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37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52

Number 377

May | June 2022

nitrogen+syngas

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Methanol markets

India's urea industry

Ammonia synthesis catalysts

Green hydrogen

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

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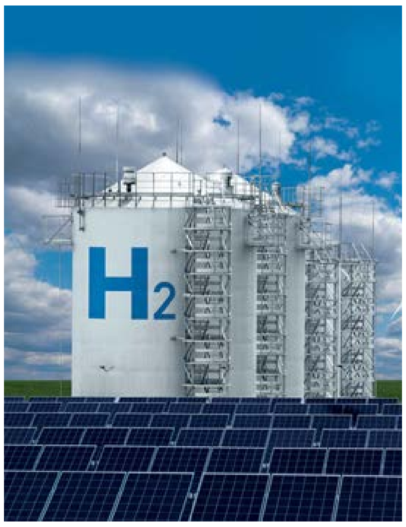


Cover: Scharfsinn86/iStockphoto.com

CONTENTS

18 **Methanol markets – chemicals to the fore**
For some years the fastest growing sector of the methanol market was Chinese olefins production. However, with growth there flattening out, it is traditional chemical uses which are taking over again as drivers of demand growth, with, longer term, a major prospect from fuel and energy applications.

22 **India's urea self-sufficiency drive continues**
India's new batch of urea plants are coming on-stream or nearing completion, but can the country regain the self-sufficiency in urea production that it enjoyed in the 1990s?

24 **Nitrogen + Syngas 2022**
A review of papers presented at this year's Nitrogen + Syngas conference, held at the Estrel Centre, Berlin, from March 28th-30th.

28 **Nitrogen project listing 2022**
Nitrogen+Syngas's annual listing of new ammonia, urea, nitric acid and ammonium nitrate plants.

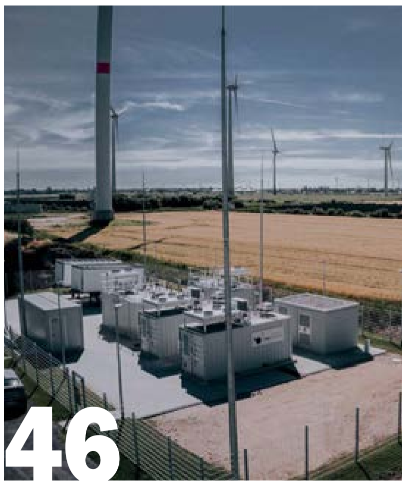
31 **Ready for large-scale decarbonisation**
Erika Niino-Esser of thyssenkrupp Industrial Solutions explains the importance of thyssenkrupp's technologies for sustainable hydrogen and ammonia value chains in the global energy transition, and how they are contributing to a climate-neutral world.

34 **Highly optimised ammonia synthesis catalysts**
Ammonia synthesis catalysts are highly optimised with respect to activity, thermal stability, and poisoning resistance. Further improvements require a deep understanding of their structure and the impact of different parameters on performance. Clariant, Johnson Matthey and Topsoe report on recent studies and developments.

46 **The potentials of power-to-X and green fuels**
Florian Gruschwitz of MAN Energy Solutions takes a look at the current investment decisions influencing green hydrogen projects on the path to decarbonisation, reviews technologies that are available today, and discusses what it will take to ramp up a global green hydrogen economy.

Indian urea

Closing the import gap



Power-to-X

Towards a green hydrogen economy

REGULARS

4 **Editorial**
Turning points

6 **Price Trends**

7 **Market Outlook**

8 **Nitrogen Industry News**

11 **Syngas News**

14 **People/Calendar**

16 **Plant Manager+**
Handling leaks in urea plants: part 1

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BCInsight

Turning points

On February 27th, in a speech to the Bundestag, Germany's chancellor Olaf Scholz described the events then unfolding as a "zeitenwende" – a historical turning point. He was speaking of German foreign and security policy, but it seems likely that Russia's February 24th invasion of Ukraine may end up marking a break with the past in many different ways. Last issue's Editorial was written when Russia's 'special military operation' was still only a few days old, and the situation was still very fluid. Two months on, and for all of the uncertainties remaining, some glimpses of the way that things are changing are becoming clearer.

The effect on ammonia markets has been as serious as feared, as the price graphs on page 7 bear out. Unheard-of price levels of $1,650 per tonne have been recorded in Tampa, and US agricultural economists have talked seriously about prices reaching $2,000/t. The impact on urea has not been quite as dramatic, after an initial price spike, but phosphates and potash markets have also seen record price levels, and the impact of high fertilizer prices on global food production remains a serious concern. Former IFA Director General Charlotte Hebdebrand, working now for the International Food Policy Research Institute, charted the potential impact upon developing countries in a recent blog post. Noting that some countries such as India and China may be able to buffer the price shock via subsidy regimes, she adds: "but those regimes are going to place tremendous fiscal pressure on budgets already stressed by substantial government outlays during the covid-19 epidemic. Relatively smaller markets, especially many African countries, face a particularly difficult situation, as producers and traders are likely to favour shipping limited supplies to larger markets. Given Africa's still-limited use of fertilizers… a decline in fertilizer use would lead to significantly reduced productivity for the continent, with potentially serious consequences for food security."

> "The impact of high fertilizer prices on global food production remains a serious concern."

The impact on energy markets has been equally serious, muted slightly by the new covid lockdowns in China, but base prices for oil look set to hover around $100/bbl for most of the rest of the year, according to the most recent forecast by the US Energy Information Administration, and Henry Hub gas prices are predicted to stay at $7.00-8.00/MMBtu for the remainder of 2022. This latter is not so serious for the US, which has been insulated by its gas surplus from the worst effects of a loss of Russian supply. However, in Europe the situation is very different. Europe was in a gas price crisis even before the events of February, and even with gas still flowing from Russia to Europe through Ukraine's pipelines – too important a trade for either side to be willing to end it for now – European wholesale gas prices have stabilised at $35.00/MMBtu. But at time of writing Russia has stopped deliveries to Bulgaria and Poland, and Ukraine had just announced it would be closing some stretches of the pipelines which carry one third of the gas across its territory. There has been a knock-on effect on global LNG prices, which were around $25.00/MMBtu in Asia at the start of May.

If there is a silver lining in any of this gloom, it may be that it rapidly accelerates a transition towards the use of renewable energy, including in ammonia and methanol production. A recent Bloomburg publication assesses the price for producing ammonia using water electrolysis to generate hydrogen at around $500-700/t at present; expensive in the context of 2020 price levels of $200/t, but looking like quite a bargain in the current market. Europe and India have both struggled with providing affordable feedstock for domestic nitrogen fertilizer production – could renewables offer them a way out of this dilemma? That could be a turning point indeed. ■

Richard Hands, Editor

1 47
2 48
3 49
4 50
5 51
6 52
7
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10
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46

Price Trends

Market Insight courtesy of Argus Media

NITROGEN

Spot ammonia prices made steep losses in west of Suez regions following the $200/t drop in the Tampa May contract price in late April, as supply and demand start to rebalance two months after the removal of Black Sea ammonia exports from the market. Yara has settled the Tampa contract price for May with Mosaic at $1,425/t c.fr, a $200/t drop from April.

In the eastern hemisphere, prices are stable as firmer contract prices start to narrow the range, but some pressure is on the downside, with the latest Indonesian sales tender attracting bids below last done spot business. No award has been confirmed following the latest Indonesian tender. Pupuk Indonesia issued a tender to sell 15,000t of ammonia for 24-25 May loading, targeting a price of $1,125/t f.o.b. Bontang.

Recent market drivers include fresh demand from Turkey, which could pick up following news that producers there will be permitted to export CAN in May. CAN producer Bagfas had reportedly been delaying finalising ammonia import cargoes until Turkish authorities confirm an end to export restrictions. In the east, the confirmation of the Indian government subsidy is expected to bring fresh inquiries from Indian buyers. The fundamentals suggest that west of Suez markets will soon realign with the east but the market remains exposed to any volatility in European gas pricing.

Urea prices dropped sharply in most markets in the wake of the Indian purchase tender at the end of April. OQ Trading bid lowest at $716.50/t c.fr on the east coast of India, and $750/t c.fr on the west coast, while price levels in southeast Asia fell by around $100/t over 24 hours, with similar revaluations seen in Americas markets too. India has now tendered again, seeking to buy around 1.5 million tonnes of urea on 9 May, at which point some stability should be found.

Trade overall remains illiquid – generally with only small lots changing hands and at sporadic intervals – but pockets of demand have emerged, and more are likely to come in the weeks ahead now the reset has happened.

Current market drivers include Indian buying: the country's tenders offer a rare opportunity to place significant urea tonnage in a global market that is currently moving at a snail's pace. Market participants around the world reference it as a hinge around which they determine their trade decisions. There is of course the Russian crisis – despite much-curtailed demand, few will take large short positions because of the fragility of supply in Europe and continued geopolitical tensions.

