed with a combined heat and power plant to generate clean electricity from surplus hydrogen. New users can come onto the hydrogen supply at any time.

Andrea Zambianco of Saipem described the massive CERES project in Australia. This 2.3 million t/a urea project is sited on the Burrup Peninsula in Western Australia, and is being developed by Perdaman Chemicals and Fertilizers, with EPC being conducted by Saipem and Clough. It has one ammonia and two urea trains, with thyssenkrupp Uhde providing the ammonia technology as well as UFT urea granulation technology. Construction has been on a modular basis, with the modules constructed in India and shipped to Australia. The modules, some weighing up to 2,700 tonnes, are then taken overland from the port to the project site for assembly and tie-in.

Zdenek Kadlec of Casale and Josef Sliva of BorsodChem in the Czech Republic described the modernisation of nitric acid production at BorsodChem in Ostrava. Production runs on imported ammonia to make a variety of downstream chemicals, including nitrobenzene, aniline and speciality amines. An accelerated project schedule has brought the overall timeline down from 36 months to 29 months. Construction will be completed in May 2026.

Terje Bakken of ATOME updated delegates on the progress of that major green fertilizer project in Paraguay, aiming to produce 260,000 t/a of calcium ammonium nitrate, using green ammonia. A 100% offtake agreement has been signed with Yara, and at the time of the conference the final investment decision had almost been reached, and was expected "within weeks".

PHOTO: POURYA GOHARI/UNSPLASH

Barcelona, venue for this year's conference.

Blue ammonia

Day two saw a number of presentations devoted to the nuts and bolts of 'blue' ammonia production; now firmly established cost-wise as the likely way for low carbon production to go in the medium term, and a clear indication of the way that the industry is moving. This begins with carbon capture strategies - Dow highlighted their high pressure regeneration process, which offers up to a 40-50% reduction in operating expenditure compared to other methods, more than offsetting the increased capex. NextChem also offers a cryogenic CO_2 recovery process, suitable for higher molar proportions of CO_2 in the gas feed (preferably above 15%) and can supply CO_2 as a liquid rather than a gas. All of this makes meeting CO_2 specifications all the more important, and Zubair Taiha of Yara discussed varying specifications and treatment strategies to remove hydrogen, oxygen, amines, ammonia, alcohols, aldehydes and solids/dust, as well as, most crucially, water, to prevent pipeline corrosion.

Saudi Aramco presented the results of a technology assessment of blue ammonia production, comparing steam reforming, autothermal reforming (ATR) and partial oxidation, concluding that ATR, though unusual for ammonia production, had the better performance for CO_2 recovery at a 'sweet spot' of around 80% efficiency, and the proven scalability for large volumes.

Other technologies

Technip have completed validation of their ammonia cracking technology at a pilot plant at Rotterdam, and are now looking for a first commercial reference. 'Hynext by T.EN' uses a structured catalyst developed with Clariant for higher mass transfer rates, lower pressure drop, and more efficient heat recovery, combined with the T.EN burner. The design minimises metal exposure to high temperature ammonia to avoid nitridation issues and can use a variety of fuels for the burner, including a hydrogen purge from the purification section.

KT Tech have an innovative solution to low carbon hydrogen production. Their NX eBLue technology uses electrically heated reformer tubes (and an electric pre-heat section) to replace the traditional SMR radiant box, which reduces gas consumption by 45%, and potentially allows higher CO_2 recovery efficiency at up to 98% via purge gas recycling. The heated tubes are supplied in modular assemblies which allow flexibility in design and operation. Feeds can also be flexible, with biogas potentially producing negative CO_2 outputs of 9-11kg CO_2/kg H_2. Electrical energy consumption is only around one third of a comparable sized electrolysis-based plant.

Casale highlighted their partnership with China's XLX (Xin Lian XIn) Group, which now includes the first world-scale ammonia-urea complex combining the N-LOOP and HYPER-U medium/high pressure self stripping technology.

Mitsubishi Heavy Industries, meanwhile, presented an innovative ammonia scrubbing system using a CO_2 bubbling unit to boost mass transfer and replace hazardous sulphuric acid scrubbing.

Dominique Flahaut of Paralloy introduced their new Omega profile reformer tube. Conventional tubes with a smooth surface have a laminar flow which can lead to an insulation layer between the tube and catalyst. Omega's grooved inner surface is designed to increased turbulence and hence heat transfer. CFD modelling shows it can lead to a temperature increase of 150C in the tube or a faster approach to temperature. Tests measured an 80°C increase at the tube exit. There is also a new strategic partnership with Casale to build this technology into new plants and revamps, as mentioned in our news item this issue. ■

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Nitrogen project listing 2026

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

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
ANGOLA							
Wuhuan Engineering	KBR	Amufert	Soyo	Ammonia	2,300	CA	2028
Wuhuan Engineering	TOYO	Amufert	Soyo	Urea	4,000	CA	2028
AUSTRALIA							
Daelim	KBR	NeuRizer	Leigh Creek, WA	Ammonia	1,600	DE	n.a.
Daelim	Stamicarbon	NeuRizer	Leigh Creek, WA	Urea	2,850	DE	n.a.
Saipem, Clough	Topsoe	Perdaman	Karratha, WA	Ammonia	3,500	UC	2027
Saipem, Clough	Saipem, TKFT	Perdaman	Karratha, WA	Urea	2 x 3,100	UC	2027
n.a.	KBR	H2Perth	Kwinana, WA	Ammonia	1,800	DE	n.a.
Tecnicas Reunidas	Topsoe	Allied Green Ammonia	Gove, NT	Ammonia	2,500	DE	n.a.
BULGARIA							
Casale	Casale	Agropolychim	Devnya	Nitric acid	n.a.	DE	2028
Casale	Casale	Agropolychim	Devnya	Ammonium nitrate	n.a.	DE	2028
CANADA							
n.a.	thyssenkrupp IS	Genesis Fertilizer	Belle Plaine, SK	Ammonia+CCS	1,500	DE	2029
n.a.	Stamicarbon, tkUFT	Genesis Fertilizer	Belle Plaine, SK	Urea	2,500	DE	2029
n.a.	thyssenkrupp IS	Genesis Fertilizer	Belle Plaine, SK	Nitric acid	n.a.	DE	2029
n.a.	thyssenkrupp IS	Genesis Fertilizer	Belle Plaine, SK	Ammonium nitrate	n.a.	DE	2029
n.a.	n.a.	Hy2Gen	Baie-Comeau, QB	Ammonia	700	FS	2030
CHILE							
TOYO	KBR	HyEx	Tocopilla	Ammonia	55	C	2025
Wood Group	n.a.	H2 Magallanes	San Gregorio	Ammonia	2,600	FS	2030
CHINA							
n.a.	Topsoe	Mintal HET	Baotou, Mongolia	Ammonia	1,800	UC	2026
n.a.	n.a.	Jilin Electric Power	Jilin	Ammonia	545	C	2025
n.a.	Casale	Henan Xinlianxin	Henan	Ammonia	2,700	CA	n.a.
n.a.	Casale	Henan Xinlianxin	Henan	Urea	3,500	CA	n.a.
n.a.	Stamicarbon	Jiangsu Huachang	Zhangjiagang	Urea	1,860	UC	n.a.
n.a.	Stamicarbon	Xinjiang Xinji	Xinjiang	Urea	3,800	UC	2026
n.a.	Stamcarbon	Shaanxi Shanhua	Weinan	Urea	n.a.	RE	2025
n.a.	Stamicarbon	Jiangxi Xinlianxin	Jiujuang, Jiangxi	Urea	3,850	UC	2027
n.a.	Stamicarbon	Qinghai Yuntianhua	Qinghai	Urea	2 x 1,200	RE	2026
n.a.	Stamicarbon	Linggu Chemical Co	Yixing	Urea	3,100	RE	2025
n.a.	n.a.	Envision	Chifeng, Mongolia	Ammonia	900	C	2025
n.a.	Stamicarbon	Hulunbier New Gold	Hulunbier, Mongolia	Urea	3,600	RE	2026
n.a.	Stamicarbon	Not disclosed	n.a.	Nitric acid	n/a/	CA	n.a.
EGYPT							
n.a.	thyssenkrupp IS	MOPCO	Damietta	Ammonia	450	UC	2027
n.a.	Stamicarbon	MOPCO	Damietta	Urea	675	UC	2027
Bilfinger	n.a.	Kima	Aswan	Nitric acid	600	UC	2027
Bilfinger	n.a.	Kima	Aswan	Ammonium nitrate	800	UC	2027
n.a.	Topsoe	Egypt Green Hydrogen	Ain Sokhna	Ammonia	210	DE	2027
n.a.	n.a.	AMEA Power	Ain Sokhna	Ammonia	910	DE	n.a.
Wuhuan Engineering	Stamicarbon	NCIC	Ain Sokhna	Urea	1,050	UC	2027
DENMARK							
n.a.	Topsoe	Skovgaard	Ramme	Ammonia	15	C	2026
ETHIOPIA							
n.a.	Topsoe	Dangote	Gode	Ammonia	2 x 2,500	DE	n.a.
n.a.	Saipem	Dangote	Gode	Urea	2 x 4,500	DE	n.a.
FRANCE							
n.a.	n.a.	FertigHy	Hauts de France	Ammonia	1,500	P	2030
HUNGARY							
Casale	Casale	BorsodChem	Kazincbarcika	Nitric acid	1360	UC	2026
INDIA							
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Nitric acid	900	UC	2027
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Ammonium nitrate	970	UC	2027
Tata	Casale	Deepak Fert & Chem	Dahej	Nitric acid	1,450	C	2026
Wuhuan Engineering	KBR	Talcher Fertilizers	Talcher	Ammonia	2,200	UC	2027
Wuhuan Engineering	Stamicarbon	Talcher Fertilizers	Talcher	Urea	3,850	UC	2027
Larsen & Toubro	Casale	Chambal Fert & Chem	Gadepan	Nitric acid	600	RE	2026
Larsen & Toubro	Casale	Chambal Fert & Chem	Gadepan	Ammonium nitrate	700	RE	2026
n.a.	Topsoe	Hygenco	Gopalpur	Ammonia	660	UC	2028
n.a.	Casale	Avaada	Gopalpur	Ammonia	1,500	BE	2029
n.a.	n.a.	AVFCCL	Namrup	Ammonia	2,100	BE	2030
n.a.	n.a.	AVFCCL	Namrup	Urea	3,800	BE	2030
thyssenkrupp IS	thyssenkrupp IS	GNFC	Bharuch	Nitric acid	600	CA	n.a.
TOYO	INCRO	GNFC	Bharuch	Ammonium nitrate	495	BE	2027
n.a.	n.a.	JK Srivastava Hynfa	Visakhapatnam	Ammonia	300	CA	2029
Larsen & Toubro	n.a.	Itochu	Kandla	Ammonia	900	DE	2030
INDONESIA							
n.a.	Casale	PT Pupuk Kalimantan	Bontang	Ammonia	1,800	RE	2026
Wuhuan Engineering	KBR	PT Pupuk Sriwidjaja	Palembang	Ammonia	1,350	UC	2027
Wuhuan Engineering	TOYO	PT Pupuk Sriwidjaja	Palembang	Urea	2,750	UC	2027
ISRAEL							
Saipem	Topsoe	Haifa Chemicals	Mishor Rotem	Ammonia	300	UC	2026
IRAN							
PIDEC	Topsoe	Hengam Petrochemical	Assaluyeh	Ammonia	2,050	C	2026
PIDEC	Saipem, TKFT	Hengam Petrochemical	Assalyueh	Urea	3,500	C	2026
Namvaran	KBR	Kermanshah Petchem	Kermanshah	Ammonia	2,400	UC	n.a.
Namvaran	Stamicarbon	Kermanshah Petchem	Kermanshah	Urea	2,000	UC	n.a.
Hampa	Casale	Zanjan Petrochemical	Zanjan	Ammonia	2,050	UC	n.a.
Hampa	Stamicarbon	Zanjan Petrochemical	Zanjan	Urea	3,600	UC	n.a.
IRAQ							
n.a.	KBR	KEEPT	Basra	Ammonia	2,300	DE	n.a.
n.a.	n.a.	KEEPT	Basra	Urea	3,850	DE	n.a.
KAZAKHSTAN							
Tecnicas Reunidas	KBR	KazAzot	Aktau	Ammonia	2,000	DE	2028
Tecnicas Reunidas	TOYO	KazAzot	Aktau	Urea	1,750	DE	2028
Tecnicas Reunidas	Espindesa	KazAzot	Aktau	Nitric acid	1,200	DE	2028
Tecnicas Reunidas	Espindesa	KazAzot	Aktau	Ammonium nitrate	1,500	DE	2028
Optimum Design	Espindesa	KazAzot	Aktau	Ammonium nitrate	1,400	CA	2027
MEXICO							
thyssenkrupp IS	thyssenkrupp IS	Proman	Topolobampo	Ammonia	2,200	UC	2027
Mota-Engil	Casale	Pemex	Escolin, Vera Cruz	Ammonia	1,200	DE	2029
Mota-Engil	Casale	Pemex	Escolin, Vera Cruz	Urea	2,125	DE	2029
NIGERIA							
Worley	n.a.	OCP	Tarfaya	Ammonia	2,300	DE	2027
n.a.	Topsoe	Dangote	Lekki	Ammonia	4 x 2,500	CA	n.a.
n.a.	Saipem	Dangote	Lekki	Urea	4 x 4,235	CA	n.a.
NORWAY							
Casale	Casale	Skipavika Green Ammonia	Skipavika	Ammonia	300	UC	2027
n.a.	Topsoe	Barents Blue	Markoppneset	Ammonia	3,000	DE	2031
n.a.	Technip	Iverson eFuels	Sauda	Ammonia	600	P	2029

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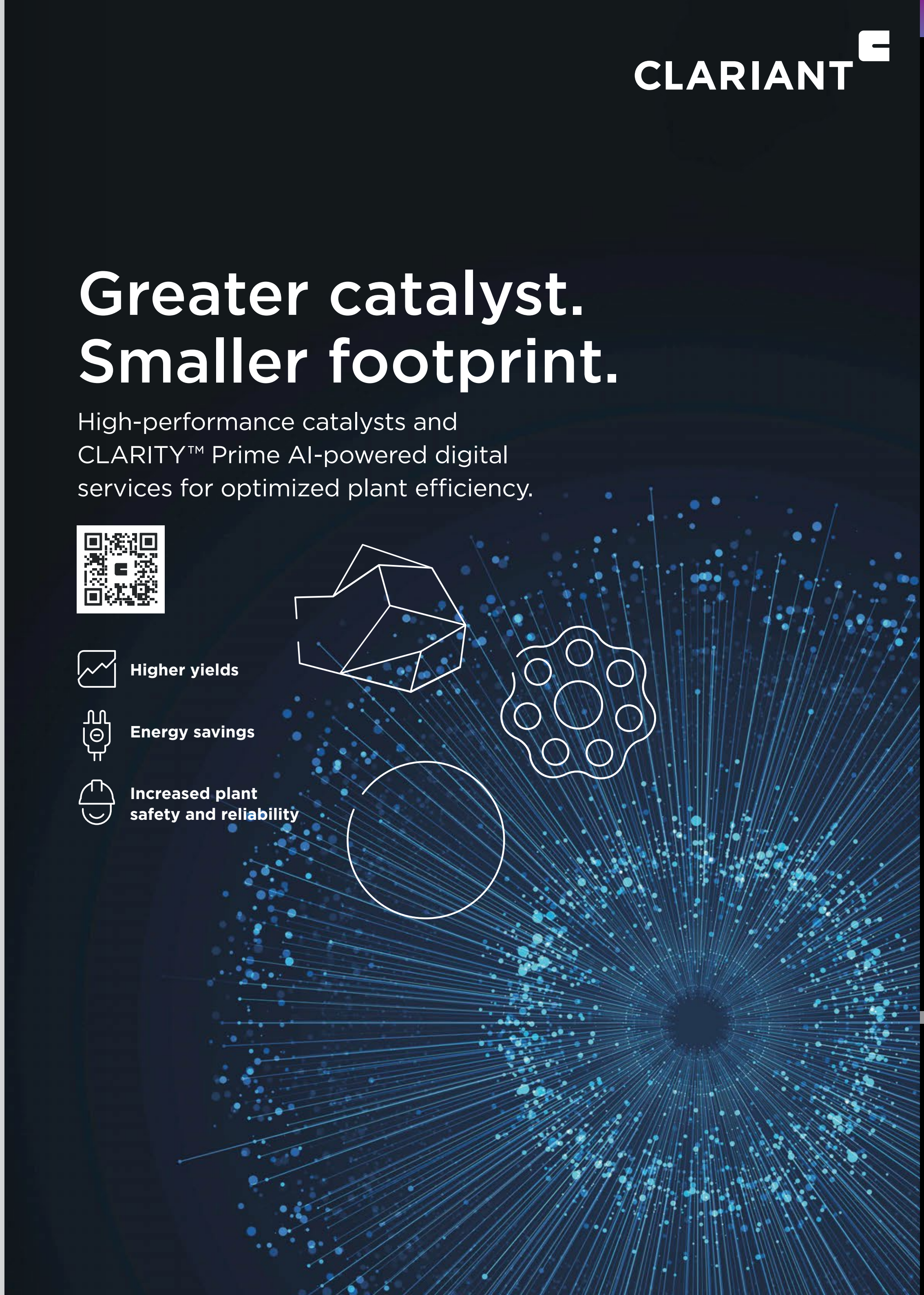
Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
OMAN							
Praxys	Espindesa	Deepak Oman Industries	Salalah	Nitric acid	30	UC	2026
n.a.	n.a.	Hyport Duqm	Duqm	Ammonia	900	DE	2030
Wood	KBR	Blue Horizons	Duqm	Ammonia	3,000	CA	2030
PARAGUAY							
Casale	Casale	ATOME	Villeta	Ammonia	300	DE	2028
Casale	Casale	ATOME	Villeta	Nitric acid	n.a.	DE	2028
Casale	Casale	ATOME	Villeta	CAN	800	DE	2028
QAFCO							
thyssenkrupp IS	thyssenkrupp IS	Qafco	Mesaieed	Ammonia	3,500	UC	2026
n.a.	n.a.	QatarEnergy	Mesaieed	Ammonia	3 x 3,500	P	n.a.
n.a.	n.a.	QatarEnergy	Mesaieed	Urea	4 x 4,500	P	n.a.
RUSSIA							
CNCCC	Topsoe	ShchekinoAzot	Pervomayskyy, Tula	Ammonia	1,500	UC	n.a.
CNCCC	Stamicarbon	ShchekinoAzot	Pervomayskyy, Tula	Urea	2,000	UC	n.a.
Tecnimont	KBR	EuroChem	Kingisepp	Ammonia	3,000	UC	n.a.
Tecnimont	Stamicarbon	EuroChem	Kingisepp	Urea	4,000	UC	n.a.
n.a.	n.a.	Lukoil	Budyonnovsk	Ammonia	3,600	P	2030
n.a.	n.a.	Lukoil	Budyonnovsk	Urea	5,300	P	2030
n.a.	Azot	AEON/VEB	Vorkuta, Komi	Ammonia	3,600	P	2030
n.a.	Azot	AEON/VEB	Vorkuta, Komi	Urea	5,300	P	2030
SAUDI ARABIA							
Larsen & Toubro	Topsoe	Neom	Neom	Ammonia	3,500	UC	2027
Tecnicas Reunidas	Topsoe	ACWA	Yanbu	Ammonia	6,000	DE	2030
SOUTH AFRICA							
n.a.	Air Products, KBR	Suiso	Kriel	Ammonia	2,200	P	n.a.
n.a.	Stamicarbon	Suiso	Kriel	Urea	2,600	P	n.a.
SOUTH KOREA							
n.a.	KBR	Hanwha	Yeosu	Nitric acid	1,200	C	2025
SPAIN							
n.a.	n.a.	Iberdrola	Puertollano	Ammonia	330	C	2026
n.a.	KBR	IGNIS	A Coruna	Ammonia	600	DE	2029
TURKEY							
Tecnimont	Stamicarbon	Gemlik Gubre Sanayl	Gemlik Gubre	Urea	1,640	UC	2026
UNITED STATES							
Tecnimont	KBR/Linde	Woodside	Beaumont	Ammonia	3,300	C	2026
Worley	Topsoe	First Ammonia	Victoria, TX	Ammonia	300	UC	2027
n.a.	Topsoe	Air Products	Ascension, LA	Ammonia	1,700	UC	2027
thyssenkrupp IS	thyssenkrupp IS	CF Industries	Blue Point, LA	Ammonia	3,300	DE	2029
n.a.	Casale	Wabash Valley Res.	West Terra Haute, IN	Ammonia	1,630	CA	n.a.
KT-Kinetics Tech	Stamicarbon	JWC Gothenburg LLC	Gothenburg, NB	Ammonia	450	CA	n.a.
KT-Kinetics Tech	Stamicarbon	JWC Gothenburg LLC	Gothenburg, NB	Urea	376	CA	n.a.
n.a.	thyssenkrupp IS	Cronus	Tuscola, IL	Ammonia	2,600	P	n.a.
n.a.	n.a.	ExxonMobil	Baytown, TX	Ammonia	3,000	P	On Hold
UNITED ARAB EMIRATES							
thyssenkrupp IS	thyssenkrupp IS	Fertil	Ruwais	Ammonia	2,120	RE	2025
Tecnimont	n.a.	Ta'ziz	Ruwais	Ammonia	3,000	FS	2028
UZBEKISTAN							
n.a.	Casale	Ferkensco	Karakul	Ammonia	1,500	UC	2026
n.a.	Casale	Ferkensco	Karakul	Urea	1,800	UC	2026
ZAMBIA							
Wuhuan Engineering	n.a.	United Capital Fert	Chilanga	Ammonia	550	UC	2028
Wuhuan Engineering	n.a.	United Capital Fert	Chilanga	Urea	900	UC	2028

KEY

BE: Basic engineering
C: Completed/commissioning
CA: Contract awarded
DE: Design engineering
FS: Feasibility study
n.a.: Information not available
P: Planned/proposed
RE: Revamp
UC: Under construction

Conversion:
1 t/d of hydrogen = 464 Nm³/h
1 t/d of natural gas = 1,400 Nm³/d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Decarbonising methanol production

As demand for renewable methanol grows we report on the latest industrial experience and technology developments from Casale, European Energy & Clariant, Toyo Engineering Corporation and Johnson Matthey.

Methanol is increasingly recognised as a versatile, low carbon energy carrier. Renewable methanol can be produced either from biomass, biogas, or waste derived feedstocks, or as e-methanol, which is synthesised by reacting captured CO_2 with electrolytic hydrogen generated from renewable electricity. These pathways enable substantial lifecycle emissions reductions when compared with conventional fossil based pathways of producing methanol. Renewable methanol, including e-methanol, can be upgraded via methanol to jet (MtJ) routes to produce sustainable aviation fuel (SAF) or used directly as a clean burning marine fuel, aligning with policies such as RefuelEU Aviation, FuelEU Maritime, and the IMO's net zero strategy.

Current global annual production of methanol from fossil fuel feedstocks such as natural gas or coal is around 98 million tonnes, resulting in emissions of around 0.3 gigatonnes of CO_2 per year. By 2050, it is expected that the methanol demand will rise to around 500 million tonnes, which could result in CO_2 emissions of up to 1.5 gigatonnes per year if production continues to be based on fossil fuels. Therefore, there is a requirement to identify ways to decarbonise methanol production.

The following sections report on new technologies in e-methanol and renewable production pathways, the first commercial scale e-methanol plant and scaling renewable methanol for aviation and maritime.

CASALE

Decarbonising the syngas value chain: New technological horizons in e-methanol and renewable production pathways

Pietro Moreo and Francesco Baratto

The strategic shift in the methanol market

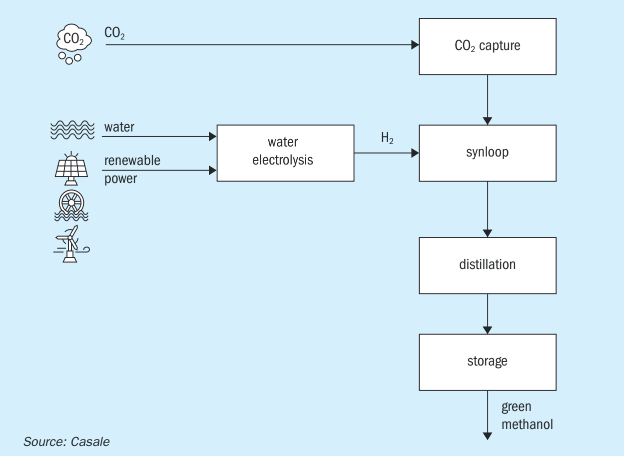
Methanol has historically been one of the most vital building blocks of the chemical industry, essential for producing adhesives, synthetic fibres, and plastics. However, the current energy transition is fundamentally redefining its role from a simple chemical feedstock to a versatile low-carbon energy carrier and marine fuel. This shift is driven by urgent environmental regulations, such as the EU's Refuel Maritime directive and the FuelEU Maritime regulation, which mandate a progressive reduction in the carbon intensity of fuels used by vessels. Methanol is uniquely positioned to meet these requirements because it is a clean-burning fuel that significantly reduces emissions of sulphur oxides (SOx), nitrogen oxides (NOx), and particulate matter compared to heavy fuel oil. Furthermore, its liquid state at ambient temperature and pressure provides significant operational advantages in terms of handling, storage, and transport compared to alternative options. To address this growing demand, industry leaders like Casale are advancing a diverse portfolio of production routes, including e-methanol, biomass gasification, and biomethane conversion, while providing the necessary technologies to decarbonise existing fossil-based assets.

The rise of e-Methanol: The eFLEX™ technology

E-methanol represents a cornerstone of the Power-to-X strategy, enabling the storage of intermittent renewable energy in a stable liquid form. The process involves synthesising methanol from carbon dioxide, captured from industrial point sources, biogenic origins, or even direct air capture, and green hydrogen generated via water electrolysis powered by renewable electricity. Casale's eFLEX™ technology is specifically engineered to optimise this synthesis loop for maximum efficiency. In a typical eFLEX™ configuration (Fig. 1), fresh green hydrogen from electrolysers is fed together with CO_2 to methanol synthesis which typically operates efficiently above 70 bar pressure.

A key technical asset of this design is the use of the Isothermal Methanol Converter (ISOPLATE steam converter), which ensures superior temperature control and higher per-pass conversion rates. Methanol recovered from the reactor generally contains organic impurities and water and the eFLEX™ process layout provides a reliable and efficient distillation design suitable to achieve quality compliant with the international standards such as Grade AA and IMPCA.

Fig. 1: **eFLEX™**



Source: Casale

The performance metrics for eFLEX™ plants are highly competitive, with single-train capacities reaching up to 2,500 t/d thanks to the axial radial layout applied to the ISOPLATE steam converter. The specific electrical power consumption of the methanol plant itself is kept below 250 kW per ton of product, excluding the power required for upstream electrolysis and carbon capture. From an environmental perspective, the product carbon intensity is less than 28.2 gCO_2e/MJ, compliant with RFNBO. To ensure the optimal performances, Casale collaborates closely with first-class catalyst manufacturers, tailoring the design based operational data focused on catalyst behaviour under the specific conditions of e-methanol synthesis.

Renewable methanol via biomass gasification: The BioFLEX™ pathway

While e-methanol relies on captured CO_2 and green electricity, the bio-methanol pathway leverages the carbon already stored in organic matter through gasification. Suitable feedstocks include a wide range of residues, such as agricultural by-products (straw, husks, manure), forestry waste (bark, offcuts), and industrial residues (sawmill, pulp and paper, etc). These materials would otherwise decompose or be burned, releasing greenhouse gases; instead, gasification transforms them into a synthesis gas (syngas) that is then catalytically converted into methanol. Casale's BioFLEX™ technology (Fig. 2) is designed to address the unique challenges of biomass-derived syngas, which is often hydrogen deficient and contains high levels of carbon oxides and, in some cases, methane.

To optimise the syngas composition, Casale recommends installing a combination of steps downstream of the gasifier, including the addition of a sour water gas shift (WGS) section, equipped with Casale axial radial converter, and an acid gas removal (AGR) stage to balance the carbon oxides content and hydrogen. As an alternative or in combination with WGS and AGR, gH_2 from electrolysers could be injected upstream methanol synthesis section to enhance plant throughput maximising the exploitation of the carbon contained in the biomasses.

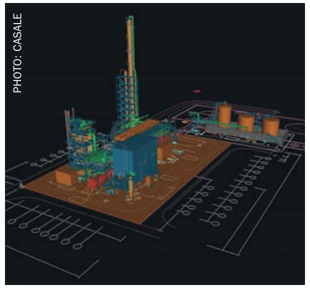


Fig. 2: BioFLEX™ unit fed by a biomass gasifier.

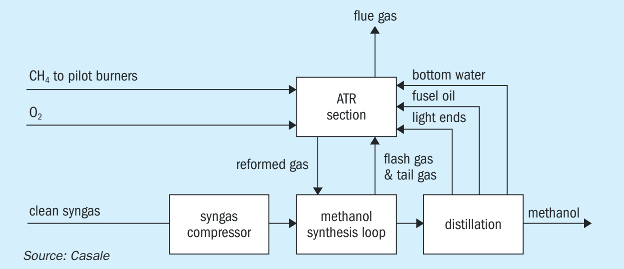
For feedstocks that result in high methane concentrations in the raw syngas (exceeding 4-5 mol-%), the BioFLEX™ layout integrates an autothermal reforming section, based on Casale HEART™, within the methanol synthesis unit (Fig. 3). This configuration is a key feature of the Advanced Methanol Amsterdam project, designed for a capacity of 260 t/d.

The integration of HEART™ significantly boosts overall carbon efficiency, achieving levels over 93%, while ensuring total CO_2 equivalent emissions, associated to product, can be limited below 28.2 gCO_2e/MJ. Compared to traditional fossil-based production, the methanol production through the BioFLEX™ route can achieve a decrease in specific CO_2 emissions in the order of magnitude of 80%. This makes biomass gasification a commercially viable and environmentally credible solution for regions with high biomass availability.

Methanol from biogas and biomethane: Optimised layouts

Utilising biogas or renewable natural gas (rNG) as a feedstock represents another critical pathway for sustainable methanol production, allowing producers to leverage existing gas-based technologies with renewable inputs. Casale offers two proven process layouts for this sector: M-ELEVA™ and Syn-POWER-M™, both developed for plant

Fig. 3: **BioFLEX™ with HEART™ integration**



Source: Casale

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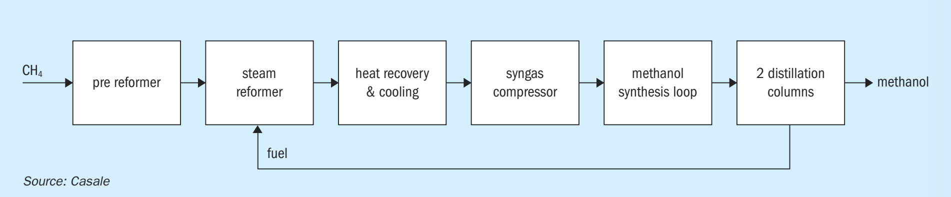
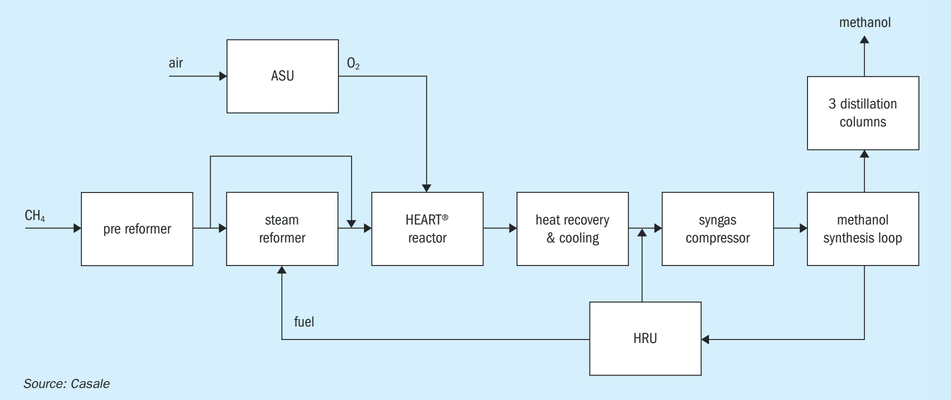
Fig. 4: **M-ELEVA™ process layout**



Source: Casale

Fig. 5: **SynPOWER-M™ process layout**



Source: Casale

fed by fossil natural gas and with excellent running references; both have been customised and optimised for the challenges linked to the sustainable methanol market. The M-ELEVA™ layout (Fig. 4) is focused on minimising capital expenditure (capex) through an efficient process involving a proprietary axial radial pre-reformer, steam methane reformer (SMR), and an ISOPLATE™ gas converter. Distillation is generally based on two columns layout. This technology is applicable also in case of biogas feedstock with exceptionally high CO_2 content.

Syn-POWER-M™ layout (Fig. 5) is designed to minimise operating expenditure (opex) and direct CO_2 emissions. This layout utilises a combined reforming scheme, consisting of a proprietary axial radial pre-reformer, SMR and autothermal reformer HEART™ (Fig. 6) to achieve high efficiency and low methane slip. The synthesis section is characterised by the ISOPLATE™ steam converter (Fig. 7) while the distillation layout is based on three columns for maximising energy savings.

A performance comparison highlights the advantages of this approach: while a standard SMR-based M-ELEVA™ plant has a specific natural gas consumption below 7.6 Gcal/t, the Syn-POWER-M™ design reduces this by 10% to 7.0 Gcal/t. More importantly, the Syn-POWER-M™ configuration leads to a 50% decrease in specific CO_2 emissions at SMR stack and an 80% reduction in demineralised water consumption compared to pure SMR designs. In view of the design carried out for a project in South East Asia, the Syn-POWER-M™ layout demonstrated its ability to produce renewable methanol with a carbon footprint as low as 32.9 g CO_2 eq/MJ. The design is suitable to reach carbon intensity, associated to methanol product, below the current thresholds set by the IMO, RTFO and RED III for biofuels.

Decarbonising fossil-based infrastructure through advanced revamping

Despite the growth of greenfield renewable projects, the existing global fleet of natural gas-based methanol plants remains a significant contributor to carbon emissions, releasing approximately 200 million tonnes of CO_2 annually. For many producers, complete asset replacement is not economically feasible; therefore, a proper revamping strategy is the most sustainable route to improve margins while meeting tightening carbon compliance costs and taxes. Casale specialises in these complex retrofits, offering a range of technologies under the RENOVO-M™ family to enhance capacity and performance while simultaneously reducing emissions.

Revamping typically targets the syngas generation section through the implementation of pre-reforming, autothermal reforming (HEART™), or partial oxidation (POX-ART™). The installation of a POX-ART™ reactor in parallel to an existing primary reformer is a particularly effective strategy. By switching a portion of the production to oxygen-blown reforming, a single POX-ART™ based unit can increase total methanol production by up to 30% while reducing natural gas consumption by 5-15%. In a project implemented by Casale, a POX-ART™ based revamp

At Casale, we believe in the power of innovation to shape a better world: this is the goal that guides everything we do.

Our commitment to sustainability drives us to integrate cutting-edge technologies with engineering, contracting, and construction solutions that harmonize industrial progress with environmental stewardship. From green ammonia, low carbon hydrogen, and renewable methanol to sustainable fertilizers, melamine, and other chemical derivatives, we are at the forefront of creating solutions for a brighter tomorrow. Driven by curiosity, we are also pioneering advances in the storage and transport of clean energy, ensuring a cleaner, more sustainable future for everyone.

Join us on our journey to make a lasting impact-together, we can build a greener future.

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resulted in a 12.7% increase in capacity, a 6% decrease in specific natural gas consumption, and a nearly 20% reduction in specific CO_2 emissions. Furthermore, retrofitting older adiabatic converters with Casale's proprietary plate-cooled, ISOPLATE™ gas internals, is essential for maximising carbon efficiency in the synthesis section. This "in situ" retrofit allows the loop to process higher make-up gas flows with superior flexibility, ensuring that decarbonisation targets are achieved alongside economic growth.

To further expand the range of decarbonisation strategies, a highly innovative revamping option involves the hybrid integration of e-methanol production elements into existing natural gas-based facilities. By implementing CO_2 injection either upstream or downstream of the SMR and combining it with green hydrogen generated through water electrolysis, plants can achieve a significant transition toward low carbon methanol production. This approach allows producers to leverage their existing fossil-based infrastructure while progressively incorporating renewable feedstocks, offering a flexible and scalable pathway to meet evolving sustainability targets without the need for a complete plant replacement.

The engine of performance: The Isothermal Methanol Converter

At the heart of both new greenfield units and brownfield revamps lies the technology of the synthesis reactor. Casale's history in converter design has evolved through three generations: from the early tube-cooled designs (1928-1979) to adiabatic reactors, and finally to the modern plate-cooled Isothermal Methanol Converters introduced in 2000 which, currently, have evolved into the ISOPLATE™ family (ISOPLATE™ gas and ISOPLATE™ steam). The ISOPLATE™'s distinctive feature is the use of heat transfer plates immersed directly in the catalyst bed, which provides several critical advantages over traditional designs. Because the plates do not require a tubesheet, the mechanical limitations on converter size are removed, allowing for significantly larger catalyst volumes and higher capacities within a single vessel. The ISOPLATE™ design utilises an axial-radial flow design to minimise pressure drop while maximising the features of the plate-cooled system. Currently, over 25 isothermal reactors employing the ISOPLATE™ design are in operation; the first units entered service in 2002.

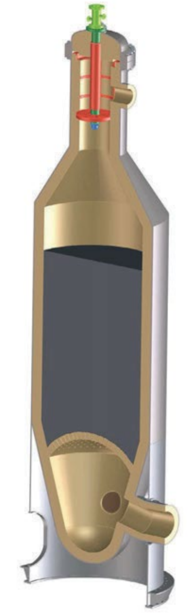


Fig. 6: HEART™ autothermal reformer.

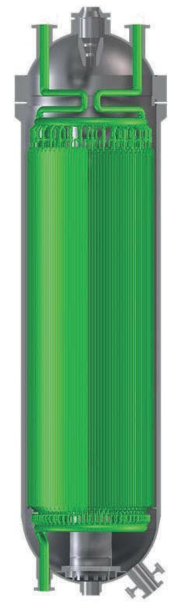


Fig. 7: ISOPLATE™ steam methanol converter.