The outlook looks weaker – demand is still mostly waiting in the wings and supply is still more-than-sufficient to meet it as it arises. ■

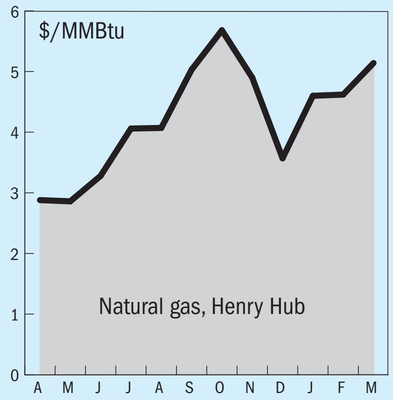
Table 1: **Price indications**

Cash equivalent	**mid-Apr**	**mid-Feb**	**mid-Dec**	**mid-Oct**
Ammonia ($/t)				
f.o.b. Black Sea	n.m.	1,115-1,140	950-1,055	603-710
f.o.b. Caribbean	1,350-1,550	1,020-1,075	875-1,000	575-675
f.o.b. Arab Gulf	975-1,150	860-985	850-1,000	580-620
c.fr N.W. Europe	1,400-1,490	1,150-1,180	1,020-1,120	680-800
Urea ($/t)				
f.o.b. bulk Black Sea	n.m.	518-620	800-905	685-765
f.o.b. bulk Arab Gulf*	700-850	750-825	810-910	730-845
f.o.b. NOLA barge (metric tonnes)	935-970	570-580	770-780	719-840
f.o.b. bagged China	690-820	560-700	830-920	520-630
DAP ($/t)				
f.o.b. bulk US Gulf	1,001-1,066	785-849	814-825	735-757
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	837-859	680-740	680-740	n.m.

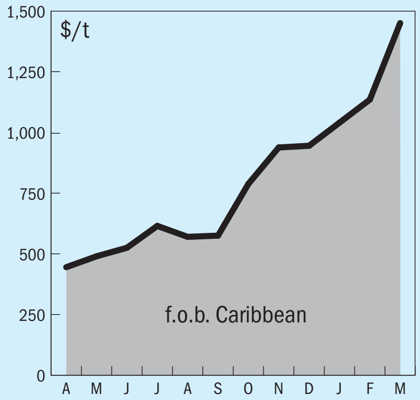
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

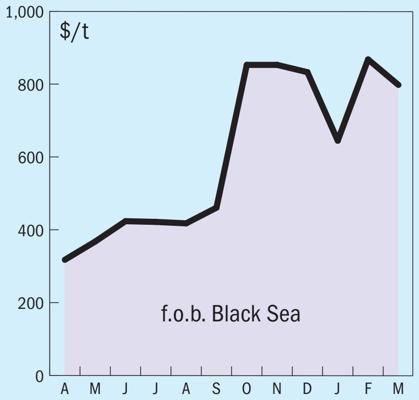
natural gas



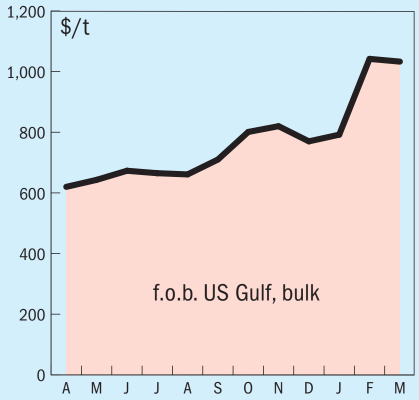
ammonia



urea



diammonium phosphate



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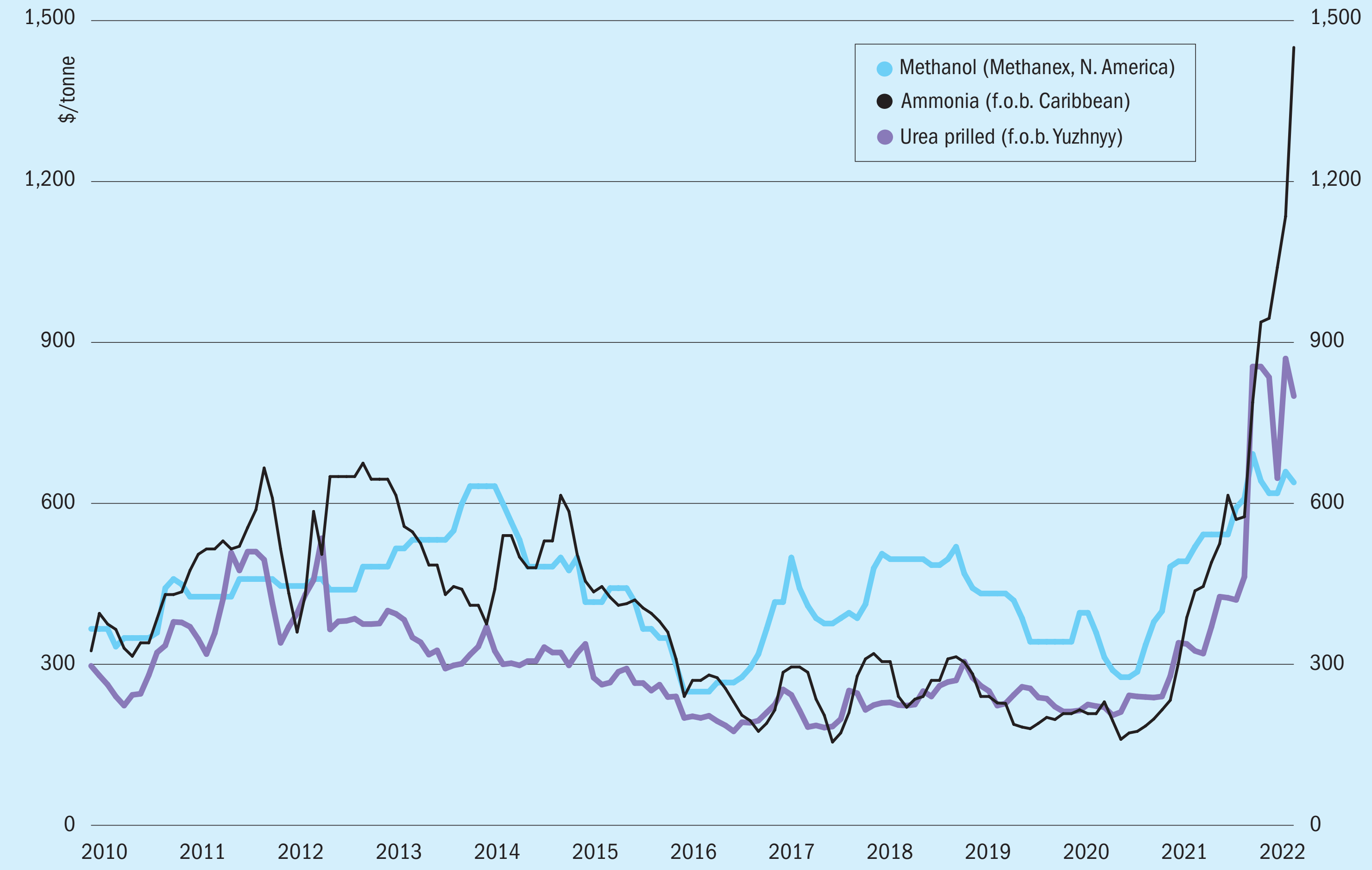
Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- Yara and Mosaic shocked markets with a settlement of $1,625/t c.fr for April, up $490/t on March, and the highest ever price recorded at Tampa, as the removal of Russian and Ukrainian ammonia supply impacted global prices, and Baltic rates soared to $1,500/t. However, April saw some of the global dislocations caused by the Russian conflict begin to ease, while the high prices saw buyers in the US delay purchases, leading to the Tampa price falling back $200/t for May loadings.
- There was also some clarification from the US government that agricultural commodities – including fertilizer – were allowed to be imported from Russia, though payment still remains problematic as Russia is unable to use the SWIFT system.
- At the moment buyers are holding back, looking to see how far prices will fall again. A sale of ammonia from Kaltim was withdrawn after failing to achieve a price target of $1,125/t f.o.b. Bontang, with unconfirmed bids said to be up to $300/t lower. Nevertheless, with up to 20% of market supply via the Black Sea out of the market, there is still strong support for prices in the absence of large-scale demand destruction.

UREA

- After a market flurry in March caused by the situation in Ukraine, urea markets quietened during April as prices began to fall again, and major buyers stayed away from the market, awaiting clarity on future pricing, leaving significant volumes uncommitted.
- India, as ever, was expected to provide support, with state purchaser RCF indicating after a delay of a month in tendering that it was likely to tender for up to 1.5 million tonnes of urea for July delivery. While India appeared to be signalling that it would not be taking urea from Russia, availability from other sources appeared to be sufficient to make up for this.
- It is expected that the RCF tender will set the tone for inquiries from other potential buyers in Brazil, Mexico and southeast Asia. However, while trade has been thin, demand is still believed to be strong and supply still uncertain in the absence of Black Sea tonnages.