PHOTO: CASALE

For BioFLEX™ and eFLEX™ units, Casale typically employs a "steam-raising" (ISOPLATE™ steam) design, where boiler feed water (BFW) is used as the cooling medium. This high degree of heat integration allows for the recovery of reaction heat as medium-pressure steam, which can then be used to drive compressors or provide thermal energy for the distillation section, eliminating the need for external steam imports. For ease of maintenance, Casale has also implemented a "full opening" design, where the entire pre-assembled internal package can be lifted out of the pressure vessel as a single piece, greatly simplifying repairs or catalyst replacement.

Conclusion: A multi-pathway future for sustainable methanol

The methanol industry is currently at a turning point. What was once purely a chemical commodity is now a critical tool for global decarbonisation, particularly in the hard-to-abate maritime sector. As demonstrated by the eFLEX™ and BioFLEX™ technologies, and the successful application of the RENOVO-M™ revamping approach, the technical solutions required to transition toward a low-carbon methanol economy are already mature and operational. The flexibility to produce methanol from diverse feedstocks, including urban waste, agricultural residues, captured CO_2, and renewable power, is its greatest strength, allowing for regional optimisation and energy resilience.

However, the transition faces challenges that must be addressed through coordinated efforts. These include securing affordable sustainable feedstocks, ensuring the availability of low-carbon electricity, and the need for clear regulatory frameworks and carbon pricing to bridge the cost gap with fossil fuels. As technology continues to improve through advancements in catalyst performance and reactor design, and as the global infrastructure for methanol bunkering expands, sustainable methanol is poised to become a central feature of the global energy system. The path forward is clear: a multi-pathway approach that combines innovation in new plants with the strategic decarbonisation of existing assets is the most effective way to build a cleaner and more sustainable planet. ■

EUROPEAN ENERGY & CLARIANT

First commercial scale e-methanol plant: Operational performance and technical support

As demand for green methanol grows, the Kassø e-methanol plant in Aabenaa, Denmark represents a significant milestone as the first commercial-scale e-methanol production facility in operation with a nameplate capacity of 42,000 t/a.

The Kassø project, demonstrates industrial-scale conversion of renewable power and biogenic CO_2 into e-methanol suitable for fuel and chemical applications. European Energy and Mitsui constructed the facility as a joint venture, integrating a 304 MW solar park with a Power-to-X (PtX) plant to supply marine and chemical markets. Construction of the Kassø e-methanol facility began in May 2023, marking one of the first commercial-scale Power-to-X investments in Europe. Following completion of the main process units, green hydrogen was produced for the first time in January 2025, and first raw e-methanol followed in March 2025, confirming the integrated operation of electrolysis, CO_2 supply, and synthesis. At full operation, the plant is designed to produce up to 42,000 t/a of e-methanol.

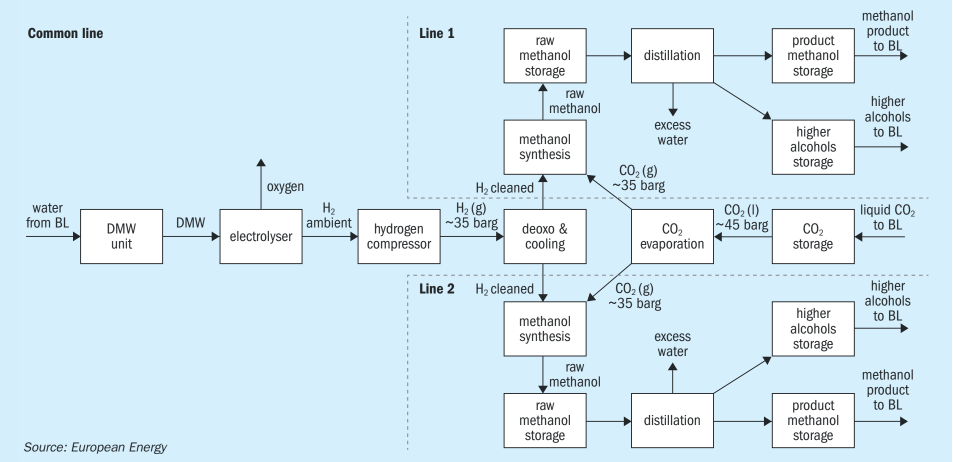
Hydrogen is produced on site via 52 MW of electrolyser capacity, yielding approximately 6,000 t/a of green hydrogen, which is subsequently converted to e-methanol. Renewable electricity is supplied primarily from the collocated ~300 MW Kassø Solar Park, currently the largest solar park in the Nordic region, with grid connection used for balancing and operational flexibility. The carbon source consists of around 45,000 t/a of biogenic CO_2, captured, purified, and liquefied at a nearby facility before being transported by road to the methanol plant. This locally sourced biogenic CO_2 enables production of RFNBO-compliant e-methanol while anchoring the project within the regional bioenergy value chain. Surplus process heat from the methanol synthesis and auxiliary systems is exported to the local district-heating network, supplying approximately 3,300 households in the Aabenraa Municipality.

Process and plant description

The Kassø e-methanol plant is designed as an integrated Power-to-X facility with two parallel methanol production and distillation trains, supplied by common hydrogen and CO_2 preparation units. The overall process configuration is illustrated in Fig. 1. Hydrogen is generated on site by three Siemens electrolysis units operating at near-atmospheric pressure. The hydrogen stream is compressed to approximately 37 barg using five reciprocating compressors. A deoxygenation unit is installed downstream of the compression stage to remove trace amounts of oxygen from the hydrogen. No dedicated hydrogen drying unit is installed prior to the synthesis loop. Carbon dioxide is supplied to the plant in liquefied form by road transport and unloaded into two cryogenic CO_2 storage tanks. From storage, the liquid CO_2 is pumped to the required pressure and subsequently evaporated to provide gaseous CO_2 for methanol synthesis. The conditioned hydrogen and CO_2 streams are combined upstream of the synthesis section and distributed to the two parallel synthesis loops.

Each synthesis loop is based on a boiling-water reactor design, operating at approximately 35 barg and 240–250°C. Within the reactor, hydrogen and CO_2 are converted to methanol over a copper-based catalyst. The reactor effluent is cooled, and the condensed methanol-water mixture is separated into a high-pressure separator,

Fig. 1: **Flow chart of Kassø Power-to-X plant**



Source: European Energy

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producing a crude methanol stream. Raw methanol from each synthesis train is routed to dedicated distillation units, where it is purified to meet IMPCA quality specifications. Purified product methanol is transferred to storage tanks and subsequently loaded onto trucks for transport to the nearby harbour, from which it is shipped to end users.

Plant operation and production capacity are adjusted in response to the availability and cost of electricity, allowing optimisation of hydrogen generation and methanol production under varying power-market conditions.

Methanol synthesis catalyst system and activation

From a catalytic process perspective, one of the main challenges in CO_2-to-methanol synthesis is the increased water content in the reaction system compared to conventional syngas-based methanol synthesis. The hydrogenation of CO_2 to methanol is an exothermic reaction and, therefore, thermodynamically favoured at low reaction temperatures and high pressure. In the absence of carbon monoxide, however, higher water formation is unavoidable, creating more demanding conditions for the catalyst. Elevated water partial pressures can accelerate hydrothermal aging, leading to reduced catalyst activity and shortened lifetime. These effects place additional constraints on reactor design and operating conditions and require catalyst formulations specifically developed for CO_2-rich synthesis gas compositions.

Green methanol production requires advanced technologies that reduce resource consumption and minimise waste. To address these requirements, the Kassø project employs a tailored methanol synthesis catalyst that demonstrates high activity under CO_2-rich conditions, high methanol selectivity, and low by-product formation, including ethanol and methyl formate, thereby supporting stable operation and simplifying downstream purification.

The methanol synthesis catalyst used in this project is MegaMax™ 900, one of Clariant's latest copper-zinc-alumina-based catalysts. Compared to earlier generations, the optimised copper loading and dispersion in MegaMax 900 increase the number of accessible active sites and the effective copper surface area. In CO_2-to-methanol applications, this translates into high catalytic activity, excellent selectivity, and low deactivation rates, supporting an expected catalyst lifetime of at least three years under the operating conditions applied at Kassø.

Catalyst loading

The methanol synthesis reactors at Kassø are designed as inward radial-flow steam-raising tubular reactors with the catalyst loaded on the shell side. This inherently limits physical access during catalyst loading. Achieving a uniform catalyst bulk density in both the radial and axial directions is therefore critical to ensure homogeneous gas-flow distribution and stable reactor performance. To address these constraints, the loading concept was developed jointly with European Energy and a loading company, based on a detailed understanding of the reactor internals and loading geometry.

Prior to catalyst loading, an internal inspection of the reactor was carried out using a borescope to verify the condition and alignment of internals and to define an appropriate loading strategy. This preparatory step was essential to minimise the risk of catalyst damage and ensure consistent packing, given the access limitations.

Catalyst loading was performed through the central pipe in discrete batches. After each batch, the catalyst bed outage was measured both at the reactor centre and close to the catalyst basket wall to verify uniform radial distribution and confirm that the axial loading density remained consistent throughout the bed. Following the first loading batch, a video inspection was conducted to assess catalyst integrity, as the free-fall height during loading exceeded seven meters. The absence of broken particles confirmed the high mechanical strength of the catalyst pellets. Based on the inspection results, minor adjustments to the loading procedure were implemented to maintain a stable and reproducible loading pattern for the remaining batches. Through this controlled and closely monitored loading procedure, a uniform bulk density of approximately 1,200 kg/m³ was achieved across the catalyst bed.

Catalyst activation

MegaMax 900 catalyst is supplied in its oxidised state, with copper present as copper oxide. Before the reactor can be put into operation, this copper oxide must be reduced to metallic copper, the active constituent for methanol synthesis. MegaMax 900 catalyst is reduced by passing a carrier gas through the catalyst and adding controlled amounts of hydrogen that reacts with copper oxide to form metallic copper and water, releasing heat according to the reaction:

$$CuO + H_2 \rightarrow Cu + H_2O \quad \Delta H = -80.8\ kJ/mol$$

Catalyst activation was performed using the plant's recycle loop, consisting of the recycle compressor, the methanol synthesis reactor, and the high-pressure separator. Nitrogen served as the carrier gas, while hydrogen was introduced upstream of the recycle compressor from a pressurised tank. The hydrogen feed rate was controlled through a combination of supply pressure and valve opening.

During heating and throughout the reduction, carbon dioxide is released from the catalyst. To prevent its excessive accumulation in the recycle loop, a continuous purge was maintained at the high-pressure separator. The purge rate depended on both the measured CO_2 concentration at the reactor inlet and the amount of nitrogen required to maintain loop pressure. Without adequate CO_2 control, elevated concentrations can significantly slow down the reduction process or, in extreme cases, cause irreversible catalyst damage.

In parallel, careful monitoring of hydrogen concentrations in the loop was required to avoid excessive accumulation, which could pose a risk of runaway reaction. For this purpose, Clariant's proprietary gas analyser was used throughout the activation procedure to track H_2 and CO_2 concentrations at both the reactor inlet and outlet. Water condensed in the high-pressure separator was collected and quantified, providing a direct indication of the reduction progress.

During the activation campaign, three unplanned trips of the recycle compressor occurred. Due to the short response times, rapid stabilisation of operating conditions, and implementation of appropriate corrective measures, no adverse effects on catalyst reduction were observed. In particular, no CO_2 or H_2 accumulation or deviations from the intended activation trajectory occurred. Continuous on-site presence of Clariant personnel ensured immediate support and close coordination with the operating team throughout these events.

During the first 15–18 hours, nearly all injected hydrogen was consumed within the reactor. As reduction progressed, an early hydrogen breakthrough was observed, indicating a shift in the reduction behaviour. At this stage, the sampling frequency was increased to avoid hydrogen accumulation in the loop and to ensure stable operating conditions. Once the inlet and outlet H_2 concentrations converged, the reduction neared completion.

Kassø e-methanol plant.

In the final phase, hydrogen concentration and reactor temperature were increased to soak the catalyst, allowing heat and reducing agent to penetrate deeper into the pellets. After several hours of soaking, completion of the reduction was confirmed by stable gas-phase measurements and by the total amount of condensed water, which was consistent with the theoretical value expected for the full reduction of copper oxide.

Operational Performance

Following start-up, plant operation has been characterised by a high degree of variability, reflecting both the challenges of the commissioning phase and the power-driven nature of the facility. Frequent load changes, intermittent shutdowns, and a number of trips occurred, particularly during the early months of operation, limiting the availability of long, uninterrupted steady-state periods. Under these conditions, reactor and catalyst performance were evaluated using indicators that remain meaningful under dynamic operation rather than relying solely on extended time-on-stream data.

Reactor performance was assessed based on reconciled operating data. Hydrogen flow to the synthesis loop was measured using a mass flow meter at the mixing point and independently verified through the electrical current consumed by the electrolyser units. Carbon dioxide flow was measured by a vortex flow meter at the mixing point and cross checked against measurements from the CO_2 evaporation unit. This data reconciliation provided a consistent basis for evaluating synthesis performance across varying operating conditions.

Despite the operational variability, the synthesis loop has shown consistently strong performance from the beginning of operations. The reactor is operated at an outlet temperature of approximately 240°C and an actual pressure of 30–31 barg, which is lower than the original design pressure. This operating point indicates high intrinsic catalytic activity and reaction rates under the applied conditions.

Catalyst performance was further evaluated using the calculated approach to thermodynamic equilibrium. Throughout the observed operating period, the approach to equilibrium remained consistently in the lower range with no systematic increase over time despite frequent load changes and interruptions. The stability of this indicator suggests that the catalyst's high activity was maintained under the prevailing dynamic operating regime.

Additional insights into catalyst activity were obtained during shutdown events. When the synthesis loop was stopped, the make-up gas flow was interrupted, but circulation was maintained. Under these conditions, loop pressure decreased to approximately 9 barg, indicating that methanol synthesis reactions continued to proceed at very low pressure. This behaviour provides qualitative confirmation of high intrinsic catalyst activity, even under strongly reduced thermodynamic driving force.

Loop stability during operation was reflected in the very low purge requirement. The purge gas flow was maintained at approximately 0.1 % of the total recirculating flow, indicating minimal formation of inert components and stable loop operation. This low purge requirement was sustained across varying loads and operating modes, highlighting the catalyst's superior performance.

Overall plant performance improved significantly during the first six months of operation. The frequency of trips decreased over time, and the plant demonstrated increasing stability and reliability as operating experience was gained, and control strategies were refined. Throughout this period of dynamic operation, no adverse impact on catalyst performance was observed.

The results demonstrate that advanced methanol synthesis catalysts such as MegaMax 900, combined with comprehensive technical support during implementation and start-up, are well-suited for e-methanol applications. The experience gained at Kassø provides confidence that robust catalyst systems and close supplier-operator collaboration enable reliable and efficient operation of future large-scale Power-to-X methanol plants operating under similarly dynamic conditions. ■

Reference

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TOYO ENGINEERING CORPORATION

Revolutionising e-methanol production with an innovative energy saving distillation system

Toyo Engineering Corporation (TOYO) has developed two proprietary technologies – g-Methanol™ and SUPERHIDIC™ – to enable ultra-low carbon e-methanol production. g-Methanol™ is an advanced process that synthesises methanol directly from CO_2 and hydrogen using the MRF-Z™ reactor. This reactor minimises catalyst volume and energy consumption. SUPERHIDIC™ is a revolutionary advanced heat pump based energy-saving distillation system. Unlike conventional distillation, it uses internal heat integration and a heat pump effect, requiring only 10–25% of the conventional reboiler duty as electrical power, and thereby achieving zero steam consumption. When powered by renewable energy, it drastically reduces greenhouse gas emissions.

This innovative approach is aligned with the evolving requirements of the energy transition, offering a practical pathway to deliver sustainably sourced, low-GHG methanol at scale. The combination of g-Methanol™ and SUPERHIDIC™ system is designed to meet emerging international standards for low-carbon fuels.

TOYO's g-methanol™ technology

In recent years, TOYO has been promoting its g-Methanol™ technology as its solution for production of e-methanol. This technology produces low-carbon methanol using CO_2 and renewable energy-derived hydrogen as feedstocks, and has attracted significant interest from numerous customers around the globe. In June 2025, the NTPC g-Methanol™ 10 t/d demonstration plant successfully produced India's first e-methanol using TOYO's g-Methanol™ technology.

At the heart of TOYO's g-Methanol™ technology is the MRF-Z™ methanol synthesis reactor, designed to achieve an ideal temperature profile through multi-stage cooling, thereby minimising catalyst consumption and reducing overall reactor dimensions. This temperature profile is established by engineering the reactor such that the reaction pathway consistently aligns with the maximum attainable reaction rate under the specified gas composition.

TOYO has had significant success with the MRF-Z™ reactor from its first pilot plant with a 50 t/d reactor in Japan, in 1985 to the 3,000 t/d plant for the Oman Methanol Company in Sohar, Oman in 2007.

MRF-Z Neo™ reactor

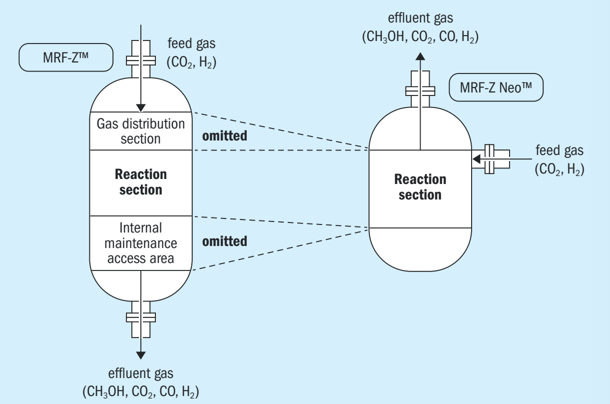
Globally, e-methanol plants are generally being designed for relatively smaller capacities, primarily due to the limited availability of renewable energy. The same trend applies to bio-methanol plants as well, given similar constraints on feedstock and energy sources. In response to this trend, TOYO has developed the MRF-Z Neo™ methanol reactor, an optimised design tailored for small-scale e-methanol production. The MRF-Z Neo™ uses the reduced reactor feed flow rate associated with lower plant capacities to optimise the feed gas distribution system within the reactor. The lower reactor feed flowrate results in a smaller reactor diameter, allowing a uniform radial flow distribution to be achieved even with a side inlet nozzle. As a result, the feed gas distribution system at the top of the reactor can be removed which results in a reduction in the reactor length. Furthermore, a re-evaluation of maintenance requirements for small to medium scale plants has enabled the elimination of maintenance access space inside the reactor. This results in a more compact reactor configuration and further size reduction.

For methanol production capacities up to a few hundred tonnes per day, the MRF-Z Neo™ reactor offers an optimised solution in terms of capital expenditure (capex). For larger capacities, the conventional MRF-Z™ reactor design remains the preferred choice. Fig. 1 presents a comparative overview of the conventional MRF-Z™ design and the MRF-Z Neo™ configuration.