METHANOL

- There were signs in late April that methanol prices had peaked, at least for the short term, in all major markets; Europe, China and North America. Argus assessed its European monthly methanol contract price at €520/t for May, down €47.5/t from April on rising inventories in Rotterdam and stable demand.
- Methanol prices tend to track oil, which also peaked in March. Longer term, however, Morgan Stanley has raised estimates for 3Q oil prices from $120/bbl to $130/bbl in spite of project demand destruction, because of the removal of 2 million bbl/d of Russian supply from the market.
- Methanol demand remains fairly strong in derivative markets in Europe and North America, in spite of rising costs and supply chain challenges. However, key market China is suffering from new covid-related lockdowns which could see methanol demand fall. ■

Nitrogen Industry News

CHINA

Casale buys AN/CAN granulation technology

Casale has acquired Hong Kong-based Green Granulation Ltd (GGL), and its proprietary technologies for the design and construction of urea and calcium ammonium nitrate (CAN) granulation systems. Casale says that the takeover is part of a broader strategy aimed at strengthening its leading position in the nitrogen market by leveraging the widest integrated portfolio of efficient technologies, enabling the company to offer a 'one stop shop' for the entire production cycle of nitrogen-based fertilizers, from raw materials to final products. GGL's addition to the Casale group includes the Cold Recycle Granulation process, an advanced fluidised bed technology designed to accept a lower concentration of urea feed melt (ca 96% urea and biuret), as well as a proprietary design for both granulator and scrubber, a team of experts and qualified technicians, and considerable experience in several industrial references. The CRG design has a horizontal layout, leading to lower structural costs and higher efficiency, as well as lower total investment costs and power consumption, lower power consumption and simplified operation, and higher operational flexibility in urea and CAN granulation.

Federico Zardi, CEO of Casale commented: "this acquisition not only adds a new technology that perfectly fits into our portfolio but it also strengthens our presence in the local Chinese market. Casale and GGL started cooperating some years ago and today's investment decision confirms our strong confidence in the CRG granulation process, which has been also incorporated in the new 594,000 t/a urea plant that will be completed in the first half of 2025 in Yangier, Uzbekistan."

UNITED STATES

Tecnimont to build blue ammonia-urea-DEF complex

Maire Tecnimont SpA has been awarded an engineering, procurement and construction contract by "a leading global chemicals producer" to build a blue ammonia plant in the US, at a cost of $230 million. The plant will include a 3,000 t/d blue ammonia synthesis loop plus necessary utilities and facilities, with project completion in 2025, according to Tecnimont. The scope of work includes full engineering activities and supply of all materials and equipment as well as construction supervision services, while construction activities will be executed by another party under a different contract, which will be directly issued by the client.

Pierroberto Folgiero, Maire Tecnimont Group CEO, commented: "This assignment is a concrete evidence of our strong positioning in the energy transition journey thanks to our technology-driven value proposition in these evolutionary times. United States represent one of the highest potential market to break the ice in industrial scale decarbonisation initiatives. Blue ammonia is playing a pivotal role in the world-wide development of decarbonized value chains and we are eager to start working on this exciting project, as it will also pave the way for future opportunities driven by the Country's large wave of investments in gas monetization and energy transition".

The same client has also awarded Tecnimont a $185 million project to build a new urea and diesel exhaust fluid (DEF) plant at the same site. The urea DEF plant will be based on proprietary Stamicarbon technology, and will include a 1,500 t/d urea production unit plus utilities and facilities, including a CO_2 purification plant. Project completion is again expected in 2025.

OCI looking at large scale Beaumont expansion

OCI says that it is considering investing up to $5 billion to expand its Beaumont complex. It is looking at adding both nitrogen fertilizer production and a renewable fuels plant to its existing ammonia and methanol plant east of Houston, according to court filings in Texas. The company has budgeted $2.8 billion for the additional fertilizer production units and $2.1 billion on the proposed lumber waste-to-fuels project, both of which would start operating in 2027. The renewable fuels project would convert wood waste into synthesis gas, with a downstream 1.0 million t/a methanol plant and 100,000 t/a methanol to renewable gasoline plant. Beaumont is close pine forest plantations, which would provide feedstock, as well as ample industrial infrastructure and access to markets. The renewable gasoline would be destined for Europe, where it can earn renewable energy credits.

The nitrogen complex, meanwhile, would include two 3,000 t/d ammonia units, using imported hydrogen and nitrogen, and a 2,200 t/d urea plant. Some of that urea would be converted to diesel exhaust fluid, while the rest would be turned into 1,530 t/d of urea ammonium nitrate.

SWEDEN

High performance nickel alloy

Sandvik has added Sanicro® 625 bar to its range of high-performing nickel-alloys. It is designed for use in advanced machine components that are exposed to acids, alkalis, seawater and other wet corrosive conditions in both cryogenic environments and temperatures up to 593°C (1,100°F). The alloy has a very high (62%) nickel content, making it virtually immune to wet corrosion. A high (21%) chromium content also offers superior corrosion resistance in oxidising (acidic) environments, and a high (8.5%) molybdenum content ensures high resistance to pitting and crevice corrosion. Uniquely, the new addition of 3.5% niobium creates a stiffening effect with the molybdenum and provides good stabilisation against intergranular corrosion. Ductility and toughness are also very high, and the material is approved by all key relevant standards.

Henrik Zettergren, Sandvik, Global Product Manager, said: "625 is among the toughest of nickel-based alloys and sets the gold standard for safety, reliability and performance. When you've got a flange, valve or fitting that simply cannot fail, it ensures high strength, extraordinary corrosion resistance, good fabricability and excellent welding properties."

UZBEKISTAN

Agreement for new ammonia-urea plant

An agreement has been signed between Ferkensco Management Ltd, Enter Engineering Pte, both based in Uzbekistan, and Casale SA to support the construction of a new ammonia-urea plant in Uzbekistan, at an estimated cost of $500 million. Casale was awarded the front end engineering design contract and licensing arrangement for the project last year, and, supported by local design institute UzlitiEngineering, has been appointed as general designer for the project. The ammonia-urea complex will be sited at Yangiyer, in Uzbeikstan's Syrdarya region, and comprise 495,000 t/a of ammonia and 594,000 t/a of granular urea capacity. The project's completion date is expected to be in the first half of 2025.

Lorenzo Pennino, Head of the Commercial Division at Casale SA stated: “We are grateful to have entered into a long-term partnership with Ferkensco Management Ltd, thus enhancing our international reach thanks to this collaboration in Uzbekistan. Our goal is to continue leveraging our strengths by providing top quality technical expertise with an unyielding focus on efficiency, reliability, and safety.”

DENMARK

Haldor Topsoe is now Topsoe

At the company’s annual general meeting on April 7th, the shareholders voted to change the name of Haldor Topsoe A/S to simply Topsoe A/S, as part of a rebranding strategy. Founded in 1940 by Dr Haldor Topsoe, Topsoe aims to become a global leader in developing solutions for a decarbonised world, supplying technology, catalysts, and services for the energy transition, including for challenging sectors such as aviation, shipping, and the production of crucial raw materials.

SWITZERLAND

Clariant joins Renewable Carbon Initiative

Clariant has joined the Renewable Carbon Initiative (RCI). The aim of the RCI is to support and accelerate the transition from the use of fossil carbon to the use of renewable carbon in the chemical industry. Switching to renewable carbon sources prevents additional fossil carbon entering the atmosphere and thus addresses a core problem of climate change. Clariant says that membership in the RCI will allow it to expand on its own solutions in the field of renewable carbon as well as collaborate more closely with partners, suppliers and the industry at large in driving this matter forward. The RCI was launched in September 2020 and is led by the nova-Institute. Members include companies from start-ups to large enterprises as well as additional partners. The initiative aims to advance the switch from fossil carbon to renewable carbon in the chemical industry by reporting on the topic, initiating further action and facilitating exchange between key stakeholders.

“I am convinced that the chemical industry plays a central role in tackling climate challenge and in shaping progress toward a more circular and bio-based economy. This journey can only be achieved through strong commitment to sustainability-driven innovation, ambitious goals, and a close collaboration with partners along the value chain,” said Conrad Keijzer, Chief Executive Officer of Clariant.

PORTUGAL

CIP looking to green hydrogen and ammonia plant

Copenhagen Infrastructure Partners’ (CIP) is teaming up with Portuguese project developer Madoqua Renewables and consultancy Power2X on a €1bn green hydrogen and ammonia plant. The MadoquaPower2X project will be based in Sines, Portugal, and will generate 50,000 t/a of green hydrogen using 500MW of electrolysis capacity, which will be used in the production of 500,000 t/a of green ammonia. Electricity will be sourced from renewable power produced in Portugal, in particular from renewable energy communities for wind and solar plants that are being developed in parallel.

Madoqua chief executive Rogaciano Rebelo said: “We are proud to bring this strong consortium to Portugal and collaborate with partners across the green hydrogen and hydrogen derivatives value chain. Portugal is structurally well positioned to play a leading role in the emerging energy transition space in Europe. The project, along with the development of dedicated renewable power generation assets, will contribute significantly towards Portugal’s National Hydrogen Strategy (EN-H2).”

A final investment decisions is expected in 2023, with first hydrogen production by 2025.

EGYPT

MoU on green ammonia plant

Egypt’s Suez Canal Economic Zone has signed a memorandum of understanding (MoU) with EDF Renewables and ZeroWaste for the eventual production of 350,000 t/a of green ammonia at the port of Ain Sokhna. The $3 billion project will be implemented in several phases according to the Egyptian government. Construction works on the first phase will begin in 2024, with commercial operation planned to begin in 2026. In the initial phase, the plant will be capable of producing 140,000 t/a of green ammonia using green hydrogen from desalinated seawater and renewable energy as feedstock. Capacity will be then gradually raised to 350,000 t/a in subsequent phases.

The ammonia will be used as shipping fuel. Other partners in the project include the Sovereign Fund of Egypt, the Egyptian Electricity Transmission Company, and the Renewable Energy Authority.

GERMANY

RWE planning ammonia complex

RWE is to build an ammonia plant at the site in Germany where it is previously announced plans for the country’s first liquefied natural gas (LNG) import terminal. Initially the firm is focusing on import of ammonia, with capacity to bring in around 300,000 t/a, and be distributed to customers. However, it expects to follow this with a large scale green hydrogen production site at Brunsbüttel neat Hamburg, with the offtakte to be transported to industrial customers via a dedicated pipeline. RWE has talked about eventual ammonia volumes of 2 million t/a.

Robert Habeck, Federal Minister for Economic Affairs and Climate Action welcomed the project, stating: “Russia’s brutal war against Ukraine has made it abundantly clear that we must become independent of fuel imports from Russia. The LNG terminal in Brunsbüttel is an important element in this, as it will increase the capabilities to import gas to Germany. Green ammonia as a liquefied hydrogen derivative can make an important contribution to supplying Germany with green hydrogen. At the same time, we can gain important experience with this project for the conversion from LNG to green hydrogen or hydrogen derivatives.”

CHILE

Wood wins contract for green ammonia facility

Wood Group says it has been chosen to provide conceptual engineering for a large-scale green hydrogen/ammonia production facility in Chile. Total Eren’s H2 Magallanes Project will be located in San Gregorio, Southern Chile, and will comprise up to 10 GW of wind capacity, 8 GW of electrolysis capacity, a desalination plant, and an ammonia plant. It will also have port facilities to transport the ammonia to domestic and international markets. Wood’s scope covers the development of the complete off-grid integrated complex.

Thomas Grell, President of Renewable Energy & Power at Wood, said: “We are very pleased to have been selected by… Total Eren to work on the H2 Magallanes

Project. This highly pioneering and innovative project represents the significant investment needed to realise not only the future of green hydrogen production but the potential of green ammonia, which is vital for ensuring sustainable food production, and an alternative clean fuel source in accelerating the energy transition. This contract signals our continued growth in the region and our determination to realise the bold ambitions shared by both our client and Chile."

VIETNAM

Black & Veatch to advance green energy production in Vietnam

Black & Veatch and The Green Solutions (TGS) have signed a memorandum of understanding (MoU) to advance the production and supply of green hydrogen and green ammonia in Vietnam. TGS specialises in renewable energy project development, manufacturing and services. The MoU involves a project to develop 30,000 t/a of green hydrogen production with the aim of generating 180,000 t/a of green ammonia in support of regional decarbonisation efforts. Black & Veatch will use solar or wind power supplied through the grid to study Vietnamese green hydrogen production and storage.

INDIA

Talcher fertilizer plant to be completed next year

The $1.7 billion Talcher Fertilizer Ltd plant is expected to be completed by September 2024 according to the latest estimate of the Ministry of Chemicals and Fertilizers, a year behind schedule. In a statement to the Indian parliament, minister Bahgwanth Khuba said that the delay was primarily due to the impact of covid-19. Physical construction, being conducted by China's Wuhuan Engineering Co Ltd, is estimated to be just over 20% complete. The project, being developed by the Gas Authority of India Ltd, Coal India Ltd, Rashtriya Chemicals & Fertilizers and the Fertilizer Corporation of India, all state-owned companies, includes a 2,200 t/d ammonia plant using coal gasification as a feed, with a 3,850 t/d urea plant. It will use around 2.5 million t/a of coal from the Talcher mines as feedstock. The project is the first coal-based urea project in India since the 1970s, but has been dogged by arguments over coal allocations and political wrangling.


PHOTO: NEURIZER

Computer model of the proposed NeuRizer plant.

AUSTRALIA

Government to fast track green ammonia project

The government of Queensland has granted 'coordinate project status' to a $4.7 billion proposal to build a green hydrogen and ammonia plat at Gladstone. This allows for a streamlined approval process for the H2-Hub Gladstone project, which will produce up to 5,000 t/d of green ammonia. The ammonia will be used by mining explosives manufacturer Orica, which is working with H2U on plans for an ammonia export terminal in Gladstone. The project includes plans to build up to 3 GW of electrolysis powered by solar and wind energy in Queensland. H2U is expected to make a final investment decision by mid-2023, with operations expected to begin in 2025 and an expansion toward the end of the decade. In a separate announcement, Clariant said that it had been selected to supply AmoMax catalyst for the ammonia synthesis section of the project, which will use Casale technology. Stefan Heuser, Senior Vice President and General Manager of Clariant Catalysts, commented, "We are excited to participate in the highly ambitious H2U project with our technology partner Casale and look forward to driving change together."

Licenses awarded for low carbon fertilizer project

KBR says that it will license ammonia technology to South Korea's Daelim Industrial for the NeuRizer carbon-neutral fertilizer project in Australia. Under the terms of the contract, KBR will provide technology licensing and engineering for the 1,600 t/d ammonia plant, due to start up in 2025. Via Daelim, NeuRizer has also appointed Stamicarbon as urea licensor for the project, which will initially produce 1.0 million t/a of urea fertilizer. NeuRizer (NRZ) is developing its NeuRizer Urea Project (NRUP), aiming to deliver low-cost, high-quality nitrogen-based fertilizer for local and export agriculture markets in South Australia, 550 kilometres north of Adelaide.

TRINIDAD & TOBAGO

HDF takes stake in low-carbon hydrogen project

Hydrogene de France has acquired a 70% stake in the NewGen low-carbon hydrogen development in Trinidad and Tobago. The French firm bought the stake from domestic company and project developer Kenesjay Green Ltd for an undisclosed sum. KGL will retain the remaining 30% interest in NewGen, which will be jointly owned by KGL and an investment vehicle that will allow for the inclusion of additional local investors, HDF said in its press release.

The $200+ million NewGen plant will produce hydrogen using a combination of solar and energy efficiency-sourced power which will then be used by the Tringen ammonia plant at Point Lisas, Trinidad. According to HDF, the NewGen facility will be capable of meeting 20% of hydrogen requirements of the ammonia plant.

WORLD

Catalyst price increases

Topsoe has said that it will increase prices on catalysts as a result of increasing raw material prices for nonferrous metals, natural gas, electricity and other key raw materials used in their catalyst production process, effective immediately. Clariant has also increased prices across its Catalysts business portfolio. The company says that the price adjustments "are driven by the significant escalation of energy and key raw materials costs, as well as the continued increase of freight and logistics costs". ■

Syngas News

NETHERLANDS

Gidara Energy plans waste to methanol plant at Rotterdam

Gidara Energy has agreed with the Port of Rotterdam to develop a new waste to methanol facility in the Netherlands: Advanced Methanol Rotterdam (AMR). Gidara will duplicate its Advanced Methanol Amsterdam project as a template for AMR, using Gidara's patented high temperature Winkler (HTW®) technology, which converts non-recyclable waste to renewable fuels. This technology has been used commercially in four other waste to syngas production facilities. AMR will convert around 180,000 t/a of non-recyclable waste into 90,000 t/a of methanol, while capturing all waste streams for use; CO_2 will be captured and led to local greenhouses; bottom product residue will be used for cement production; and other streams like ammonia and salts will be sold and put to use as feed stock for other industries and road salt respectively, creating a fully circular concept. The facility is scheduled to start detail engineering and construction in the first half of 2023, when a permit is received, and start production of renewable methanol in 2025.

The Port of Rotterdam has allocated an 8.5 ha site at the Torontostraat within the Botlek area of the port, connected to feedstock providers, storage terminals and other companies. The Port of Rotterdam's strategy is to facilitate its existing industries in reducing their carbon footprint and attracting new businesses that fit its ambition to be a CO_2 neutral port and industrial complex by 2050.


Rendering of the proposed new waste to methanol plant.