TOYO's SUPERHIDIC™ technology

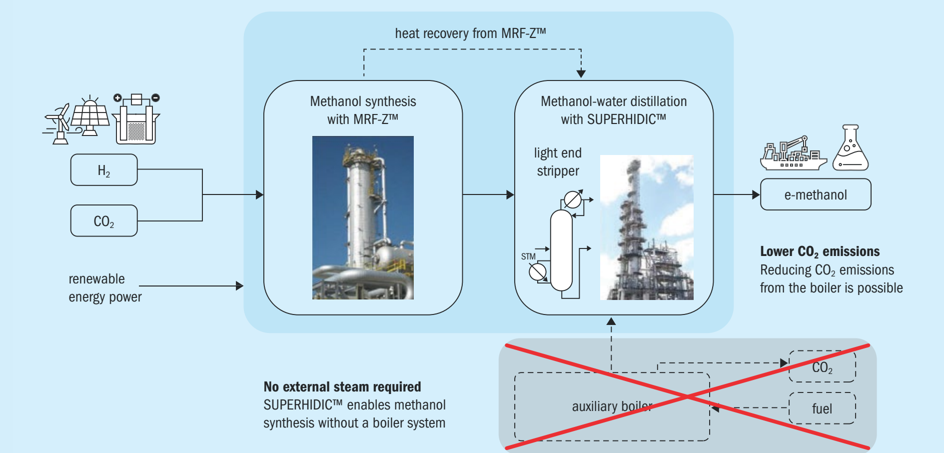
SUPERHIDIC™ technology is an energy efficient distillation technology which can provide energy savings of typically up to 50 to 60% depending on the service of distillation. The working principle of SUPERHIDIC™ is derived from the general concept of a Heat Integrated Distillation Column (HIDiC), but employs a more sophisticated and superior approach to the heat integration.

Fig. 1: **Comparison of the reactor arrangement for MRF-Z™ and MRF-Z Neo™**



Source: TOYO

Fig. 2: **Integration of g-Methanol™ and SUPERHIDIC™**



Source: TOYO

Combining g-Methanol™ and SUPERHIDIC™ technologies

In a methanol plant, one of the major energy consumers is the methanol–water distillation section. In a conventional methanol plant which includes a syngas generation section, or a reformer section, part of the energy for distillation is provided by waste heat recovery from the reformer section by energy integration. However, in e-methanol plants, hydrogen and carbon dioxide are fed separately to the methanol plant and there is no reformer section. As a result, the energy for distillation must be supplied from elsewhere.

In a conventional methanol plant, it is possible to supply around 40% to 45% of the energy from the methanol synthesis reaction heat generated in the methanol reactor, whereas in an e-methanol plant, only 20% to 25% of the total energy can be supplied. This is essentially because the CO_2 to methanol reaction (which predominantly occurs in an e-methanol process) generates less energy compared to the CO to methanol reaction (which predominantly occurs in a conventional methanol process).

Thus, in case of an e-methanol process, the remaining energy for the distillation must be supplied from outside the methanol process plant. An example is by using an auxiliary boiler which produces medium pressure steam and supplies the required energy. However, typical auxiliary boilers generate steam by burning hydrocarbon fuels such as off-gases from the methanol plant or natural gas. The burning of fuels can lead to CO_2 generation and emission which thereby increases the carbon intensity of the product methanol which is not desirable when it comes to an e-methanol process.

Applying SUPERHIDIC™ technology to the methanol-water distillation eliminates the requirement of steam for distillation during normal operation. Steam generated from the methanol synthesis reactor would satisfy the requirements of other parts of the methanol plant. As a result, the auxiliary boiler is not required to be operated during normal operation, which in turn means zero CO_2 emissions from the methanol plant. Thus, combining the SUPERHIDIC™ technology with MRF-Z™ methanol synthesis reactor in the synthesis section, an optimal process scheme from the viewpoint of a combination of capex, opex and carbon intensity is made possible. Fig. 2 shows the overall block flow diagram of a combined process scheme.

In addition, SUPERHIDIC™ technology uses only around 20% to 23% of the energy (as electrical power) required for methanol-water separation compared to the conventional process. This corresponds to an energy consumption of around 55% to 65% of the conventional methanol-water separation, by the SUPERHIDIC™ technology, assuming the efficiency for electrical power generation as around 36%, which is typical for a coal fired power plant.

Economic impact: LCOM and capex considerations

The integration of g-Methanol™ and SUPERHIDIC™ aligns well with the economics for a full e-methanol plant. The additional high-pressure columns, compressors, and heat-exchange equipment required by the SUPERHIDIC™ system increase the methanol plant capex by about 10%, but opex remains almost unchanged compared to the conventional system. However, In a typical e-methanol configuration, the renewable power plant dominates total investment, meaning that only a small fraction of the overall capex is tied to the methanol plant itself. As a result, even with the introduction of SUPERHIDIC™, the impact on cost for the total e-methanol production system, or the levelised cost of methanol (LCOM), is limited to roughly 4%, leaving the overall LCOM to be essentially unchanged. Future cost reduction in LCOM may be achievable through regulatory incentives. ■

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JOHNSON MATTHEY

Scaling renewable methanol: Unlocking clean energy for aviation and maritime

Methanol is emerging as a critical low carbon energy carrier, and the rapid scale up of renewable and e-methanol production demands technologies that combine high efficiency, flexible operation under intermittent renewables, and demonstrable commercial maturity. Johnson Matthey (JM), with more than six decades of methanol technology deployment, brings a proven foundation to this challenge through its eMERALD™ CO_2–to–methanol technology. JM's eMERALD technology integrates JM's tube cooled converter, high activity CO_2 hydrogenation catalysts, and advanced digital design and de-risking tools into a single synthesis loop solution engineered for high recycle ratios, robust heat integration, and responsive load following performance.

JM licensed the first phase of the world's first CO_2–to–methanol plant in 2011, and JM's CO_2–to–methanol technology, eMERALD, has been operational since 2022 at HIF's Haru Oni facility in Chile. A block flow diagram for JM's eMERALD technology is shown in Fig. 1.

Designing an e-methanol plant to operate flexibly under fluctuating renewable power requires careful consideration of turndown limits across the synthesis loop, distillation system, and compression and control hardware, whilst considering the impact of turndown levels on levelised cost of methanol.

JM's eMERALD technology directly addresses the critical barriers to scaling e-methanol by offering:

- A reliable, low risk pathway to financing and project success, supported by proven methanol plant designs, demonstrated turndown operation, and digital de risking tools.
- Industry leading feedstock and energy efficiency, ensuring reduced levelised cost of methanol (LCOM) under renewables constrained conditions.
- Operational flexibility to manage intermittent renewable power and variable feedstock availability without compromising safety or product quality.
- A scalable, future ready solution that supports sustained operation with minimal downtime, enabling long term deployment as renewable penetration rises.

Technical approach addressing key design criteria

The technical approach underpinning JM's eMERALD technology focuses on a reactor–catalyst–flowsheet integration strategy designed to achieve high energy and feedstock efficiency, high turndown, and stable operation in intermittent operating environments. Within this framework, the converter, synthesis loop, and associated control strategy are central to achieving efficient and flexible operation under intermittent renewable power.

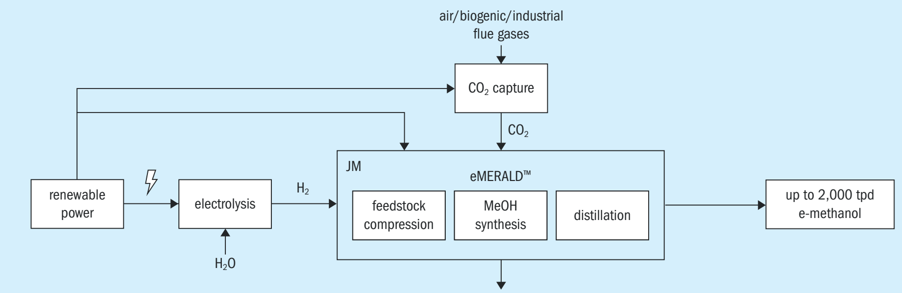
Tube cooled converter (TCC) architecture

JM's eMERALD technology is built around JM's Tube Cooled Converter (TCC), which meets the process requirements of high recycle ratios, flexible heat integration, and high converter volume utilisation. The TCC recovers reaction heat via direct heat integration at the converter exit, which is more energy efficient than via raising steam. As the converter doesn't necessitate a steam system it allows other heating philosophies to be adopted, like the use of electrically heated hot oil system if preferential for given project.

The open tube top configuration mitigates tube sheet constraints and differential thermal expansion risks, while shell side catalyst loading simplifies handling and provides the higher catalyst inventory needed for CO_2-based feeds with higher water content and slower kinetics. Its axial flow configuration provides counter current heat exchange between the feed gas and reacting mixture, creating a favourable temperature profile for catalyst performance.

The reactor operates primarily by controlling inlet temperature, simplifying instrumentation, improving reliability, and enabling high turndown without compromising catalyst integrity or product quality, while also maintaining controllability under transients. The TCC offers lower mechanical complexity, reduced material costs, and has been deployed from pilot units to multi kiloton per day plants, evidencing scalability and resilience under frequent starts and stops. These characteristics collectively support efficient, flexible, and commercially robust CO_2 to methanol operation.

Fig. 1: **JM's eMERALD technology: delivering unprecedented efficiency with proven technology**



Source: Johnson Matthey

JM's eMERALD 201 catalyst for CO_2 rich syngas

eMERALD™ 201, JM's latest generation methanol synthesis catalyst, builds on silica-doped predecessors that operated under variable industrial conditions, including seasonal shutdowns and reduced load periods. This commercial experience informed its development for renewable driven applications. The catalyst offers higher intrinsic activity, enabling either reduced inventory or increased throughput and, in some configurations, lowering or removing the need for a dedicated RWGS step. JM's eMERALD 201 catalyst incorporates the latest combination of promoters, delivering exceptional hydrothermal stability and superior resistance to thermal sintering – the primary cause of catalyst deactivation and performance decline – outperforming previous generation catalysts. Its extended operating life reduces replacement frequency and associated downtime, and production is supported by a mature manufacturing base and established global supply chain.

These characteristics collectively support efficient and stable plant performance and enable reliable turndown during load following operation, maintaining catalyst integrity and product quality under intermittent renewable power.

Digital tools for design and operation under renewable intermittency

JM has been collaborating closely with customers to develop digital tools that help optimise methanol plant performance under both steady state conditions and the transient behaviour associated with renewable power intermittency. These tools support design, operation, and future optimisation of e-methanol systems.

Dynamic modelling for design and scenario testing

JM has developed an in-house dynamic model of the methanol flowsheet to simulate plant behaviour under transient conditions, including start-up, ramping, and turndown. This modelling enables different production scenarios to be evaluated and their impact on methanol output, buffer sizing, and control strategy performance to be understood. The insights gained are used both to guide customer projects and to inform ongoing development of JM's eMERALD technology.

Catalyst performance reporting and unit health monitoring

JM has deployed the JM-LEVO™ platform with customers to provide catalyst activity trends and deactivation insights, supporting more informed catalyst management decisions. Building on this capability, JM has also developed tools for early, non-invasive detection of anomalies in key methanol loop equipment, helping to improve unit availability and reduce unplanned downtime.

AI-based design and operational optimisation

JM is developing AI models to accelerate evaluation and optimisation of plant design and operation. This includes steady state set point advisors for further methanol unit optimisation, as well as renewable aware operational advisors that recommend proactive adjustments based on forecasted power availability.

Results

LCOM impact

JM's integrated reactor–catalyst–digital approach presents early reference project evidence and financial modelling which demonstrates an estimated ~7% reduction in the levelised cost of methanol for a 100 kt/a Spain case vs an unoptimised design. This improvement is driven by higher feedstock utilisation, reduced hydrogen losses, and stable loop behaviour across the operating envelope, combined with the activity and durability benefits of eMERALD 201 catalyst.

Understanding the cost structure of e-methanol production helps contextualise the significance of this reduction. Today, many e-methanol projects are more expensive than conventional methanol, largely because electrolysers and renewable electricity costs dominate both capex and opex, with hydrogen production typically accounting for around half of total production cost. While the methanol synthesis section contributes less than 10% of total project cost, improvements in synthesis efficiency have cascading impacts; reducing hydrogen demand, lowering CO_2 conditioning requirements, and improving overall plant utilisation. These upstream effects, combined with reduced operational risk, translate into more competitive offtake pricing, stronger bankability, and improved project viability.

Turndown economics

Modelling indicates that enabling turndown provides clear operational value, but the economic benefit tapers as plant loading moves into the lowest ranges. In the reference case assessed, extending turndown capability below roughly 20% of nameplate delivered only small additional reductions in LCOM (generally <1%), as lower load operation introduces efficiency penalties such as increased compressor spillback, reduced separation performance, and greater control complexity.

A design target of around 20% turndown therefore offers a practical balance for many project configurations: it accommodates the majority of renewable variability expected in real world power profiles while avoiding the disproportionate cost and complexity associated with very deep turndown. Most e-methanol plants can achieve this range without major hardware additions.

While individual project conditions – such as renewable intermittency, storage strategy, or grid availability – may shift the precise optimum, the overall trend is consistent across scenarios evaluated: moderate turndown yields meaningful flexibility benefits, whereas pushing to very low loads provides diminishing economic returns.

Additional projects such as La Robla NE, HIF Paysandú e-Fuel facility, ET Fuels' Rattlesnake Gap and other ongoing implementations provide further confidence in scaling continuous and variable-load e-methanol production. ■

Reference

Coxon K., Vijh N. and Yorath N. (Johnson Matthey): "Scaling renewable methanol: Unlocking clean energy for aviation and maritime", presented at Nitrogen+Syngas 2026, Barcelona, 10-12 February 2026.

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The power of integrated catalyst and digital solutions

Christian Berchthold, **Anton Kariagin** and **Felicitas Cokoja** of Clariant demonstrate how ammonia plant performance can be maximised through advanced low temperature shift solutions. Clariant's combination of ShiftMax 217 Plus and CLARITY Prime delivers benefits that neither superior catalysts nor digital tools could achieve alone.

In today's competitive ammonia production landscape, the low temperature shift (LTS) converter is a critical factor in plant profitability and operational excellence. As one of the highest total cost catalysts in ammonia and hydrogen facilities, the shift catalyst's performance directly influences plant economics, energy efficiency, and environmental compliance.

The strategic importance of LTS performance

The stakes in LTS operations are remarkably high. A mere 0.1% improvement in CO conversion translates to approximately 1% additional ammonia production – particularly significant for plants without purge gas recovery systems. Superior LTS catalyst performance reduces inert concentration in the ammonia synthesis loop, minimising costly purge gas losses while optimising overall energy efficiency. Conversely, subpar performance carries substantial risks: methanol by-product formation consumes valuable hydrogen, with each tonne of methanol produced resulting in a loss of approximately 1.1 tonnes of ammonia. Additionally, operators face the constant threat of condensation, sulphur poisoning, and temperature control challenges that can lead to production losses and increased pressure drop, ultimately shortening catalyst lifetime.

PHOTO: CLARIANT

Fig. 1: ShiftMax™ 217 Plus low temperature shift catalysts

Introducing next-generation solutions

Clariant addresses these critical challenges with two breakthrough innovations: ShiftMax™ 217 Plus and CLARITY Prime Shift Optimizer. ShiftMax 217 Plus represents the evolution of proven LTS technology, delivering ultra-low methanol formation – achieving 40-50% reduction compared to previous generations – without compromising the high activity that ammonia producers demand. Its enhanced mechanical strength ensures lower pressure drop increase over time, extending catalyst lifetime and maintaining optimal performance even under harsh operating conditions.

Complementing this advanced catalyst technology, CLARITY Prime Shift Optimizer harnesses the power of artificial intelligence and machine learning to provide real-time insights into catalyst performance. The digital platform CLARITY has already demonstrated its value at leading ammonia facilities.

Together, these innovations empower ammonia producers to maximise production, minimise energy consumption, extend catalyst life, and reduce operational risks.

ShiftMax 217 Plus

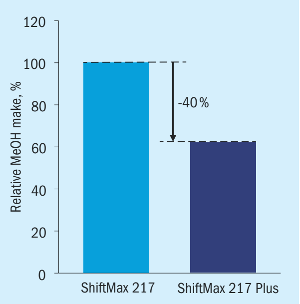
ShiftMax 217 Plus represents an evolution of Clariant's ShiftMax 217 catalyst, which has demonstrated exceptional performance since 2010, serving over 60 global customers. Clariant's development team built upon this proven foundation, utilising the same trusted chemical composition that made ShiftMax 217 an industry standard. The breakthrough came through an optimised production process that achieves a more homogeneous distribution of active metals and promoters within the catalyst matrix, unlocking superior selectivity and reduced by-product formation while maintaining the high activity operators depend on (Fig. 1).

Three pillars of performance

Ultra-low methanol formation

ShiftMax 217 Plus delivers a game-changing 40% reduction in methanol formation compared to its already impressive predecessor – without any compromise on activity. Laboratory testing confirmed that the catalyst provides the same high level of CO conversion while dramatically minimising this costly by-product (Fig. 2). The benefits cascade throughout plant operations: increased ammonia production and energy savings, reduced costs in downstream treatment systems, including condensate handling and solvent regeneration, lower VOC/COD emissions for environmental compliance, and elimination of capacity increase limitations caused by emission constraints. Given that each tonne of methanol produced represents a loss of 1.1 tonnes of ammonia, this improvement directly impacts plant performance.

Fig. 2: **By-product formation**



Source: Clariant

Superior mechanical robustness

Beyond selectivity improvements, ShiftMax 217 Plus exhibits significantly enhanced mechanical strength, demonstrated by its impressive 202% relative side crush strength in reduced form – compared to 174% for ShiftMax 217 and 100% for earlier generation catalysts (Fig. 3). This superior physical integrity translates directly to operational advantages: lower pressure drop increase over time on stream, extended catalyst lifetime, and sustained performance even under challenging operating conditions. For plants operating above design capacity, where even minimal pressure drops of 0.1 bar impact energy consumption, this robustness proves invaluable.

Uncompromising high activity

ShiftMax 217 Plus maintains the same exceptional CO conversion performance like ShiftMax 217 (Fig. 4). The catalyst demonstrated in a laboratory test consistently high activity across a wide operating window, performing effectively at both 230°C (GHSV: 22,500/h) and low inlet temperatures below 200°C (GHSV: 10,000/h). This versatility ensures optimal performance whether plants are operating at standard conditions or pushing for maximum efficiency at equilibrium.

Proven commercial success

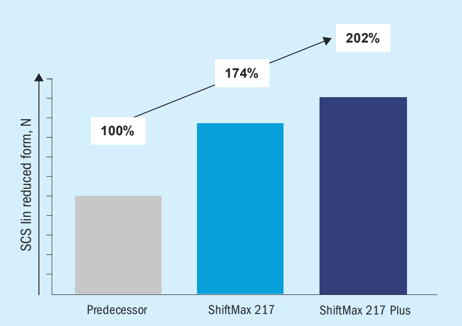
Since its commercial introduction, ShiftMax 217 Plus has been successfully installed in over 20 plants worldwide, building on the strong foundation established by its predecessor's presence in more than 60 facilities.

Case study

European ammonia producer achieves regulatory compliance and economic gains

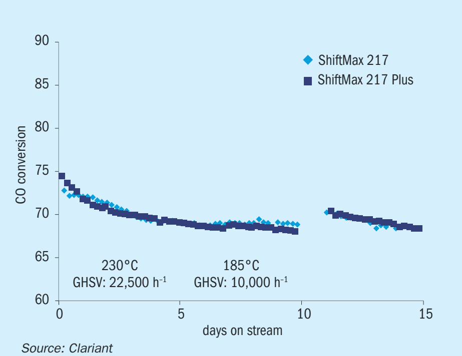
A European ammonia producer faced strict VOC emission limits with significant penalties for non-compliance, and despite installing ShiftMax 217 in 2018, methanol concentrations remained challenging to manage during the high-activity start-of-run phase. In 2022, amid escalating energy costs, the producer upgraded to ShiftMax 217 Plus. The results were remarkable: ShiftMax 217 Plus achieved more than 50% reduction in methanol concentration in the CO_2 knock-out drum during start-of-run compared to its predecessor, enabling easy compliance with emission limits and eliminating penalty risks (Fig. 5). The catalyst also demonstrated exceptional performance at equilibrium, maintaining superior selectivity even at low inlet temperatures below 200°C while minimising hydrogen losses and improving plant economics.

Fig. 3: **Side crush strength (SCS) comparison**



Source: Clariant

Fig. 4: **CO conversion**



Source: Clariant

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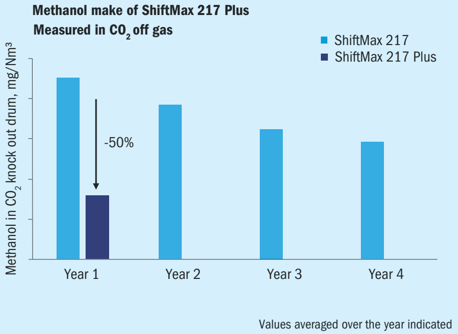
Fig. 5: **Case study ShiftMax 217 Plus**

Ammonia plant
1,569 t/d,
EUROPE, 04/2022

Meet regulatory limits for VOC emissions and improve plant economics (increased ammonia production and reduced energy consumption due to increased H_2 production).

RESULTS
MeOH concentration in the CO_2 knock-out drum was reduced by more than 50%.
Excellent performance at equilibrium and inlet temperature < 200°C.

BENEFIT FOR THE CUSTOMER
Regulatory VOC limits are easily met (avoidance of penalty)
Expected additional profit of > $500,000* over typical catalyst life (6 years) due to increased NH_3 yield (at NH_3 price of 500 USD/kg).



Values averaged over the year indicated

Source: Clariant

Digital intelligence for optimised catalyst performance

While ShiftMax 217 Plus delivers exceptional catalyst performance, Clariant recognises that this is only part of the equation. To help customers maximise their catalyst operations, Clariant developed CLARITY – a digital platform powered by Navigance that offers plant operators real-time insights into catalyst performance, helping optimise plant efficiency, sustainability, and safety. Built on machine learning algorithms combined with internal kinetic models, CLARITY features a web-based interface that ensures easy access to plant data alongside Clariant catalyst experts' comments, evaluations, and recommendations for optimising catalyst operations. Since its market introduction in 2023, more than 220 plants have been onboarded to the CLARITY platform, taking advantage of digitalisation's benefits.

CLARITY Prime: AI-powered optimisation

CLARITY Prime represents the evolution of this digital platform, employing sophisticated AI and machine learning technologies that enable predictive maintenance, enhanced performance insights, and advanced technical support. The platform uses machine learning to project catalyst performance throughout its lifecycle, allowing production plants to adjust operating parameters proactively and schedule maintenance more effectively. This advanced system transforms how operators interact with their catalysts, moving from reactive troubleshooting to proactive optimisation.

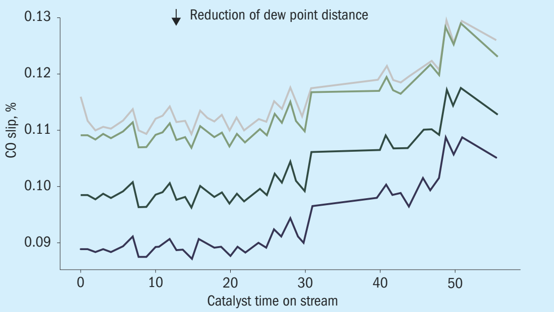
The Shift Optimizer

At the heart of CLARITY Prime for syngas plants lies the interactive Shift Optimizer, a powerful tool that combines first-principle models with plant-specific machine learning to enable independent optimisation of shift section performance. This feature allows operators to quickly optimise setpoints after load changes to minimise CO slip and maximise production, ensuring the shift reactors operate at peak efficiency regardless of operating conditions.

Fig. 6: **Retrospective analysis of optimisation potential**

Optimised catalyst inlet temperature under load changes

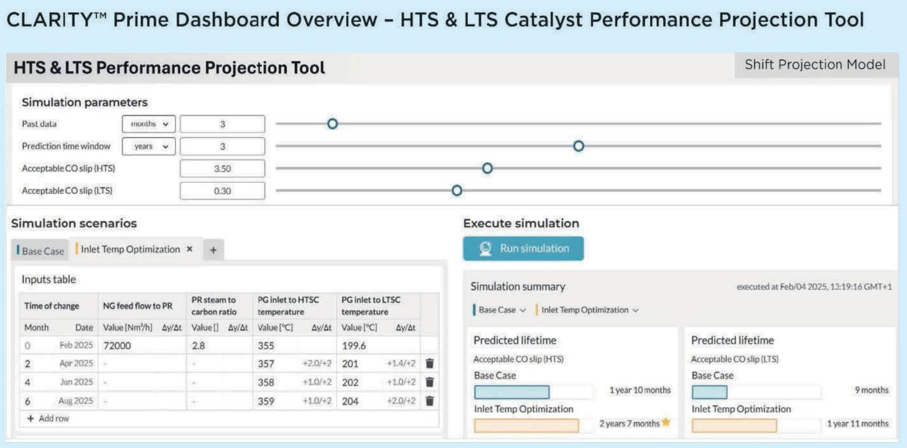
Dew point as key constraint for distance to dew point
20°C (normal operation)
15°C
10°C



Source: ©Clariant and CLARITY

Observed and optimised CO slip with distance to dew point as modelling constraint

Fig. 7: **CLARITY Prime dashboard**



CLARITY™ Prime Dashboard Overview – HTS & LTS Catalyst Performance Projection Tool

HTS & LTS Performance Projection Tool

Shift Projection Model

Simulation parameters

Past data: months 3
Prediction time window: years 3
Acceptable CO slip (HTS): 3.50
Acceptable CO slip (LTS): 0.30

Simulation scenarios

Base Case | Inlet Temp Optimization × | +

Inputs table

Time of change		NG feed flow to PR		PR steam to carbon ratio		PG inlet to HTSC temperature		PG inlet to LTSC temperature	
Month	Date	Value [Nm³/h]	Δy/Δt	Value []	Δy/Δt	Value [°C]	Δy/Δt	Value [°C]	Δy/Δt
0	Feb 2025	72000		2.8		355		199.6	
2	Apr 2025	-		-		357	+2.0/+2	201	+1.4/+2
4	Jun 2025	-		-		358	+1.0/+2	202	+1.0/+2
6	Aug 2025	-		-		359	+1.0/+2	204	+2.0/+2

+ Add row

Execute simulation

Run simulation

Simulation summary

executed at Feb/04 2025, 13:19:16 GMT+1

Base Case | Inlet Temp Optimization

Predicted lifetime
Acceptable CO slip (HTS)
Base Case: 1 year 10 months
Inlet Temp Optimization: 2 years 7 months

Predicted lifetime
Acceptable CO slip (LTS)
Base Case: 9 months
Inlet Temp Optimization: 1 year 11 months

Source: © Clariant and CLARITY

Case Study 1

Yara achieves substantial energy savings

Yara has adopted CLARITY across its worldwide network of ammonia production facilities, with one plant transitioning to CLARITY Prime to access advanced capabilities including innovative soft sensors, catalyst lifetime projection tools, and the interactive Shift Optimizer. The results have been impressive: retrospective analysis of operating data using the Shift Optimizer has resulted in daily energy savings of 20-40 GJ at a single plant, translating to annual cost reductions of €100,000-200,000. Additionally, when a gas chromatograph experienced technical issues, CLARITY Prime's soft sensors – which use mathematical models, existing sensor signals, and process knowledge to estimate critical variables – provided reliable CO concentration estimates at the LTS reactor outlet, allowing the plant to maintain optimal shift reactor performance despite the instrument failure. The enhanced availability and accuracy of measurements have allowed Yara's plants to safely operate closer to design limits, maximising production efficiency.

Retrospective analysis showing optimisation potential in Yara's ammonia plant through intelligent dew point constraint management illustrates how CLARITY Prime's predictive analytics can optimise CO slip while maintaining safe operating parameters (Fig. 6).

Case study 2

Indorama optimises HTS performance

CLARITY Prime was first adopted at Indorama's world-scale fertilizer manufacturing facility in Port Harcourt, Nigeria, in one of their ammonia trains. The implementation delivered immediate value through automated health alerts that provide real-time performance indicators, enabling proactive measures to maintain production stability. These automated alerts helped Indorama's team collaborate with Clariant technical experts to optimise the high temperature shift (HTS) reactor's inlet temperature, improving carbon monoxide (CO) slip performance and preventing production losses. Furthermore, the catalyst performance projection capability has significantly enhanced decision-making for turnaround planning based on economic considerations, allowing for more strategic resource allocation.

In Fig. 7 the CLARITY Prime dashboard shows the HTS and LTS catalyst performance projection tool used at Indorama's ammonia plant. The modelling interface enables data-driven decision-making for catalyst lifecycle management and maintenance planning.

Conclusion

Clariant's combination of ShiftMax 217 Plus and CLARITY Prime represents a paradigm shift in ammonia plant optimisation, delivering benefits that neither superior catalysts nor digital tools could achieve alone. ShiftMax 217 Plus provides the foundation with its ultra-low methanol formation, enhanced mechanical robustness, and high activity, while CLARITY Prime's AI-powered Shift Optimizer ensures these capabilities are fully leveraged through real-time performance insights and proactive setpoint adjustments. Together, this integrated approach enables ammonia producers to simultaneously maximise production, minimise energy consumption, ensure regulatory compliance, and extend catalyst lifetime – translating to annual cost savings of €100,000-200,000 or more per plant. The synergy between advanced catalyst technology and digital intelligence empowers operators to move from reactive troubleshooting to predictive optimisation, maintaining peak performance throughout the entire catalyst lifecycle. As the industry faces increasing pressure to improve efficiency and sustainability, Clariant's holistic solution positions ammonia producers to meet these challenges while maximising profitability and operational excellence. ■

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Revamp pathway for incremental ATR methanol capacity

In this study **VK Arora** of Kinetics Process Improvements (KPI) demonstrates that controlled ethane co-feeding combined with intermediate methanol condensation in the synthesis loop provides a practical, low capital, low-risk revamp strategy to increase ATR methanol plant capacity by approximately 5% while remaining fully within existing equipment, metallurgical, and compression limits.

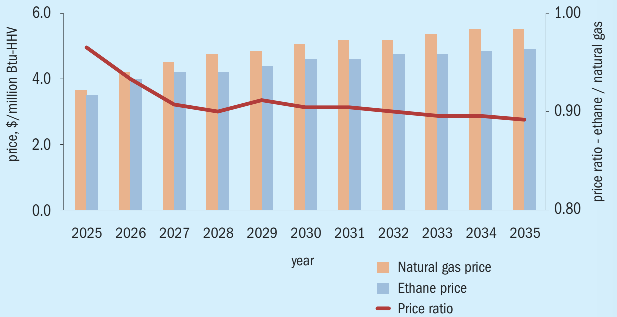
Growing global methanol demand and tightening margins are pushing producers toward brownfield expansions that extract more value from existing assets. This study evaluates an integrated set of front-end and synthesis-loop modifications designed to deliver a 5% throughput increase in a 5,000 t/d autothermal reformer (ATR)-based facility equipped with parallel water-cooled converters (WCCs) and a tube-cooled converter (TCC). The revamp concept applies two complementary measures: controlled ethane co-feeding at a modest, operationally manageable level that increases syngas production while remaining within established ATR operating limits, and intermediate methanol condensation to raise per-pass conversion in the synthesis loop.

Feedstock flexibility is a key enabler of this strategy. On the United States Gulf Coast, long-term pricing trends (Fig. 1) show that ethane consistently maintains a meaningful cost advantage over natural gas on an energy-equivalent basis. This structural advantage is supported by sustained growth in natural gas liquids production, stable petrochemical demand, and expanding export capacity. Ethane also provides higher carbon-to-methanol efficiency, strengthening feed economics across the forecast horizon.

Intermediate methanol condensation removes the methanol formed in the first converter stage, shifts the equilibrium toward additional conversion, and enables higher loop productivity without replacing existing loop equipment. The existing synthesis loop configuration is shown in Fig. 2, and the modified configuration in Fig. 3, where the added heat exchange and separation steps are incorporated into the overall loop arrangement. Together, these measures provide a practical pathway to incremental capacity expansion with limited capital exposure and manageable execution risk.

Importantly, the resulting increase in methanol production is not simply a recovery of lost performance or a catalyst-driven improvement; it represents throughput beyond the plant's established hydraulic, equilibrium, and compression-limited maximum, which would otherwise require major equipment replacement to exceed.

Fig. 1: **Pricing trend (2025-2035) – USGC (natural gas and ethane)**

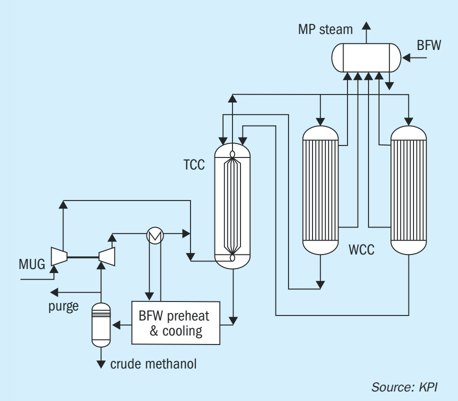


Data source: EDA/EIA Chart: KPI

Front-end operating strategy: controlled ethane blending

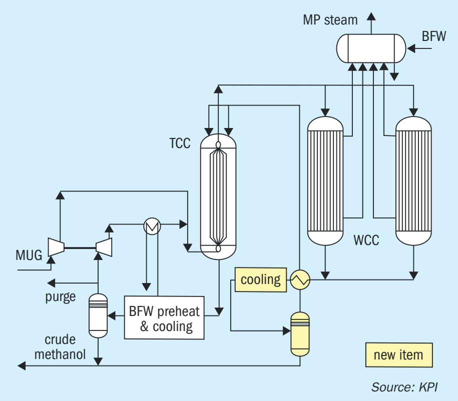
The front-end upgrade introduces a controlled amount of ethane into the natural gas feed to increase syngas production while keeping all reforming equipment within established safe and reliable operating envelopes. The approach ensures that the prereformer, steam methane reformer (SMR), and ATR continue to operate within design and metallurgical limits while maintaining sufficient hydrogen availability from the existing pressure swing adsorption (PSA) system.

Fig. 2: **Existing methanol synloop**



Source: KPI

Fig. 3: **Revamped methanol synloop**



Source: KPI

The study assessed combined feed ethane concentrations ranging from 7 to 15% on a carbon basis to quantify impacts on the steam balance, pre-reformer and SMR performance, tube metal temperatures, ATR operation, and PSA capacity. The base natural gas composition contained approximately 3.5% ethane, typical of the US Gulf Coast; the evaluated range represents additional ethane blended into this feed. Ethane was introduced only as part of the feed blend and was not used for firing, which continued to rely on available purge gases, with natural gas serving as the balancing fuel. The R ratio (H_2–CO_2)/($CO+CO_2$) in the makeup gas was maintained throughout to preserve synthesis loop stability.

Process simulations assessed the combined effects of ethane addition on reforming reactions, thermal profiles, equipment constraints, and the integrated steam system. The analysis confirmed that only a limited ethane blend could be accommodated without exceeding metallurgical limits, burner constraints, or steam system capacity. Based on these considerations, the allowable ethane blend increased methanol production by approximately 60 t/d. Although higher ethane concentrations could theoretically provide larger capacity gains, achieving such levels would require significant modifications to the reforming section and associated systems, which were considered uneconomic for this study. The ethane injection strategy requires no hardware changes to the reforming equipment other than the provision of a suitable gaseous ethane tie-in.

Synthesis loop enhancement through intermediate condensation

The synthesis loop upgrade introduces an intermediate condenser between the water-cooled converter (WCC) outlet and the tube-cooled converter (TCC) inlet. In the current configuration (Fig. 2), effluent from the water-cooled converters flows directly to the tube-cooled converter, achieving high per-pass conversion but carrying uncondensed methanol and water into the downstream reactor. This reduces the reaction driving force and increases overall loop circulation.

The proposed upgrade (Fig. 3) adds a controlled cooling and condensation step that removes methanol and water before the gas enters the tube-cooled converter. The modification includes cooling the reactor effluent, separating the condensed liquid, reheating the cleaned vapor to the required inlet temperature, and adjusting loop control to maintain stable operation. The treated gas contains significantly lower methanol and water concentrations. Because only methanol and water are removed, inert levels remain unchanged, while the reduction in circulating product shifts the equilibrium in accordance with Le Châtelier's principle, thereby improving the thermodynamic driving force in the downstream converter.

The lower gas flow, combined with reduced methanol concentration and a more favorable temperature profile, allows the tube-cooled converter to operate closer to equilibrium, thereby increasing single-pass conversion and reducing overall loop circulation. This allows additional syngas conversion beyond what can be achieved by installing a higher-activity or newer catalyst, because the binding limitation being removed is equilibrium and loop circulation rather than intrinsic catalyst kinetics.

Simulation results indicate that this intermediate condensation step provides an additional 4% increase in plant throughput and improved carbon efficiency. When combined with the front-end ethane-blending upgrade, the overall revamp supports a total capacity increase of approximately 5%.

Integrated steam system configuration and revamp impacts

The plant operates with an integrated steam system that supports all major rotating equipment, including the air separation unit (ASU) main air compressor. High-pressure steam is generated in the ATR waste heat boiler and further superheated in the SMR convection section. Because this steam generation does not fully meet the demand of all steam-driven equipment, additional high-pressure superheated steam is supplied from an auxiliary off-site boiler.

Medium-pressure steam is produced in the synthesis loop and is also superheated in the SMR convection section. High-pressure steam drives the syngas compressor, the synthesis loop recycle compressor, and the ASU air compressor. The syngas compressor turbine operates on an extraction cycle, with the extracted steam providing

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NITROGEN+SYNGAS
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process steam for the steam-to-carbon ratio, ATR burner cooling, and other front-end requirements. Any surplus extraction steam is let down to the medium-pressure header.

The medium-pressure header supplies steam to the forced-draft (FD) and induced-draft (ID) fans, boiler feedwater pumps, and ASU compressor services. Excess medium-pressure steam is used for power generation in an extraction–condensing turbine, and the turbine exhaust flows to the low-pressure header to improve overall energy recovery. Condensate from turbines and from medium- and low-pressure systems is routed to the deaerator to reduce its steam demand. Process condensate is stripped with low-pressure steam, and the off-gases are recovered as SMR fuel to support overall energy efficiency.

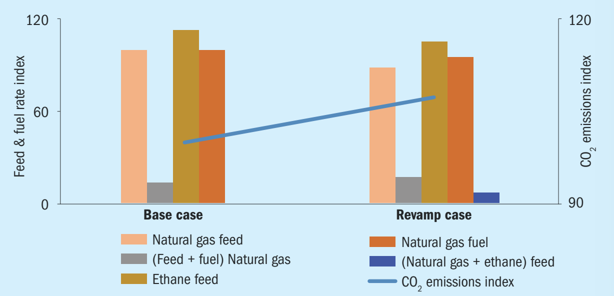
The combined front-end and synthesis-loop modifications introduce coordinated changes across this integrated steam system. On the front end, the natural gas feed rate decreases while natural gas firing increases, resulting in a lower total natural gas requirement for the revamp case (Fig. 4). The SMR experiences a modest increase in firing duty, and auxiliary firing also increases due to lower internal high-pressure steam generation. High- and medium-pressure steam production operates at slightly reduced levels, driven primarily by the lower boiler feedwater preheat temperature in the synthesis loop, resulting from reduced circulation rates.