PHOTO: GIDARA ENERGY

Allard Castelein, CEO at Port of Rotterdam, said: "We welcome GIDARA Energy's decision to set up this state-of-the-art facility to produce sustainable methanol in our Port. The Advanced Methanol Rotterdam plant matches very well with our long-term vision for the transition of the industry in the Port. This development also shows the importance of clear and reliable governmental policies regarding the energy transition. In this case, regulations regarding the use of sustainable transport fuels make companies confident they can invest in plants like this." ■

INDIA

Coal to methanol demonstrator plant

Bharat Heavy Electricals Ltd has inaugurated a pilot coal to methanol unit in Hyderabad. The pilot unit has a capacity of 250 kg/d (82.5 t/a), and aims to demonstrate an Indian-developed fluidised bed gasification technology specially adapted to cope with the high ash content of domestic coal. India is trialling methanol as an alternative fuel for vehicles.

SINGAPORE

Maersk collaborating on green methanol plant

Six companies in the shipping and energy industry have jointly signed a memorandum of understanding to establish what they describe as "Asia's first green methanol plant," which will convert captured biogenic carbon dioxide from decomposition of organic matter and green hydrogen and convert them into methanol. The six companies are: AP Møller-Maersk, which will use the methanol to power container vessels; Air Liquide, which will develop and provide the carbon capture and methanol production technologies; PTT Exploration and Production Public Company, which will integrate the green hydrogen and methanol plant; Oiltanking Asia Pacific, which will provide the methanol storage and bunker supply chain solution; Kenoil Marine Services, which will transport the methanol and carry out bunkering to Maersk ships; and YTL PowerSeraya, which will study the renewable power solution.

At present there is a feasibility study on the technical and economic aspects of producing the fuel in Singapore before the pilot plant is constructed, which is expected to be completed by the end of 2022. The pilot facility would be built by 2025, and have a capacity of 50,000 t/a.

Another methanol fuelled tanker for NYK Group

NYK Group in Singapore has taken delivery of the methanol-fuelled tanker Grouse Sun, built by Hyundai in South Korea subsidiary. The ship has a dual-fuel engine that can use not only heavy fuel oil but also methanol. It also has a new technology that suppresses NOx production by adding water to methanol to lower its temperature during combustion. As a result, the vessel can comply with the IMO's stringent Tier III NOx emission standard and contribute to environment-friendly transportation without the need for an exhaust gas recirculation (EGR) system and a selective catalytic reduction (SCR) device. The vessel will be engaged in a long-term charter contract with Methanex subsidiary Waterfront Shipping Ltd.

FINLAND

Methanol recovery from pulp waste

Paper manufacturer Metsä Fibre has signed a partnership agreement with Veolia for the production of biomethanol from pulp and paper wate at the Äänekoski mill. As part of this agreement, Veolia will build, own and operate a methanol refining plant at Äänekoski, closely integrated into the bioproduct mill processes. The Kraft pulping process transforms wood chips into pulp, from which a broad range of paper products are made. Black liquor is the waste by-product from the and contains most of the original inorganic elements and the degraded, dissolved wood substance, including methanol, as well as hundreds of other components. Veolia has been a major supplier to the pulp and paper industry since the 1960s for black liquor evaporation systems, which feature methanol rectification and handling systems, among other characteristics. Raw methanol recovered from the pulp process needs to be purified, removing nitrogen and sulphur components, and then further refined for use as commercial biomethanol. The refinery will have an annual production capacity of 12,000 t/a and is due to come on stream by 2024.

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UNITED STATES

'Green' methanol to gasoline project

Modular Plant Solutions (MPS) has been contracted by Arbor Renewable Gas for the construction of a modularised green gasoline plant. The Spindletop Plant, located in Beaumont, Texas, will convert woody biomass in the form of pre-commercial thinnings and forest residue into gasoline via a methanol production step using MPS' Methanol-To-Go® modular small-scale methanol technology. MPS will also project manage the engineering and technology partners for the entire plant, from procurement and construction to operation. MPS' modularisation process and patent-pending ISO frame-based modular design for the plant will streamline transportation of plant components, making it easier to assemble and minimising construction issues. The plant will then use Topsoe's TIGAS methanol to gasoline technology to generate green gasoline.

HIF selects site for methanol plant

Chilean developed HIF says that it has selected a site outside Bay City, Texas, for its first US green methanol facility. HIF is developing a pilot plant in Chile together with Porsche AG, and has raised $260 million in funding. However, the company says it is aiming to have commercial scale plants up and running by the end of 2025 in Chile and Texas and later Australia.

BELGIUM

Declaration to boost electrolyser production

At the European Electrolyser Summit in Brussels, co-organised by the Hydrogen Council and the European Commission, a joint declaration was signed by the Commission, Hydrogen Europe and 20 European companies including Topsoe on increasing electrolyser manufacturing capacity in the EU. The declaration backs the EU's decision to double its previous target of 5 million t/a of domestic production of renewable hydrogen to 10 million t/a by 2025 – 10 times its current value – as well as an additional 10 million t/a of hydrogen imports.

Roeland Baan, CEO of Topsoe, said: "Power-to-X and energy independence will not happen in the EU unless we ramp up the manufacturing of electrolysers in the EU as well. Therefore, I am extremely happy to see commitment from both the EU and industry to do exactly that… If the EU wants to be independent of Russian gas we need to produce 10 million tons of renewable hydrogen in the EU every year. Manufacturing of electrolysers must therefore be scaled up significantly. This represents both an unprecedented challenge and a significant opportunity for Topsoe."

The joint declaration features three pillars:

1. Ensuring a supportive regulatory framework through adequate permitting rules and committing to stand up for the ambitious targets included in the revision of the Renewable Energy Directive and the Alternative Fuels Infrastructure Regulation Proposal.
2. Facilitating adequate access to finance by revamping the Innovation Fund to be inclusive of innovative zero and low-carbon equipment manufacturing such as electrolysers. In addition, accessing state aid to de-risk investments, and put in place Carbon Contracts for Difference to further incentivise large-scale deployment of clean hydrogen technologies.
3. Integrating supply chains by way of expanding research and development and ensuring the availability of required components and materials in a timely and affordable manner.

Under the joint declaration, Europe's leading electrolyser manufacturers agreed to increase their manufacturing capacity to reach 17.5 GW by 2025 and to further increase capacity by 2030 in line with projected demand for renewable hydrogen.

UNITED KINGDOM

Velocys provides update on GTL projects

Velocys plc has published a statement detailing updates on its sustainable fuels projects. In the UK, together with partner British Airways, they are progressing the Altalto Immingham municipal solid waste to jet fuel project where Velocys is providing project development services, engineering and FTS technology. Over the last few months, Velocys has completed site engineering, a geotechnical survey and the integration of carbon sequestration of biogenic CO_2 in preparation for the connection of the Altalto plant, when built, into the new East Coast Carbon Capture and Storage (CCS) cluster, which is due to be completed in 2027, at the same time that the Altato plant is commissioned.

In Louisiana, engineering contractor Worley has completed interim engineering and Koch Project Solutions continues to provide project development support to the Bayou Fuels sustainable aviation fuel biorefinery project, ahead of finalisation of contract execution strategy and FEED award subject to financing. A full 15-year SAF and environmental credit offtake agreement with Southwest Airlines and a 10 year SAF and environmental credit offtake MOU with IAG were entered into in November 2021.

The company has also secured a 15 year lease for a modern and sustainable facility in Columbus, Ohio where it will be consolidating its catalysis services, microchannel reactor core assembly and technology licensing under one roof.

Henrik Wareborn, CEO of Velocys, said. "The Velocys group is well positioned at the nexus of energy security and the net zero transition. Through the deployment of our patented demonstrated FT and catalyst technology, we provide decarbonization solutions for hard-to-abate sectors such as commercial aviation, to supply negative carbon intensity fuels to airlines and others committed to net zero targets, while also reducing import dependency on fossil fuels.

INDONESIA

Indonesia to build second coal gasification plant

Indonesia's biggest coal miner PT Bumi Resources and Air Products and Chemicals Inc will develop a $2 billion joint venture methanol facility in Indonesia. Bumi's Kaltim Prima Coal subsidiary will develop the facility at the Batuta industrial park in Bengalon, East Kalimantan, with an annual capacity of 1.8 million tonnes of methanol, according to press reports, and supply coal feedstock for the plant, which will be built, owned and operated by Air Products. Bumi will take all of the methanol produced. The site is currently being cleared in preparation for construction, with completion tagged for late 2025/early 2026.

CANADA

Nauticol secures investment funding

Canadian asset management company Purpose ESG will invest in Nauticol Energy's zero carbon 'blue' methanol project in Alberta, using carbon capture and storage. Nauticol says that the 1.7 million t/a plant is making "significant progress" in securing regulatory permits and agreements for commercialisation, and has support from indigenous communities and investors. Construction is due to begin for the first plant this year, with a target completion date of 2026. Nauticol has also secured transpor-

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tation deals with TC Energy and CN Rail, as well as port access via Prince Rupert, British Columbia. It has also secured offtake agreements for 80% of its production.

"Nauticol's first project is competitively positioned adjacent to abundant natural gas feedstock and vast underground deposits of natural gas in Grand Prairie, Alberta," said Young Bann, CEO of Purpose ESG. "Methanol can be used as an alternative to conventional transportation fuels and is particularly popular in the marine transport industry. It has not previously been proactively adopted due to heavy pollution caused by conventional coal-based production."