Oxygen demand rises slightly; however, the oxygen requirement per unit of methanol shows a small improvement. A minor increase in CO_2 emissions is observed, largely reflecting the shift in fuel composition as a greater fraction of purge gas is routed to the PSA for hydrogen recovery. This adjustment helps maintain the target R ratio in the makeup gas.

Within the synthesis loop, intermediate condensation significantly increases single-pass conversion and improves carbon efficiency, thereby reducing the required purge rate (Fig. 5). A larger share of the remaining purge is directed to the PSA for hydrogen recovery and recycle, supporting the target R ratio but reducing the heat available from tail gases. This reduction is offset by additional natural gas firing. Importantly, these changes do not impose any additional power demand on the makeup gas or recycle compressors.

This confirms that the incremental methanol production is not achieved by pushing the existing synthesis loop to higher circulation or compression, but by removing equilibrium and product buildup constraints that normally define the plant's maximum achievable rate.

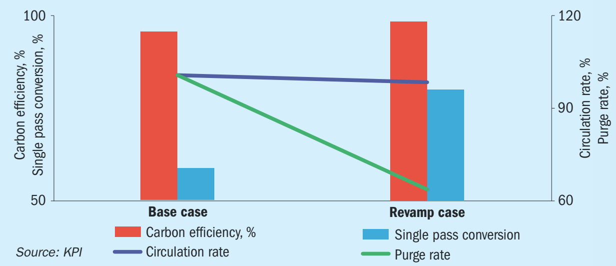
Fig. 4: **Feed, fuel and CO_2 emissions**



Note: All the numbers are represented as % of base natural gas feed rate

Source: KPI

Fig. 5: **Carbon/conversion efficiency and circulation/purge rate**



Source: KPI

Overall, the revamp reflects a balance between improved carbon efficiency in the synthesis loop and modest adjustments to front-end energy use. The integrated steam system accommodates these shifts in circulation, boiler feedwater preheat temperature, and purge gas routing without requiring modifications to steam generation or any equipment, resulting in a net capacity increase of approximately 5% with manageable impacts on utilities and emissions.

Purification System Considerations

The introduction of ethane into the reformer feed and the use of intermediate methanol condensation in the synthesis loop increase both crude methanol production and reaction water generation, resulting in proportionally higher process loads entering the purification section. The primary impacts are increased vapor and liquid traffic through the light ends, refining, and rectification columns, along with corresponding increases in reboiler and condenser duties. These changes are a direct consequence of higher overall throughput rather than any shift in reaction chemistry or impurity formation.

Importantly, the upstream modifications do not alter the fundamental impurity speciation. The relative formation of oxygenates, higher alcohols, and heavier components remains essentially unchanged, and the reduced loop circulation associated with intermediate condensation does not introduce new by-products. As a result, relative volatilities and separation factors remain stable, and no additional mass-transfer limitations are expected.

Conventional three-column methanol purification systems typically include sufficient hydraulic and thermal design margins to accommodate the modest increases in flow and duty associated with a 5% capacity revamp. Nevertheless, a focused review of column hydraulic capacity, heat-transfer margins, and tray or packing performance is recommended to confirm operability at the increased throughput. Overall, the revamp does not require changes to the purification configuration or product quality specifications.

Economic evaluation and project viability

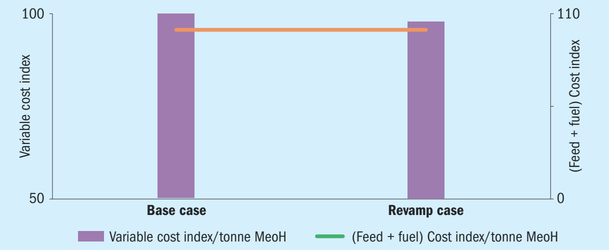
The economic performance of the proposed revamp is governed by methanol netback, feedstock economics, capital intensity, and the period over which incremental benefits are realised. The base case is evaluated over a four-year period, consistent with conservative screening criteria commonly applied to brownfield revamps. When assessed over this short horizon, project economics reflect the limited ability of incremental capacity projects to fully monetise their benefits within a compressed timeframe.

As shown in Fig. 7, project economics strengthen materially when evaluated on a longer-term operating basis, without any increase in capital investment. The revamp delivers stable incremental margin through higher throughput and improved carbon utilisation in the synthesis loop, and these benefits compound over time. When viewed over a realistic remaining asset life, the NPV-to-Capex ratio increases progressively across all netback scenarios, clearly demonstrating the modification's underlying economic resilience and value-creation potential. This behaviour is typical of low-capex revamps, where durable operating improvements outweigh short-term payback metrics and generate sustained returns over extended operating periods.

Feedstock considerations further support the economic case. On the US Gulf Coast, ethane maintains a structural cost advantage relative to natural gas on an energy-equivalent basis, supported by abundant NGL supply and established pipeline infrastructure. Where ethane is available via an existing or nearby pipeline, co-feeding improves reforming economics without introducing material supply risk or requiring capital-intensive storage or logistics. Combined with the improved carbon efficiency achieved through intermediate methanol condensation, the revamp benefits from both margin enhancement and feedstock efficiency.

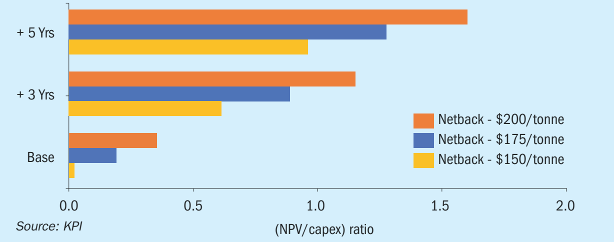
The capital expenditure used in this analysis is intentionally conservative, incorporating allowances for tie-ins, execution risk, and the installation of incremental synthesis-loop equipment, while all existing major process equipment remains unchanged. In practice, site-specific factors may reduce realised Capex, further improving economic outcomes. Sensitivity to both lower and higher Capex levels can be evaluated on a plant-specific basis to reflect layout, constructability, and integration constraints. Facilities with favourable integration opportunities or extended asset-life planning horizons will find the economics particularly attractive.

Fig. 6: **Variable cost index (per tonne MeOH)**



Source: KPI

Fig. 7: **(NPV/capex) ratio**



Source: KPI

Conclusion

This study demonstrates that controlled ethane co-feeding combined with intermediate methanol condensation in the synthesis loop provides a practical, low-risk pathway to increase methanol plant capacity by approximately 5% while remaining fully within existing equipment, metallurgical, and compression limits. The revamp removes equilibrium and circulation constraints that define the plant's current maximum sustainable operating rate – constraints that cannot be addressed solely through catalyst replacement.

From an economic standpoint, the analysis confirms that while conservative short-term evaluation may understate project value, the revamp's full benefit is realised when assessed over a longer-term operating perspective. The incremental capacity and efficiency gains are structural and enduring, allowing value to accumulate steadily over time without additional capital exposure. This characteristic makes the revamp particularly well-suited for producers with asset stewardship strategies that extend beyond near-term payback criteria. Favourable feedstock dynamics, particularly the sustained cost advantage of ethane given existing infrastructure, further enhance margin durability and operating cost competitiveness.

Based on conservative capital assumptions and achievable operating improvements, the proposed revamp represents a balanced, economically resilient option for producers seeking incremental capacity, improved carbon efficiency, and enhanced long-term competitiveness in existing ATR-based methanol facilities. The combination of minimal capital intensity, proven technology within existing equipment envelopes, and progressive value accumulation over extended evaluation periods positions this approach as an attractive pathway for capacity optimisation. ■

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Next generation hydrogen technology

NX eBlue™ is a next-generation hydrogen production technology, ready for industrial deployment, that integrates electrification with renewable energy to deliver a low-carbon, high-efficiency alternative to traditional steam methane reforming. **M. Antonelli**, **M. Mennella**, and **Dr. S. Romagnuolo** of KT Tech S.p.A. describe NEXTCHEM's proposal for the electrification of steam methane reforming.

The global chemical industry is a cornerstone of modern society, providing essential products such as fuels, polymers, and specialty chemicals. However, it is also a significant contributor to greenhouse gas emissions, primarily due to its reliance on fossil-based energy and feedstocks. Among these emissions, carbon dioxide (CO_2) represents the largest share, posing a critical challenge in the context of climate change and international decarbonisation targets.

Electrification of chemical processes has emerged as a promising pathway to mitigate CO_2 emissions by replacing conventional thermal energy – typically derived from combustion of natural gas or other hydrocarbons – with renewable electricity. This transition enables the integration of low-carbon energy sources, such as wind, solar, and hydropower, into chemical manufacturing, thereby reducing the carbon footprint of core industrial operations. Beyond emission reduction, electrification offers additional benefits, including improved process controllability, enhanced energy efficiency, and compatibility with emerging digitalisation strategies.

One of the most impactful contributions to the CO_2 emissions lies in steam methane reforming (SMR), the dominant industrial route for hydrogen production. SMR accounts for a substantial fraction of global CO_2 emissions because it combines high-temperature endothermic reactions with direct combustion of fossil fuels to supply heat.

By substituting conventional fired heaters with electrically powered systems – such as resistive heating, induction, or microwave technologies – the SMR process can significantly reduce direct emissions and enable coupling with renewable electricity grids. This approach not only aligns with the growing demand for low-carbon hydrogen but also supports broader decarbonisation efforts across sectors like refining, ammonia synthesis, and methanol production.

However, the electrification of steam methane reforming also introduces significant changes to the process, defining new characteristics such as a substantial reduction in feedstock consumption and an almost complete capture of the CO_2 produced.

NX eBlue™ reactor and process

Overview of the NX eBlue™ concept

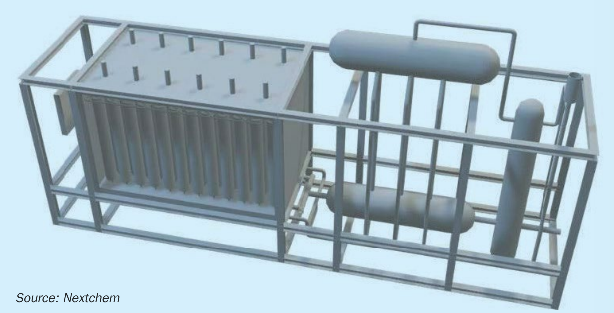
NX eBlue™, a patented electric reforming technology developed by NEXTCHEM is designed to address the urgent need for decarbonisation in hard-to-abate sectors by enabling sustainable hydrogen production through the electrification of steam methane reforming (SMR). By leveraging renewable electricity, NX eBlue™ significantly reduces both feedstock consumption and CO_2 emissions, positioning itself as a solution for industrial applications and utilities seeking low-carbon hydrogen.

NX eBlue™ is not only an advanced electrified reactor but also an innovative process architecture capable of accommodating a wide range of feedstocks – including natural gas, naphtha, LPG, off-gas, and biogas. It integrates state-of-the-art CO_2 capture technologies and delivers high-purity hydrogen with minimal pollutant emissions. The captured CO_2 can be recovered in gaseous, liquid, or supercritical form, enabling flexible downstream utilisation or storage.

Reactor technical features and design

At the heart of the NX eBlue™ process is a proprietary electric reformer (Fig. 1). This reactor utilises commercial electric heating elements arranged around a compact set of tubular reactors.

Fig. 1: **Typical modular layout for small capacity NX eBlue™ reactor**



Source: Nextchem

Key technical features include:

- Simplified maintenance: Electrical components, wiring, and junction boxes are easily accessible, streamlining inspection and replacement.
- Extended component lifespan: Uniform operating temperatures enhance the durability of electric parts.
- Catalyst compatibility: The system employs well-proven commercial catalyst pellets, eliminating the need for specialised catalysts.
- Operational flexibility: The modular design allows for continued operation even if individual heating elements fail, ensuring high reliability and adaptability.

NX eBlue™ pilot validation and industrial readiness

The NX eBlue™ reactor has undergone extensive pilot testing, demonstrating:

- Use of commercial, long-life electric heating elements.
- High operational flexibility and straightforward maintenance.
- Reliable performance across all industrial procedures, including start-up, shutdown, and emergency scenarios.

These results confirm the technology's readiness for market deployment, with offering of licenses, process design packages, proprietary equipment, and digital support services.

The pilot (Fig. 2) was in Chieti, Italy at "Parco Scientifico e Tecnologico d'Abruzzo" (PSTd'A) and is moving to the new NEXTCHEM Green Innovation District (GID) located in Rome, Italy.

Fig. 2: NX eBlue™ pilot

Process design

The NX eBlue™ process integrates renewable power to enable low-carbon hydrogen production through an electrified reforming pathway (Fig. 3).

The system begins with heating and feed preparation, where hydrocarbon feed is conditioned (typically through desulphurisation).

Afterward, two separate mixing points – one handling recycle gas from the CCU and the other for steam – establish the ideal ratio of hydrocarbons to steam before they enter the steam methane reforming reactor.

Electric heating, powered by renewable energy, supplies the necessary thermal input to the subsequent section, reformer preheating and the NX eBlue™ reactor, which converts the feed into a hydrogen-rich gas stream.

Downstream, water-gas shift (WGS) unit(s), heat recovery and steam generation optimise hydrogen yield while recovering energy for process efficiency.

Next, a pressure swing adsorption (PSA) purifies the hydrogen product to high quality.

A CO_2 capture unit, electrically driven, removes carbon dioxide from the PSA byproduct gas stream, ensuring near-zero emissions and supply. It should be emphasised that CO_2 capture occurs on a pressurized gas stream, which has a high CO_2 concentration, thereby facilitating the separation process and minimising associated costs.

Finally, the process incorporates gas recirculation and water recovery to maximise efficiency and sustainability, delivering hydrogen with minimal carbon footprint.

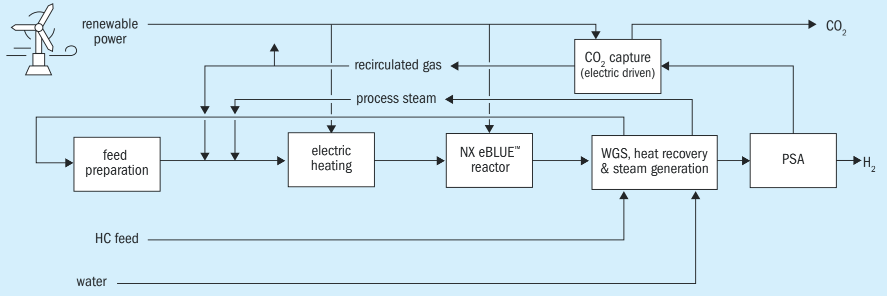
A designated outlet for flare discharge is provided to facilitate the management of inert components within the feedstock.

NX eBlue™ performance

NX eBlue™ technology offers notable performance benefits, especially concerning environmental impact and overall reduction in feedstock, as outlined below:

- It achieves a reduction in CO_2 production ranging from 33% to 45% compared to any grey and blue steam methane reforming technologies, with nearly complete carbon capture efficiency exceeding 98%. The CO_2 production is around 5.5 kg per H_2 kg.
- Due to the process's high efficiency and extensive use of renewable electricity throughout all stages, it achieves a natural gas consumption rate between 2.0 and 2.3 kg per kilogram of H_2 produced.

Fig. 3: **NX eBlue™ process scheme**



Source: Nextchem

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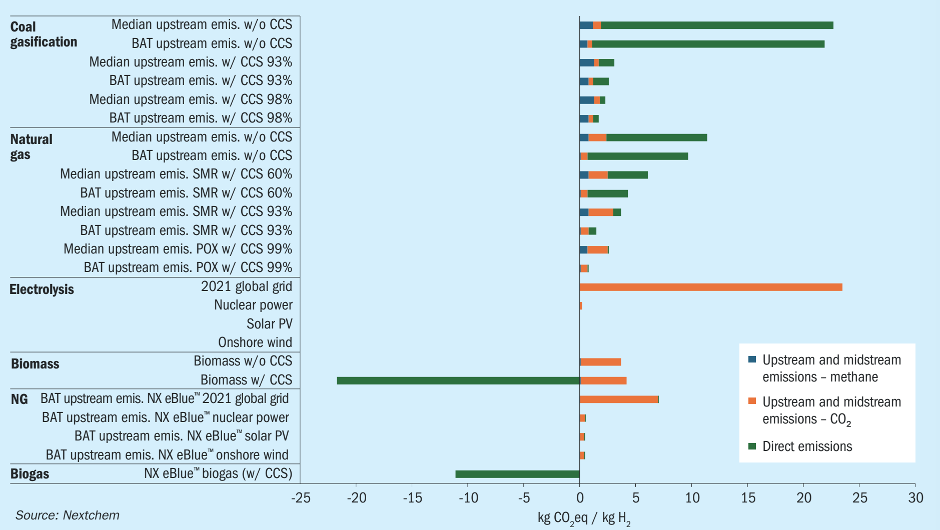
Fig. 4: **NX eBlue™ environmental impact compared to other hydrogen production routes**[1]



Source: Nextchem

- It operates using less than one-third of the renewable energy typically needed for electrolysis, allowing it to effectively complement green hydrogen facilities by ensuring continuous hydrogen production even when renewable power is limited. The renewable power consumption is around 16 ekWh per H_2 kg produced.
- It has the potential to act as a CO_2 negative technology when utilising biogenic feedstocks such as biogas – reflecting the removal of biogenic carbon from the atmosphere during capture and storage. It achieves an exceptionally high CO_2 capture rate, ranging from 9 kg to 11 kg of CO_2 per kg of H_2, depending on the composition of the biogas.

Environmental impact of hydrogen production routes

In 2023, the International Energy Agency (IEA) published a comparative analysis of the emissions intensity of hydrogen production pathways (Fig. 4 – NX eBlue™ has been added for comparison). Coal gasification-based hydrogen without CCS shows the highest impact, with total emissions exceeding ~22 kg CO_2-eq/kg H_2, while even best-available CCS (98% on the flue gas) reduces this to values that range from 1.7 to 3.1kg CO_2-eq/kg H_2.

Natural gas SMR without CCS emits roughly 9–11.5 kg CO_2-eq/kg H_2 totally, dropping to ~1 kg at 99% capture on the flue gas.

Electrolysis powered by the 2021 global grid is highly carbon-intensive, reaching ~23 kg CO_2-eq/kg H_2, whereas renewable-powered electrolysis (solar PV or onshore wind) approaches near-zero direct emissions, with only minor upstream contributions (from 0.2 kg CO_2-eq/kg H_2 of nuclear power to ~0 kg CO_2-eq/kg H_2 of onshore wind and solar PV).

Biomass pathways are unique: without CCS, they emit ~3-4 kg CO_2-eq/kg H_2, but with CCS, they achieve negative emissions of approximately –17.5 kg CO_2-eq/kg H_2, reflecting the removal of biogenic carbon from the atmosphere during capture and storage. This negative value indicates that the process not only offsets its own emissions but also actively reduces atmospheric CO, positioning biomass with CCS as a critical technology for net-negative hydrogen production and climate mitigation.

NX eBlue™ emission intensity

When powered by the 2021 global grid electricity mix, upstream CO_2 emissions dominate, reaching totally around 7 kg CO_2-eq/kg H_2, while direct process emissions remain near zero due to >98% CO_2 capture.

Switching to low-carbon electricity sources such as nuclear, solar PV, or onshore wind reduces upstream emissions dramatically to ~0.5 kg CO_2-eq/kg H_2, positioning NX eBlue™ close to near-zero lifecycle emissions.

The most striking result appears for biogas-based operation with carbon capture and storage: direct emissions become strongly negative, around –11 kg CO_2-eq/kg H_2, reflecting the removal of biogenic carbon from the atmosphere during capture and storage. This negative value confirms NX eBlue™'s potential as a net-negative hydrogen production route when integrated with renewable feedstocks and CCS, offering a critical pathway for deep decarbonisation and climate mitigation.

In summary, NX eBlue™ technology offers a low carbon alternative to conventional steam methane reforming for hydrogen production, supporting a sustainable low carbon hydrogen economy and contributing to the decarbonisation of hard-to-abate sectors. ■

Reference

1. IEA (2023), Comparison of the emissions intensity of different hydrogen production routes, 2021, IEA, Paris https://www.iea.org/data-and-statistics/charts/comparison-of-the-emissions-intensity-of-different-hydrogen-production-routes-2021, Licence: CC BY 4.0 (Last updated 29 Jun 2023)

A regenerative amine system for CCS

A novel high-pressure regeneration (HPR) process for carbon capture in blue hydrogen applications is introduced as a new offering for reducing costs. The process combines a specially formulated solvent with a heat integration network to deliver the separated carbon dioxide at high pressure while reducing capital costs and equipment sizes.

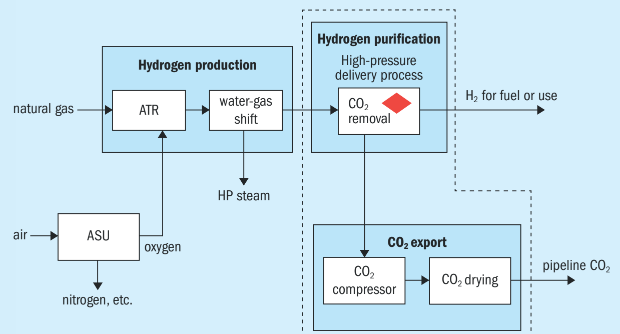
J. R. Dowdle, S. E. Demirel, A. Hassanzadeh and J. M. Binz (Dow, Inc.)

The global low emissions hydrogen market is expected to grow substantially over the next decade, driven by growth in use as fuel as well as its conventional uses in refining and ammonia production. A key contributor to the growing low emissions hydrogen supply is projected to be blue hydrogen production, which requires capture of CO_2, distinguishing it from grey hydrogen production in which CO_2 is vented to the atmosphere. Policy is essential for driving market growth and carbon capture costs need to be reduced, as conventional methods for capturing CO_2 in grey hydrogen applications are not optimised for the new constraint of compression and dehydration required in blue hydrogen production. It is within this context that Dow introduces the HPR process as a new offering for reducing CCS costs in blue hydrogen applications.

Fig. 1 shows a high-level block diagram of a blue hydrogen process, including the scope of the HPR process. The feedstock fuel is usually methane-rich natural gas. A reformer, typically an autothermal reformer (ATR), generates synthesis gas (syngas) from the fuel and an oxygen feed, supplied by an air separation unit (ASU). The syngas is then fed to a water-gas-shift (WGS) reactor, wherein more hydrogen (H_2) is generated and CO is converted to carbon dioxide. The resulting gas stream is referred to as shifted syngas and is then fed downstream to the CO_2 capture unit after heat recovery.

While many technology choices are available for CO_2 capture from shifted syngas, this article compares solvent-based absorption processes using aqueous amine solutions. The CO_2 capture unit removes CO_2 from the shifted syngas stream and delivers it to the compression train where it is dried and compressed to pressures typically exceeding 150 bar and transported for storage or use. The resulting hydrogen stream may be used as fuel for combustion, or upon further cleanup, as a feedstock for other low carbon products such as blue ammonia.

Fig. 1: **Blue hydrogen process showing the scope of the HPR process (dashed line)**



Source: Dow

The CO_2 capture and compression sections represent a significant portion of the total capital and operating costs of a blue hydrogen production facility. Recent reports show as much as one-third of the capital cost resides in the amine unit and compression section, with about half of the combined amine unit + compressor costs attributable to the compressor itself. The main cost drivers for the compression section are a product of the properties of the feed stream: the relatively low delivery pressures, and thus gas density, create the need for large equipment to process the gas which is further compounded by the fact that the CO_2 is water-saturated (in aqueous amine processes), which dictates stainless steel as the material of construction. Hence, delivery of low-pressure CO_2 from the CO_2 capture section will necessarily lead to high compression capital and power requirements.

Delivering CO_2 to the compression train at as high a pressure as possible holds promise as a method to reduce compressor costs by minimising or even eliminating the capital and operating costs of low-pressure compression stages. This requires operating the vessels contained within the regeneration section of an amine flowsheet at the highest pressures economically attainable, considering the limits of the feed pressure, solvent properties and stability, and other factors affecting process cost. The present article introduces an evolution of the amine absorption process

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built around this concept and performs a high-level cost comparison to conventional amine processes.

Available processes, qualitative benefits, and trade-offs

The general process for using aqueous amines to remove acid gases, including carbon dioxide, from gaseous mixtures was first patented in 1930 by Bottoms. Since that time, aqueous amine solvents have found widespread use in acid gas removal applications, including natural gas purification, oil refining, synthesis gas purification, and carbon capture from flue gases. The classic process for removing acid gases from a gas stream using aqueous amines is shown in Fig. 2 (a).

Conventional single-stage process

The process shown in Fig. 2(a) is referred to as the conventional single-stage absorption process due to the absorber having a single feed point for the solvent and hence a single mass transfer contacting section for CO_2 absorption. It has the advantage of simplicity, as the equipment count and process complexity are the lowest of the processes considered in this article. Further, the high CO_2 concentrations typical of shifted syngas streams require a relatively high ratio of solvent circulation rate to feed gas rate (L/G ratio) compared to that of other commonly encountered acid gas removal applications (e.g., pipeline natural gas treating for liquified natural gas production). Unlike post-combustion applications where the absorber diameter is set almost entirely by the gas rate, the high L/G ratio seen in blue hydrogen CCS can cause the liquid rate to have a significant influence on absorber size, which tends to be the highest capital cost item within the amine unit. Because the entirety of the solvent is fully regenerated in the conventional single-stage process, the circulation rate is the lowest of the processes considered in this article, leading to the lowest capital cost of the absorber and amine unit.

The conventional single-stage process has two significant drawbacks, however. The first, which has already been mentioned, is that like all conventional amine processes the CO_2 is delivered from the regeneration section at a low pressure – typically 5-15 psi(g). This leads to high capital and operating costs for the compressor. The second disadvantage arises due to the requirement to meet the H_2 product specifications in the treated gas, which are typically 100 ppmv or lower for blue H_2 applications. Such low CO_2 concentration can only be met if the gas is in contact with a solvent that has been thoroughly stripped of CO_2 (i.e, a solvent with a very low CO_2 loading – defined as the ratio of moles of CO_2 to moles of amine in the solvent). Since all of the solvent is fed to the top of the absorber, this requires that the entire flow of solvent be fully regenerated to this low CO_2 loading, which leads to the highest steam consumption of the processes considered. In turn, operating costs of the single-stage process are relatively high.

Conventional two-stage process

In situations where the high steam consumption of the single-stage process is prohibitive, an alternative is offered by the two-stage absorption process shown in Fig. 2 (b). The idea behind this process is to perform bulk removal of CO_2 with a solvent that is flash regenerated (i.e., pressure swing only, requiring no steam), and to only fully regenerate that portion of the solvent which is necessary to meet the product specification. The absorption thus occurs in two stages: (1) a top polishing section where the lean solvent removes the last remaining amount of CO_2 down to the product specification, and (2) a bulk removal section, where a partially regenerated (semi-lean) solvent performs bulk CO_2 removal. The exact ratio of the flow of semi-lean solvent to lean solvent varies by case and can be optimised for site-specific steam and capital costs.

The advantage of the two-stage process is it requires considerably less steam than the single-stage process. When desired, the reboiler of the regenerator can often be driven entirely from process waste heat from the shifted syngas itself, thus consuming zero steam. The drawback is that the cyclic capacity (difference between the rich and lean loading) of the semi-lean solvent is much lower than the fully regenerated solvent of the single-stage process. Hence, the circulation rate of the two-stage process (sum of the lean and semi-lean flows) is much higher, driving capital costs higher for the absorber and other equipment. Further, the two-stage process retains the problem of low CO_2 delivery pressure and thus leads to high compression capital and power requirements.

High-pressure regeneration process

A new process offering, the HPR process, is shown in Fig. 3. In this process, the rich solvent is introduced into a heat exchange network to maximise heat recovery and thus increase the amount of flashed CO_2 in a series of high-pressure (HP) and medium-pressure (MP) flashes prior to the regenerator. These flash vessels deliver gas into the compression system at a higher net density, decreasing the overall hydraulic sizing and power requirements for the compressor. The HP flash is delivered to the suction of third stage compression, MP flash to the suction of second stage compression, and the LP regenerator to the suction of first stage compression. There is a LP steam auxiliary heater prior to the flashes for startup purposes and intermittent use, but is it not required in normal operation for all instances of the HPR design.

The solvent, UCARSOL™ CC 510, is a crucial element of the HPR process. It is formulated to maximise the amount of CO_2 delivered from the HP and MP flashes, to minimise steam consumption, and to enable operation of the LP-regenerator at a pressure to eliminate the lowest stage of compression present in the conventional one-stage and two-stage processes previously discussed. It is important to note that the solvent is based on commercialised chemistries dating back decades and is not new to CO_2 removal applications. Furthermore, the operating conditions of the HPR process are within the known operating window of the solvent, and increased thermal degradation due to the temperature and loadings of the flashes is expected to be economically manageable.

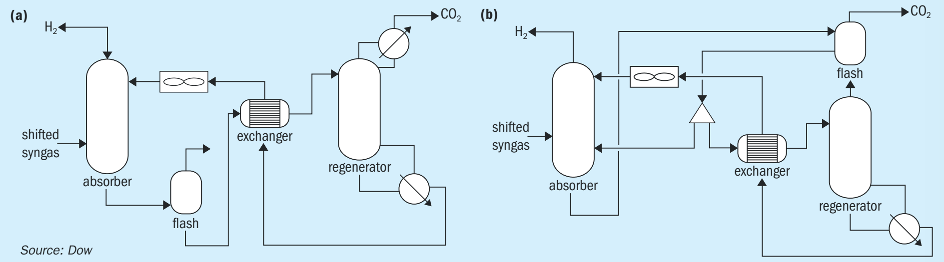
The heat exchange network is a second crucial element of the HPR process. Its key feature is heat integration of the rich solvent with at least three streams: the lean solvent, the semi-lean solvent, and the shifted syngas. There may be multiple points of heat exchange with the shifted syngas, and it is also possible to incorporate compression discharge heat and/or overheads heat into the heat exchange network. Prior to entering the heat exchange network, the shifted syngas is used to supply heat to the LP regenerator reboiler.

The HPR process shown in Fig. 3 is a two-stage process and thus incorporates a semi-lean stream to minimise steam consumption like the conventional two-stage process. A key benefit of the HPR process over the conventional process is the delivery of CO_2 at conditions to reduce compression power and capital. The heat integration design features also enable considerable reduction in solvent circulation rate compared to the conventional two-stage design, reducing capital of the HPR amine unit in addition to the compression savings.

It is important to note that the additional heat extracted from the shifted syngas does not necessarily come at the expense of heat recovery in other parts of the overall hydrogen facility (e.g., boiler feedwater preheating). The additional heat used by the HPR process is heat that is sometimes wasted by conventional systems, in some instances being thrown away in a cooler prior to feeding the shifted syngas to the amine unit.

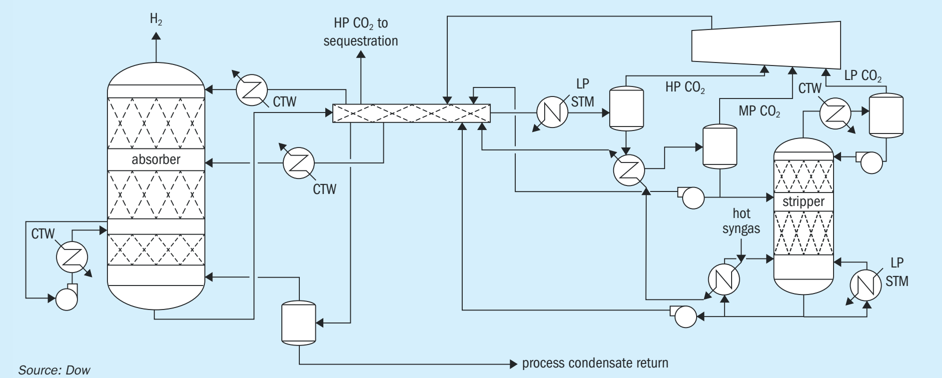
A technical comparison of solvent-based carbon capture options for blue hydrogen applications was performed for conventional processes as well as the HPR process. The results show that the HPR process achieves the lowest operational cost of all processes considered under the assumptions of the case study. It is further shown that the increased exchanger cost required to achieve the results offered by the HPR process are more than offset by the reduction in compression capital and absorber capital, leading to lower capital costs than the conventional processes (Fig. 4). The HPR process presents a technically advanced pathway for reducing carbon capture costs in blue hydrogen applications by improving regeneration efficiency and minimising compression demand. ■

Fig. 2: **(a) Conventional single-stage and (b) conventional two-stage absorption processes for acid gas removal**



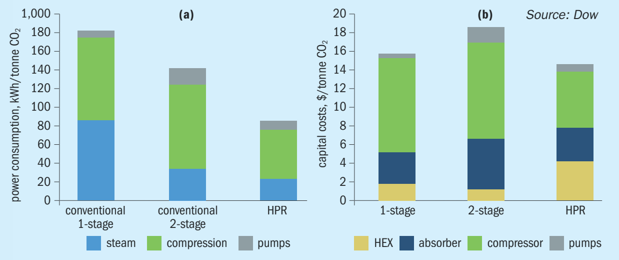
Source: Dow

Fig. 3: **High-pressure regeneration absorption process for acid gas removal from gaseous mixtures using UCARSOL™ CC 510**



Source: Dow

Fig. 4: **(a) Power consumption per tonne of CO_2 and (b) capital cost estimates per tonne of CO_2 for key equipment[1]**



Source: Dow

Reference

1. Dowdle J.R, Demirel S.E., Hassanzadeh A., Binz J.M.: "High pressure regeneration amine system for CCUS in blue hydrogen applications", presented at Nitrogen+Syngas 2026, Barcelona, Feb 10-12, 2026.

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Hybrid cryogenic technologies for high-purity CO_2

The selection of the post-combustion carbon capture technology to be implemented for a decarbonisation project is a crucial element during the early feasibility phases and it is strongly affected by the characteristics of the plant on which it has to be installed. **F. Ferrari**, **E. Disarò**, **P. Felici** and **A. Orsetti** of NextChem highlight the comparative advantages of absorption technologies and the alternative opportunities of using a cryogenic configuration to reach the desired carbon capture rate.

The IEA's Net Zero Scenario requires global carbon capture, utilisation, and storage (CCUS) capacity to reach over 1 gigaton (1,000 Mt) of CO_2 annually by 2030. This is a massive acceleration from current levels, highlighting the necessity of substantial efforts in the direction of implementing new carbon capture facilities that can eliminate between 90% and 99% of CO_2 emissions from industrial facilities.

This article provides a comparative analysis of two main post-combustion carbon capture technologies (i.e. absorption and cryogenic), focusing on their technical principles, operational challenges, economic implications and selection criteria.

Absorption carbon capture

Chemical absorption methods are the most mature option for extracting CO_2 from low-concentration gas streams, offering a robust and scalable solution. Within this category, amine-based carbon capture is recognised as the most referenced technology. A prime example of its effectiveness is in post-combustion CO_2 capture, where carbon dioxide is removed from flue gases after complete combustion of fuel.

Amine-based capture systems are typically structured into three main sections: flue gas pre-treatment, CO_2 absorption, and solvent regeneration; each section plays a critical role in ensuring the overall effectiveness and stability of the process.

The two main columns, i.e. the absorber and the regenerator, are the most critical for the performance and cost structure of the amine-based capture system.

Advantages

Absorption technologies can be considered the most used and widespread solution. Industrial applications for post-combustion amine carbon capture technology range from very large capacities equivalent to 4,776 t/d (e.g. Petra Nova plant in Thompsons, USA) to a wide spectrum of flue gas qualities including very low carbon dioxide concentrations lower than 2 mol-% (e.g. Casalborsetti plant in Ravenna, Italy).

The technology's maturity significantly reduces the risks of adoption, including in industrial sectors that have not previously implemented such units. Moreover, the technology can reach a very high capture rate reaching potentially up to 98% of CO_2 removed from the flue gas in conventional industrial plant such as steam methane reforming plants for hydrogen production.

Challenges

The process involves the use of formulated amine-based solvents, which are subject to degradation in presence of oxygenates therefore raising environmental concerns that shall be adequately addressed in design of the unit.

The additional issue is represented by the corrosivity of the solvent that requires a dedicated material selection of the asset to ensure the long-term operation of the unit but also might impact on the associated capex.

The main challenge for amine carbon capture units is represented by the thermal energy demand necessary for solvent regeneration that dramatically affects plant opex.

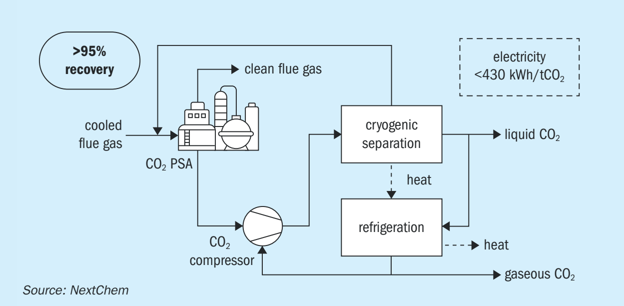
This element is less critical in those contexts where low pressure steam might be available in the complex, but can be an issue when the upstream facilities do not have additional waste heat to be recovered and dedicate to the regeneration of the carbon capture section, such as in power plants or cement factories.

Cryogenic carbon capture

Cryogenic carbon capture involves a physical separation process based on the differences between the boiling points and the transition from gas to solid phase for the components in the mixture.

Thanks to the high recovery rates and high CO_2 purity downstream of the carbon capture unit, in recent years cryogenic technologies has been gaining a considerable attention and multiple licensing companies have been proposing both conventional and non-conventional solutions.

Fig. 1: **Schematic of NX CryoCOOL™ unit**



Source: NextChem

However, to overcome bottlenecks in conventional technologies, the possibility to combine two or more CO_2 separation methods ensures a better performance (usually identified as hybrid processes).

In particular, the most promising solution would leverage on the possibility to combine an adsorption step, using a pressure swing adsorption unit (PSA) specifically dedicated to CO_2, plus a cryogenic section to ensure its separation in liquid phase from the other molecules.

NextChem has developed its own proprietary configuration, commercially identified by the name NX CryoCOOL™, which is characterised by a strong thermal efficiency through the minimisation of thermal losses and the maximisation of the available frigories utilisation.