EGYPT

MoU on green methanol plant

A joint venture between UAE renewable energy company Masdar, and Egypt's Hassan Allam Holding Group, says that it will set up green hydrogen production plants in Egypt in Sokhna in the Suez Canal Economic Zone and on the Mediterranean coast. The two companies have signed Memoranda of Understanding (MoU) with The General Authority for Suez Canal Economic Zone, Egypt's New and Renewable Energy Authority, the Egyptian Electricity Transmission Company, and The Sovereign Fund of Egypt (TSFE) for the projects, Masdar said in a press statement.

The partnership will set up a green methanol plant by 2026 as part of the first phase with a capacity of 100,000 t/a for the bunkering market in the Suez Canal, Masdar said. The partnership has also set a target of building 4 GW of electrolyser capacity by 2030 with an annual output of up to 480,000 t/a of green hydrogen and 2.3 million t/a of green ammonia for export and domestic consumption.

ICELAND

PCC SE and Landsvirkjun to convert CO_2 to methanol

Landsvirkjun, The National Power Company of Iceland, and German investment company PCC SE have agreed to explore the possibility of capturing and utilising carbon emissions from PCC's silicon metal plant in northeast Iceland. Carbon emissions would be used to produce green methanol, using hydrogen from water electrolysis. PCC SE aims for its silicon metal plant at Húsavík to become carbon-neutral by replacing fossil carbon reductants with renewable alternatives. The plant at Bakki emits about 150,000 tonnes of CO_2 per year as part of the reduction of quartzite (SiO_2) to produce silicon metal.

HUNGARY

MOL to build green hydrogen facility

Hungary's MOL Group has announced a partnership with Plug Power Inc. to build a green hydrogen plant in Százhalombatta using a 10 MW electrolysis plant form Plug Power, at a projected cost of $23 million. The plant will produce 1,600 t/a of carbon neutral annually, and is due to be operational in 2023. MOL will use the hydrogen in its Danube refinery.

"We are convinced that hydrogen is not only one of the most important energy carriers of the already ongoing energy transition, but it will be an essential factor in the new, carbon-neutral energy system as well," said Gabriel Szabó, Executive Vice President of Downstream at MOL Group. "This new technology allows the introduction of green hydrogen production in Hungary, Százhalombatta, which makes MOL Group one of the most important players in the sustainable energy economy in the region." ■

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People

Maire Tecnimont has announced the resignation of **Pierroberto Folgiero** from the positions of Director, Chief Executive Officer and Chief Operating Officer of the Company, effective from May 15, 2022. Interim appointments to senior positions are subject to article 2386 of the Italian Civil Code, with a list drawn up at the time of appointment. However, with designated successor **Alessandra Conte** unwilling to accept the position, it has passed to Alessandro Bernini, previously Group Chief Financial Officer of the company since 2013, who will now also become the new Chief Executive Officer and Chief Operating Officer of Maire Tecnimont. The company board has also conferred on Bernini executive powers for the management and coordination of the Group's activities. The resolutions will be effective from 15 May 2022. Alessandro Bernini will remain in office, according to the law, until the next shareholders' meeting of the Company.

Bernini began his professional career as an auditor, joining Ernst & Young in 1980 and dealing with the auditing of important Italian (Saipem, Pirelli) and international groups as well as participating in the development of auditing standards and supporting the National Council of Certified Public Accountants in the drafting of the first formulation of the National Accounting Principles. He was appointed a partner in Ernst & Young in 1994 and took the responsibility for the office located in Brescia while continuing to maintain responsibility for important forensic engagements of the Milan central office. In 1996 he joined the Saipem Group as Chief Financial Officer and, since 2002, he has been also appointed Head of the Corporate Secretary and Corporate Governance. In 2008 he was called to assume the role of Chief Financial Officer of the ENI Group, which he held until December 2012. In 2013 he joined Maire Tecnimont Group as Group Chief Financial Officer, also covering the position of Director in several Group companies.


Darlene S. Schuster.

The board of directors of the American Institute of Chemical Engineers (AIChE) has announced that **Darlene S. Schuster**, PhD, AIChE's current Chief of Technical Operations, Membership, and Business Development, has been appointed as the new Chief Executive Officer and Executive Director of the Institute. An experienced business leader, Dr. Schuster will become CEO and Executive Director effective from April 25th. She will succeed June C. Wispelwey, who is retiring on April 22.

In making the announcement, Christine Grant, AIChE's 2022 President, said "The board and I are delighted that Darlene will serve as AIChE's next CEO and Executive Director. She has a deep knowledge of AIChE, and her background as a chemicals industry leader from a corporate, academic, and non-profit perspective, as well as her deep understanding of the dynamic of the chemical engineering professional, will be an asset to the continued growth of AIChE."

Grant noted Schuster's strong track record of developing and executing strategies to structure and achieve significant, sustainable growth, which will lead AIChE to its next phase. "Darlene personifies the values and integrity that are essential as the next leader of AIChE. I want to express my special thanks to the search committee for their commitment and hard work in this process," added Grant.

"I am excited by this opportunity to lead AIChE, an organisation that has meant so much to me over the course of my career – as we expand our many points of excellence across the chemical engineering profession, inclusive of all," said Schuster. She added, "In our ever-changing world, AIChE is pleased to be the global home of chemical engineers as we continue to provide career support and lifelong learning opportunities for the broad engineering community, and continue to serve the chemical engineering profession." ■

Calendar 2022

! The following events may be subject to postponement or cancellation due to the global coronavirus pandemic. Please check the status of individual events with organisers.

MAY

31-2 JUNE

China International Fertilizer Show 2022,
SHANGHAI, China
Contact: CCPIT Sub-Council of Chemical Industry, Beijing
Tel: +86 10 84 255 960
Email: zhengyingying@ccpitchem.org.cn

JUNE

2-3

NH3 Event Europe 2022,
ROTTERDAM, Netherlands
Contact: Rianne Vriend,
NH3 Event Europe
Tel: +31 10 4267275
Email: info@nh3eventeurope
Web: nh3event.com

9-10

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

12-15

International Methanol Technology Operators Forum (IMTOF), LONDON, UK
Contact: Polly Murray, Johnson Matthey
Email: polly.murray@matthey.com

SEPTEMBER

11-15

66th AIChE Safety in Ammonia Plants and Related Facilities Symposium,
CHICAGO, USA
Contact: Ilia Kileen, AIChE
Tel: +1 800 242 4363
Web: www.aiche.org/ammonia

12-14

Argus World Methanol Forum,
HOUSTON, Texas, USA
Contact: Michelle Ladiana, Argus Media
Tel: +44 (0) 20 7780 4340
Email: conferencesupport@argusmedia.com
Web: www.argusmedia.com/en/conferences-events-listing/methanol-forum

OCTOBER

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Ammonium Nitrate/Nitric Acid conference,
HOUSTON, Texas, USA
Contact: Hans Reuvers, BASF
Karl Hohenwarter, Borealis
Email: johannes.reuvers@basf.com
karl.hohenwarter@borealisgroup.com
annaconferencehelp@gmail.com
Web: annawebsite.squarespace.com


Science
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Technology

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Plant Manager+

Handling leaks in urea plants: part 1

Leaks in the high-pressure synthesis section of a urea plant may lead to catastrophic consequences. In 2017, building on an incident database set up by UreaKnowHow.com, AmmoniaKnowHow.com and UreaKnowHow.com introduced FIORDA, the Fertilizer Industry Operational Risk Database, a global open source risk register for ammonia and urea plants.

A surprising conclusion from this database is that most safety risks in a urea plant lead to the sudden release of a toxic cloud of ammonia. Early detection of a leak is important as minor and small leaks can be easily contained.

But what action is required after a leak has been detected? Are all leaks critical? Can a flange connection be retightened, can a temporary clamp solve the problem, or does the plant need to be shut down?

This series of articles explains why leaks in the high-pressure synthesis section of a urea plant are dangerous, what happens when there is a leak, possible consequences and prevention and mitigation measures.

Several examples of leaks in urea plants.

Why are leaks in the HP synthesis section so critical?

The pictures in Fig. 1 show several examples of leaks in urea plants.

Leaks can easily occur in urea plants due to corrosion and sealing challenges.

Corrosion challenges

In a urea plant one must continuously take into account the risk of corrosion due to the presence of ammonium carbamate. At the relatively high temperatures, ammonium carbamate behaves like a strong Brönsted acid. Proper material selection of the equipment is important and the presence of a sufficient amount of oxygen is especially critical to keep the corrosion rates within certain limits (passive corrosion). Even when sufficient oxygen is present, there will always be some passive corrosion, in the order of 0.01-0.02 mm per year (0.0004-0.0008 inches/year). This means that wall thicknesses reduce slowly over time and finally leaks can occur. Where there is insufficient oxygen, for example, in crevices or dead ends or in condensing liquid in a gas phase, passive corrosion will turn into active corrosion with much higher corrosion rates occur, some 30-50 mm per year (1-2 inches per year).

Sealing challenges

Due to the corrosive medium only a limited number of special urea grade materials can be applied in a urea plant. This means that the required hardness difference between, for example, flanges and the lens ring is not easy to realise, because for a proper sealing the difference in hardness should be minimum 20 hV. In addition, selection of the type of seals is limited; a design with gaps or crevices cannot be used. Consequently, greater attention is required to obtain proper sealing.

A lens ring joint with carbon steel threaded flanges and carbon steel nuts and bolts is often used in urea plants (see Fig. 2). The shape of the lens ring is such that a line-shape sealing ring is created as indicated in Fig. 3.

The big advantage of a line-shape sealing ring is that less force is required to create the seal. The sealing effect is achieved by elastic deformation of the surfaces which implies that applying the right bolt load is very important. Lens ring gaskets are in principle

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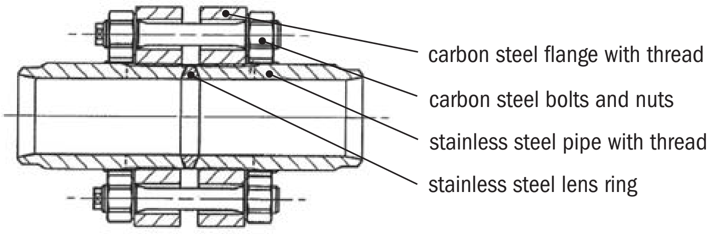


Fig. 2: A typical lens ring flange connection

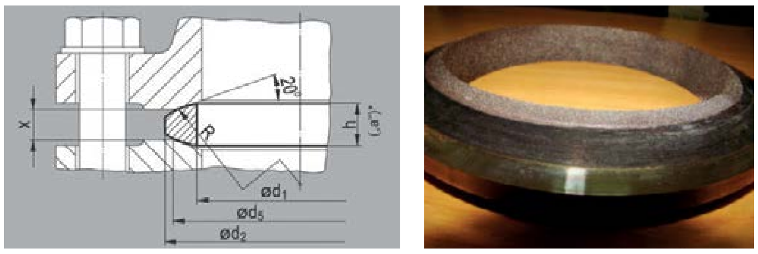


Fig. 3: Line sealing principle of a lens ring (left) and a real life example showing normal passive corrosion on the process side of the ring (right).

reusable, but in a urea plant it is not recommended to reuse a lens ring gasket. Lens ring gaskets are also sensitive to high bolt forces. With increasing loads, the lens ring gasket deforms and the shape changes, the radius becomes flatter and the contact surface between the lens ring gasket and flange increases (flat surface sealing), increasing the risk of crevice corrosion.

What happens when it leaks?

It is common knowledge that crevices should be avoided in the high-pressure synthesis sections of urea plants. In a crevice ammonium carbamate liquid enters, oxygen will be depleted and corrosion rates (active corrosion) increase leading to crevice corrosion and the flange connection will start to leak. Fig. 4 shows the result of crevice corrosion on a stainless steel flange face.

However, a crevice and/or a leak can occur in a lens ring flange connection due to several causes such as no proper alignment, insufficient torque on the bolts, too thin lens ring gaskets, lateral defects in the face of the lens ring or flange face, pipeline vibrations (reciprocating pumps, high pressure drops) or excessive stresses due to not proper piping design/installation. Fig. 5 shows a typical leak of a lens ring flange connection.

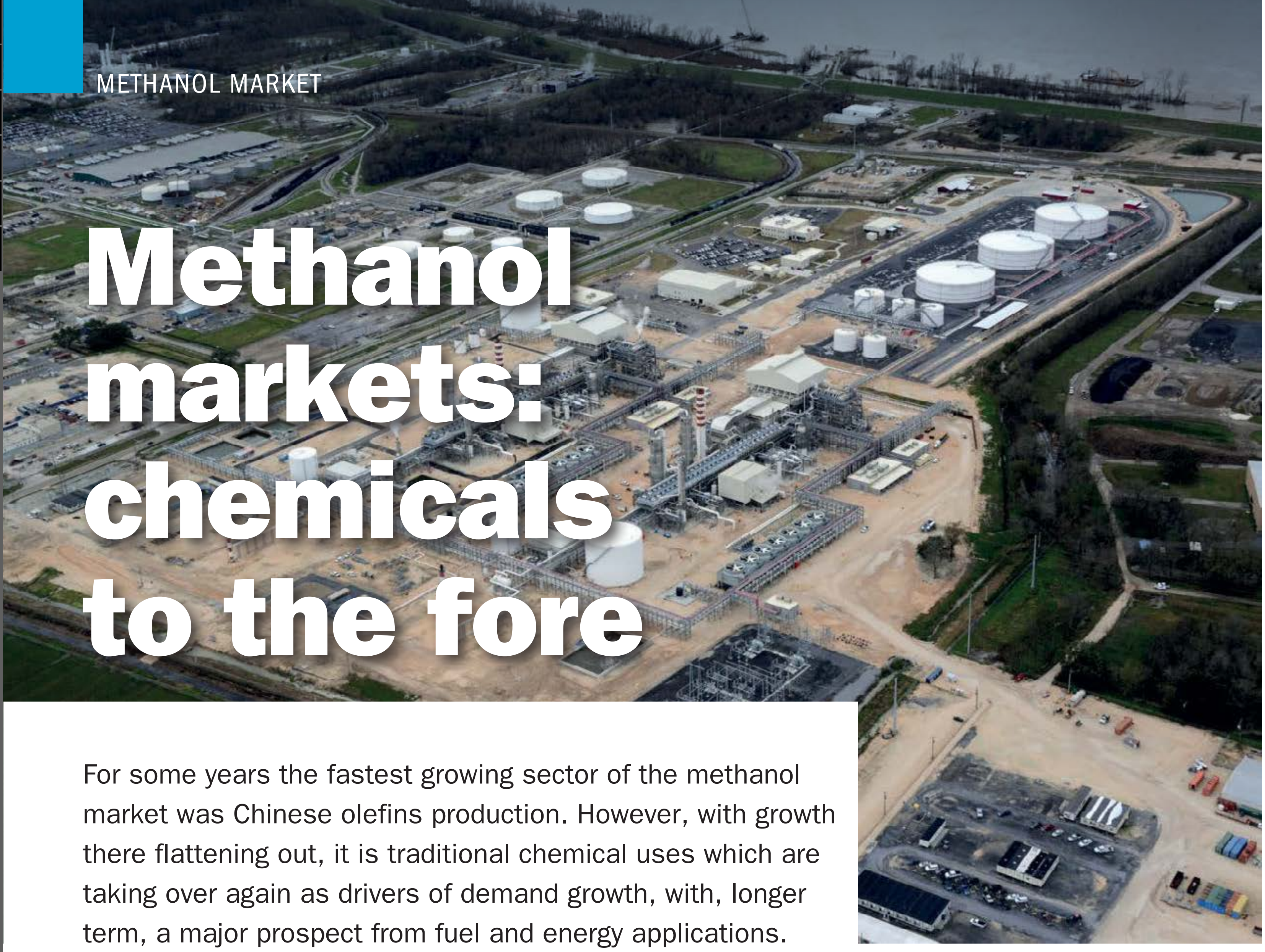
Typically, a leak cannot be stopped anymore because solids, which are formed during the flashing from high pressure to atmospheric pressure, will erode the leak path. Furthermore, the leaking ammonium carbamate is extremely corrosive for carbon steel parts like the threaded flanges, bolts and nuts as shown in Fig. 6.

The mechanical integrity of stainless steel parts can also be at risk due to the leak. In a crevice, active corrosion will occur due to the lack of sufficient oxygen present, resulting in high corrosion rates (active corrosion). ■

Fig. 4: Signs of crevice corrosion of a stainless steel flange face.

Fig. 5: A typical leak of a lens ring flange connection.

Fig. 6: Corroded carbon steel bolts.



Methanol markets: chemicals to the fore

PHOTO: METHANEX

For some years the fastest growing sector of the methanol market was Chinese olefins production. However, with growth there flattening out, it is traditional chemical uses which are taking over again as drivers of demand growth, with, longer term, a major prospect from fuel and energy applications.

While ammonia continues to be the largest syngas derivative by tonnage, reaching 180 million t/a in 2021, methanol consumption has grown at a far more rapid rate, more than doubling over the past decade to reach 110 million t/a in 2021. Almost all of this growth has been driven by Chinese demand, as China took the strategic decision in the 2000s to try and use coal-based methanol production to reduce imports of oil-derived products from overseas. This began with methanol being used in some cities and provinces as a blendstock in gasoline, followed by use of methanol derivative dimethyl ether (DME) as a blendstock in liquefied petroleum gas (LPG), often used for domestic heating or cooking. Around 9% of China's vehicle fuel is provided by coal-based methanol. However, large scale demand really took off with the development of domestic technology to convert methanol into propylene and ethylene and hence downstream polyolefins for plastics production, replacing olefins derived from oil or gas conversion.