As shown in the simplified scheme in Fig. 1, the compressed and cooled flue gas is delivered to a CO_2 PSA unit where the feedstock is separated in a concentrated CO_2 stream and in a nitrogen-rich flue gas stream.

The tail gas from the PSA is then compressed in a dedicated machine to reach the pressure level that ensures the generation of the necessary frigories through the Joule-Thompson effect.

The incondensable gases are then separated in the cryogenic section to be recycled back to the PSA and reach the maximum achievable CO_2 recovery.

The purified CO_2 stream is either separated in the cryogenic section in liquid phase or vaporised to recover additional frigories for CO_2 condensation, therefore reducing the specific consumption per tonne of CO_2 captured.

Table 1: **Technological qualitative comparison**

	Absorption (amine based)	**Hybrid cryogenic**
Technology maturity	High	High, but not yet industrially applied*
Carbon capture rate (typical/max)	High, 98%	High, 95%
Minimum CO_2 concentration (for economic feasibility)	2 mol%	15 mol-%
Product CO_2 phase	Gas	Liquid (Gas optionally)
Capital expenditure (capex)	Low	High
Operational expenditure (opex)	High as thermal consumption	High as electrical consumption, but lower than absorption case
Layout demand	Low, possibility to adapt in case of reduced space availability	High

Source: NextChem elaboration based on executed multiple Feasibility Studies.

**Each single technological unit operation has been already applied multiple times, but a combined configuration has been rarely implemented.*

Advantages

Hybrid cryogenic configurations for carbon capture can be considered a combination of very consolidated technologies, therefore, even if its application has not yet been fully implemented at industrial capacity, the associated technological risk should be considered minimal.

On the other hand, the technology offers the opportunity to provide a fully electrified solution that does not necessarily require complex heat integrations with the upstream assets to ensure its operability, while the absence of any solvent does not create any issue on the eventual presence of degradation component that might be critical for environmental authorities.

The additional advantage of this solution is the possibility to achieve very high CO_2 purity without the need for major purification steps downstream of the unit.

Challenges

The necessity to reach cryogenic temperatures requires the utilisation of a refrigerant and it is therefore energy intensive due to the high electrical demand from the associated compressors.

This element can be partially mitigated if the CO_2 is to be delivered in gaseous phase, therefore allowing for a partial recovery of the frigories by flashing the product stream, but still requires all the necessary assets to manage the refrigeration.

The complexity of specialised equipment together with the insulation required for the cold service have a dramatic effect on the unit capex. The combined effect of the opex and capex constraints usually limits the opportunity to install such a cryogenic configuration on post-combustion carbon capture when the CO_2 concentration is above 15 mol-%.

Qualitative technical comparison

Based on NextChem experience in performing multiple feasibility studies in different industrial sectors, a technological comparison of the two technologies is qualitatively summarised in Table 1.

The qualitative evaluation might suggest a slight preference for absorption technologies, mainly due to the high capex required for cryogenic configurations unless a significant advantage on the associated opex is present.

The results of more analytical evaluation highlight the following points for

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Table 2: **Utilities consumption comparison**

	Absorption (amine based) + liquefaction	Hybrid cryogenic
LP steam, t/t CO_2	1.1 – 1-4	N/A
LP steam, kWh/t CO_2	650 - 850	N/A
Power, kWhe/t CO_2	150 - 300	400 - 500
Cooling water, t/t CO_2	80 - 180	80 - 15

Source: NextChem elaboration based on executed multiple feasibility studies.

further attention when selecting the technology to be applied:

- The CO_2 concentration in flue gas should be the first parameter checked to exclude, a priori, the possibility of adopting a specific technology. For example, if the concentration is below 15 mol-%, only absorption solutions may be technically or economically feasible.
- The product phase should be addressed ex ante, because the need to deliver the product in liquid form may substantially increase the additional capex/opex of the selected technology, requiring the installation of a dedicated liquefaction section.
- The availability of utilities – such as low-pressure steam for amine regeneration – and the potential high cost of electricity are critical drivers that should be factored into the technology comparison; in some cases, they can overturn a solution's apparent capex advantage because of substantially higher opex.

To provide a fair comparison between the two technological solutions, a comparison is made with the following starting elements:

- CO_2 concentration at 15 mol-%;
- CO_2 to be delivered in liquid phase.

To align the overall analysis between the two technologies, the hypothesis is to couple a conventional licensed absorption solution with NextChem CO_2 liquefaction technology NX CLIQ™ – the basis for the hybrid solution that combines a cryogenic configuration with CO_2 PSA is NX CryoCOOL™ technology.

Configurational comparison

Starting from the emission point, both technologies share configurational similarities for the initial gas conditioning stage: Flue gas undergoes cooling in a quencher, a direct-contact column where recirculated water reduces the gas temperature to levels suitable for downstream processing.

In the case of the absorption technology, upon exiting the quencher, the cooled flue gas is directed through a blower to ensure sufficient pressure to overcome only the pressure losses across the absorber. In the case of a hybrid cryogenic it is necessary to foresee a compressor/blower, which raises the pressure high enough to allow the CO_2 PSA to adequately perform the target carbon dioxide separation from flue gas.

Downstream of the CO_2 separation stage both technologies require a subsequent step in which the CO_2-rich stream is compressed to enable the subsequent cryogenic separation.

The topological configuration is almost equivalent, but the main difference is represented by the quality of the stream to be treated because downstream of the regenerator in the absorption case the CO_2 is almost pure, while in the hybrid case the tail gas from the CO_2 PSA is only partially concentrated because the final separation from incondensables is performed within the cryogenic section in the liquefaction column.

This compositional difference necessitates overdesign of the affected equipment, meaning the hybrid configuration requires larger pieces of equipment than those needed for the liquefaction unit downstream of the absorption carbon capture section.

All these elements, together with the need to install specialised heat exchangers, cryogenic equipment, and insulation materials, typically lead to higher capex for the hybrid configuration. This increase may be partially offset when calculating total investment cost if some items can be modularised (e.g., the PSA), thereby reducing overall construction costs.

Operational comparison

The comparison between the two options is not complete without accounting for the differing operating consumptions required by each technology. Although the hybrid configuration requires larger equipment in the cryogenic section, the energy needed to regenerate an aminic process is the most critical factor affecting the competitiveness of the absorption technology.

As shown in Table 2, the absorption technology coupled with a liquefaction section has specific consumption that is substantially higher than that required by the cryogenic solution. Therefore, in some regions the 20-year opex may offset the higher capex.

KPIs for technology selection

When selecting a carbon capture technology, the following parameters should be considered:

- Carbon capture rate (%): CO_2 captured from flue gas
- CO_2 purity (%): Achievable as requested by the downstream users/off-takers
- Energy consumption (kWh/ton CO_2): Total energy required (thermal and electric)
- Unit flexibility: Capability of the technology to be integrated with the upstream system
- Capex
- Opex
- Layout

When a post-combustion carbon capture unit is installed as a revamp of an existing plant, the ability to properly integrate the new equipment into the current system is the key factor in ensuring the feasibility of the new configuration.

Conclusions

By analysing the different options when selecting the post-combustion carbon capture technologies to be applied, it is revealed that each approach has distinct advantages and challenges depending on the industrial application.

Absorption technologies are the most mature solution for large-scale plants especially at low carbon dioxide concentration, offering a high carbon capture rate but demanding significant energy input and careful solvent management.

Hybrid cryogenic technologies provide the opportunity for achieving high-purity CO_2 and might be the preferred option to minimise the system opex, especially if the flue gas is concentrated in CO_2 and the product must be delivered in liquid phase. ■

SOURCE: SIEMENS

Lower site emissions and energy costs

Toby Hallitt, **Kunpeng Guo** and **Mayank Patel** of Siemens Digital Industries Software explain how digital process twins and real-time optimisation can be used to achieve significant cost savings and reduce emissions at industrial sites.

Industrial sites face mounting pressure to reduce carbon emissions and energy costs while maintaining operational reliability.

The chemical and process industries are under unprecedented pressure to reduce carbon emissions and energy costs while maintaining operational efficiency. Global sustainability goals, tightening regulations, and rising and spot energy prices demand innovative solutions that go beyond incremental improvements. Industrial sites face mounting pressure to reduce carbon emissions and energy costs while maintaining operational reliability. With carbon pricing expected to rise significantly worldwide, companies that fail to act risk losing competitiveness and market share. Reducing emissions is not just an environmental imperative – it is a direct path to cost reduction and long-term sustainability.

Siemens believes achieving sustainability goals requires a three-phased approach:

- optimising energy usage to reduce current emissions;
- mitigating harmful emissions through technologies like carbon capture and storage (CCS);
- and developing low-carbon process alternatives.

While carbon capture and process alternatives are long-term strategies, energy efficiency remains the most immediate and cost-effective enabler of decarbonisation. For many organisations, the challenge is clear: how to achieve significant reductions in carbon footprint without major capital expenditure and while meeting plant demand?

The complexity of utility systems poses a barrier to optimisation

Utility systems – typically comprising of boilers, turbines, cogeneration units, complex steam, condensate, renewable resources, fuel gas and power networks – are at the heart of this challenge (Fig. 1). As the backbone of industrial chemical operations, they are major contributors to energy consumption and emissions. Consequently, managing them manually has become increasingly challenging, not only due to their inherent complexity, dynamic nature, and the multitude of variables at play, but also because of the recent integration of renewable resources (solar, wind, and green hydrogen) and fluctuating spot energy prices, demanding far more than just experience and intuition. The key question becomes: how can we produce and distribute utilities in a way that minimises both costs and emissions?

The digital twin as operational imperative

Digital replicas of operating assets that combine plant data with high-fidelity process models are bringing a new level of decision support to the operation of utilities systems. They provide many benefits to operators, from information on monitoring and 'soft-sensing' to advice on optimal set-points and energy trade strategy. At the heart of such shadowing systems is an always-current predictive process model of the assets which updates itself periodically based on real-plant performance.

In the context of utility systems, digital process twin technology is now being implemented in many applications in the chemical industry. The associated benefits include: equipment monitoring to determine the real state of equipment; real-time 'soft-sensing' to provide up-to-date performance information which is either difficult or impossible to measure; forecasting to determine future performance based on current equipment state and anticipated operation; operational optimisation to give advice to operators regarding set-points; and finally 'what-if' analysis to anticipate how to operate for future/alternative operating scenarios.

"Digital process twins are a powerful way of providing actionable energy-saving insights and informed choices on how to balance productivity and sustainability goals." – Multinational energy company.

Siemens gPROMS Utilities digital application exemplifies this approach by applying advanced process modelling technology to deliver actionable insights and measurable benefits for utilities systems. The solution integrates seamlessly with plant IT/OT systems and cybersecurity policies. Installed either on a dedicated computer or within a private cloud environment, the system efficiently retrieves plant data before

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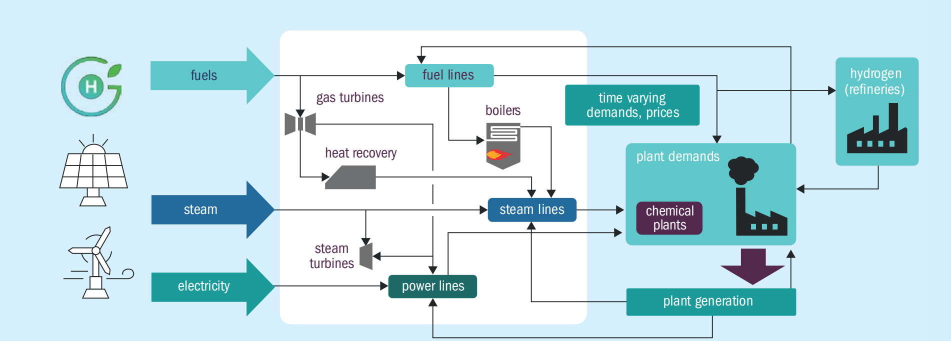
Fig. 1: **The complexity of utility systems**



Source: Siemens

performing comprehensive data validation and reconciliation; a critical process designed to address faulty or missing measurements and ensure the accurate closure of both mass and energy balances. Subsequently, it runs advanced optimisation routines and presents the results clearly on user-friendly dashboards. Key features include:

- Real-time optimisation: Frequent updates based on live plant data and running 24 hours a day, 7 days a week to continuously provide the optimum operation conditions for operator's guidance.
- Custom dashboards: Tailored views for management, finance, and operations teams.
- Parameter management: Easy one-click updates and maintenance for engineers without deep-diving the process modelling.
- What-if analysis: Quick evaluation of scenarios such as steam and power demand changes or energy price fluctuations.

One of the biggest challenges in deploying advanced optimisation tools is ensuring operator acceptance. A sudden shift from manual decision-making to fully automated recommendations can be overwhelming. Siemens addresses this through a multi-level optimisation strategy, which introduces changes gradually and builds trust over time.

For example, at the first level only the continuous steam flowrate is treated as a decision variable and the boiler, cogeneration and steam turbine unit statuses are fixed. This helps build the operator's confidence in the solution, by keeping the number of variables to be adjusted, and thus the recommended actions, to a minimum and increasing savings step by step.

At the second level optimisation, more decision variables can be added, such as the load distribution and status of the cogeneration, boilers and steam turbine units, to further minimise the total operating costs. Furthermore, this multi-level optimisation also provides significant advantages for future closed-loop implementation.

Predictive optimisation for dynamic markets

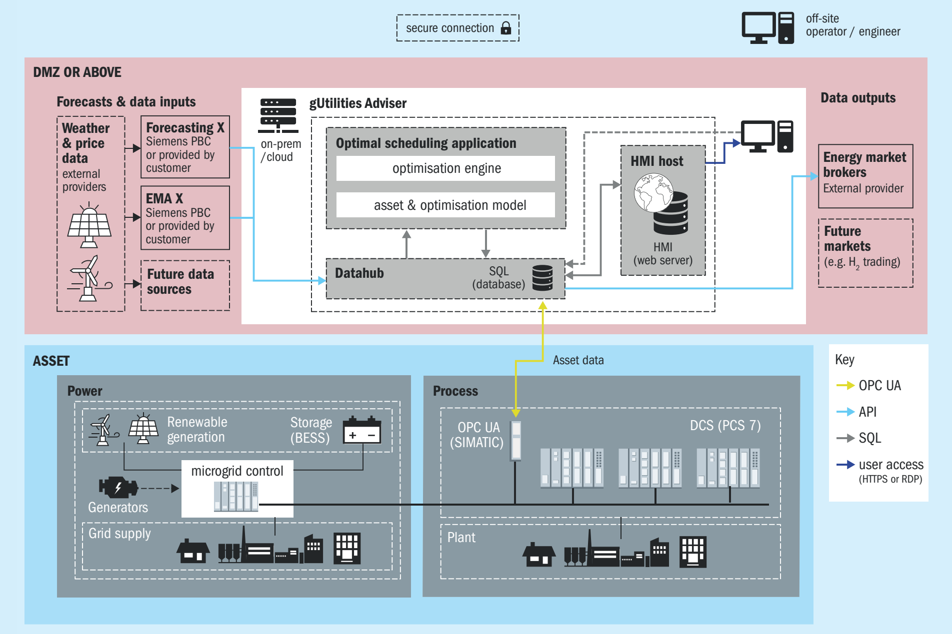
European industries are increasingly adopting decarbonisation and responding to spot energy pricing primarily due to stringent regulations, ambitious climate targets, and the growing integration of renewable energy sources into liberalised markets. However, the renewable energy resources, like solar, wind and green hydrogen, will make the system more complicated to handle due to the availability of weather-dependent features. Also, to enable grid operators to proactively plan generation, maintain a crucial real-time supply-demand balance, and ensure overall system stability and market efficiency, the day-ahead submission of energy demand is a fundamental requirement in a spot energy market, largely because electricity cannot be easily stored.

Siemens gPROMS Utilities operates as a digital process twin, mirroring and optimising an industrial facility's entire energy ecosystem. It does this by seamlessly integrating and interpreting forecast data and comprehensive day-ahead weather forecasts, which are essential for predicting both the availability of on-site renewable generation and the facility's overall energy demand. It also incorporates dynamic, often volatile spot energy prices that shape market opportunities, as well as the facility's detailed production schedule, which defines its underlying energy consumption profile. This powerful integration enables the system to perform complex, predictive optimisation, charting a precise course for the entire subsequent day, broken down into granular hourly or even 15-minute intervals. The ultimate purpose of this intricate analysis is twofold. First, to generate highly refined operational setpoints that guide the facility in dynamically adjusting energy-intensive processes, optimising equipment performance, and intelligently managing energy storage solutions. Second, to formulate a strategic energy trade plan that dictates the most advantageous times and quantities for buying electricity from the grid or selling surplus power back into the market. Through this proactive, data-driven approach, Siemens gPROMS Utilities empowers facilities to not only significantly reduce their overall operating costs by capitalising on market fluctuations and maximising the utilisation of cheaper, often greener energy sources, but also to effectively avoid the substantial financial penalties typically associated with energy imbalances, inefficient consumption patterns, or deviations from grid commitments.

Reducing CO_2 emissions: A real-world success story

In the way of example, a major European refinery faced some of the aforementioned challenges in optimising its utility system. The refinery involved in this project is a relatively complex crude oil refinery with a fluid catalytic cracker and a hydrocracker. Its utility system consists of a cogeneration plant with numerous boilers. The large number of steam headers and the mixing of several fuels gives rise to multiple decisions that affect performance.

Fig. 2: **gPROMS Utilities Energy Optimisation Tool**



Source: Siemens

Rising energy costs and carbon taxes made it imperative to reduce emissions and operating expenses without compromising production reliability. The objective was to minimise operating costs, including fuel, electricity, water, and CO_2 taxes.

gPROMS Utilities Energy Optimisation Tool was implemented to reduce energy consumption and CO_2 emissions, leveraging real-time plant data to run optimisation models and provide actionable recommendations via user-friendly dashboards. The twin is linked to plant data systems, updating itself through machine-learning capabilities, validating actual performance and, where appropriate, identifying departures from normal operation.

A multi-level optimisation strategy, as outlined previously, was adopted to ensure operator confidence and smooth adoption of the technology, along with the deployment of user-friendly web-based dashboards in the control room, highlighting easy to follow instructions on beneficial operating changes which operators can view and act upon. These dashboards were developed through a collaboration between all stakeholders, and they provide a comprehensive summary of utility system performance, all presented on a consistent basis. Visualisation of the twin is seen to be critically important to give operators greater insight and confidence to operate the process safely at the optimum point with a view to reducing green-house gas emissions and reducing energy consumption.

The immediate savings following the project delivery were estimated to be approximately €800,000 with a payback time of less than six months. A further €3.6M in incremental savings was achieved in the next few months through continued use of the solution, resulting in significant base-line savings on the refinery site. With a proven track record of continuous operation spanning more than six years, the solution unequivocally demonstrates its remarkable robustness.

As a wider beneficial impact, operators transitioned from intuition-based decisions to data-driven optimisation and there has been improved understanding and knowledge of energy consumption across the refinery within different stakeholders, with the Utilities Twin acting as a focal point to make improvements in many different aspects of energy consumption. As such, the twin is delivering improvements, keeping the refinery utility system running optimally, and making a significant contribution to the refinery's decarbonisation and energy reduction goals.

In conclusion, Siemens' gPROMS Utilities solution delivers a unique combination of accuracy, adaptability, and ease of use. By leveraging digital process twins and real-time optimisation, industrial sites can achieve significant cost savings, reduce emissions, and secure a competitive edge. ■

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