The first large-scale methanol to olefins (MTO) plant became operational in 2010 at Baotou in Inner Mongolia. It was followed by another two dozen units over the next decade, with total capacity close to 20 million t/a of olefins, representing nearly 40 million t/a of methanol demand equivalent. Collectively around 20-25% of China's polyolefin production comes from MTO units. Around 70% of this is in integrated facilities where the full production cycle of coal gasification, methanol production and olefins manufacture were present, mainly in the northeast of the country; the majority of coal production lies in the northern provinces of Inner Mongolia, Shanxi and Shaanxi, responsible for over 60% of domestic supply. However, the remainder depends upon 'merchant methanol', and are often in coastal locations, buying methanol either from other producers within China, or on the international market, and these plants are responsible for China's rising tide of imports of methanol from overseas.

As Table 1 shows, MTO has come to be the largest single demand sector in the methanol market, representing over 30% of consumption, all of it in China. Fuels and energy uses, mostly (though not exclusively) in China, have come to represent a similar slice of the market, while traditional chemical uses, which until around 2000 were 95% of methanol use, now only account for 45% of methanol demand. This rapid growth in Chinese consumption has not only led to huge methanol capacity building – indeed, over-building – within

Above: Methanex's Geismar site, now becoming one of the company's most important production hubs.

Table 1: **Methanol demand by end-use, 2021**

Use	Million t/a	Percent
Olefins		**31%**
MTO	35.1	
Fuel/energy		**28%**
Gasoline blending	13.6	
MTBE/TAME	11.3	
Biodiesel	3.2	
DME	3.1	
Chemical uses		**41%**
Formaldehyde	25.1	
Acetic acid	7.8	
Chloromethanes	2.5	
Methyl methacrylate	1.9	
Methylamines	1.7	
Other	6.7	
Total	**112 million t/a**	

Source: MMSA

China, but has also meant that China has come to dominate the traded methanol market, which stood at a total of 30 million t/a in 2021, of which China represented 13 million t/a, or 43%.

China's change of tack

The past decade has been a dramatic time for the methanol market, so much of which has come to depend upon Chinese government policy. But China's appetite for MTO is slowing rapidly, for a variety of reasons. One short term factor has been the lockdowns in Shanghai, and now spreading to other Chinese cities to combat a fresh covid outbreak. MMSA suggests that Chinese methanol imports are down 16% in 2022 and that this year could see the first ever year on year fall in Chinese methanol demand, albeit only by about 3%.

Against this, MTO production has so far held up well this year. MTO's economic viability depends upon the relative prices of oil and coal (and imported methanol, in some cases), and MTO producers had suffered over the past few years by the development of ethylene steam cracker capacity that was able to operate more cheaply than domestic Chinese MTO plants. This has been the main reason for the slowdown in new MTO plant construction – poor or negative margins for MTO mean that major investors are no longer interested in MTO projects. However, the current crisis in Ukraine has pushed oil back up to prices above $100/bbl, making methanol-based olefin production cheap by comparison once more, at least for the time being. MMSA sees Chinese MTO production accounting for around 35 million tonnes of methanol demand this year, around the same as 2021.

But perhaps the greatest factor for future MTO demand is changing Chinese environmental policy. This affects MTO producers in two ways. China is trying to cut down on pollution from industrial plants, as well as use of water in areas suffering from shortages, such as the dry northwest of the country where many of the coal to olefins plants are based. But longer term, the country is also trying to shift itself away from coal burning in order to meet targets for reducing CO_2 emissions. China has already moved coal's share of China's energy provision from around 70% in 2005 to about 55% today (even though the total has actually increased), by rapidly expanding renewables capacity and forcing consolidation in the coal industry. However, this led to two power crises last year, in May and then August-October, when domestic electricity demand outpaced supply and China was forced to ration power. One of the effects of this was to force a temporary shutdown of much of the country's coal to olefins capacity, as well as a large tranche of methanol capacity. For example, methanol plants in Yulin cut operation rates by 50% in 4Q 2021, reducing supply by 1.3 million tonnes.

These targets for coal and energy use and intensity are operated by the powerful provincial governments. China currently implements a "dual control mechanism", under which provinces are given targets for both total energy consumption and energy intensity (the amount of energy consumed for each unit of GDP growth) by the National Development and Reform Commission (NDRC). In January, president Xi indicated that this mechanism would eventually be extended to control CO_2 emissions and carbon intensity, i.e. the volume of emissions per unit of GDP growth.

With growth in MTO demand slowing, and methanol's use as a fuel in China seeming to have matured, most new demand for methanol in China is projected to come from traditional chemical uses. Formaldehyde for resin production is the largest sector of demand after MTO, as Table 1 shows, and China represents about 50% of all global formaldehyde demand. Other important industrial chemicals like acetic acid and methyl methacrylate are also continuing to show strong growth; overall demand for these sectors in China is projected to grow by around 5-6% year on year over the next few years.

North America

After China, the largest slice of methanol demand comes from North America. The region, if Trinidad is also counted, is also one of the largest concentrations of methanol production. The US in particular rapidly expanded methanol output over the past decade, as the boom in domestic natural gas production due to shale gas exploitation transformed the US chemical industry. This led to the reopening of shuttered capacity and the building of new plants, including Methanex's relocation of 2 million t/a of capacity from Chile to Louisiana, and now – after a delay due to covid – the company's decision to build a third, 1.8 million t/a plant at its Geismar site in Louisiana.

The rapid rise of US methanol capacity did lead a number of companies, often Chinese backed, to look at building export-oriented plants aimed at supplying Chinese MTO production. However, uncertainty over future Chinese MTO demand and local opposition have stalled or killed many of these projects, most notably the Chinese-backed Northwest Innovation Works (NWIW), which had aimed to build three 1.7 million t/a methanol plants in Washington and Oregon states.

US methanol demand was 9.4 million t/a in 2020, and production still ran below this, at around 7.3 million t/a, but new capacity is expected to turn the US into a net exporter over the next couple of years. Last year saw the start-up of Koch's YCI Methanol One plant, adding 1.7 million t/a of capacity, and once Methanex's Geismar 3 project is complete the US is expected to be a significant net exporter of methanol. Trinidad, conversely, has suffered from gas supply constraints on its own methanol production, in spite of the completion of a new 1.0 million t/a plant in 2020. The increase of US methanol production has also reduced Trinidad's traditional market for its methanol, and it has had to look further afield, particularly Europe.

Middle East

The Middle East is the largest exporting region for methanol, with Saudi Arabia and Iran the largest producers. There is also capacity in Oman, Qatar and Bahrain. In all the region has over 20 million t/a of capacity, and with little domestic demand beyond some MTBE production for fuel blending, most of the region's methanol production is exported, to India and especially China. Outside of Iran, however, new plant building has slowed down as gas supplies become more constrained, while Iran has faced sanctions which have slowed its new capacity additions and ability to sell its product overseas.

Russia

Russia is a major producer of methanol, with 8 million t/a of capacity, though production was only 4.4 million t/a in 2020. The country has ambitious plans to increase methanol production, though undoubtedly the sanctions regime imposed after Russia's invasion of Ukraine will complicate that picture greatly. Russia exported 1.8 million tonnes of methanol in 2021, most of it to Europe, with Finland, Poland and Slovakia collectively accounting for 70% of that.

India

India, like China, is a coal-rich country, and there have been some investigations into the possibility at trying to emulate China's move to domestic fuel and plastics production based on coal-derived methanol. In 2018, government think tank NITI Aayog launched its Methanol Economy initiative with the aim of increasing domestic consumption of methanol from its present 2 million t/a to 30 million t/a, and production from 250,000 t/a to many millions of tonnes, allowing a reduction in oil imports. However, ambitions have so far run far ahead of reality. A 15% methanol blend in gasoline is now being trialed in Assam, and there is a pilot plant for converting high ash Indian coal into methanol (see Syngas News, this issue), but no major project forthcoming as yet.

Sectoral demand

Outside of China, MTO has not caught on as an idea, with the sole exception of Uzbekistan, where the country is hoping to use MTO to monetise stranded natural gas resources. A $2.5 billion project to produce 720,000 t/a of polyolefins is under development, with a target onstream date of 2024. For the most part, though, it is now chemical uses which are likely to form the bulk of new methanol demand over the next five years. These tend to roughly follow growth in GDP, though in industrialising countries, especially in south, southeast and east Asia, above-trend growth rates are expected.

Methanol as a fuel

The economies of scale provided by large-scale (5,000+ t/d) methanol plants has pushed the cost of methanol down to levels where it can compete in some areas with oil-derived products like gasoline and LPG, and this has encouraged its use in fuel and energy applications. Within China, it is blended into gasoline at levels of 10-15%, as well as higher levels for specially adapted vehicles. It can also be used to produce DME for blending into LPG. Outside of China, though, methanol's direct use as a fuel has been limited, although it is used for esterification of waste vegetable oils to produce biodiesel, which has had particular take-up in Europe, and it is also used in the production of ethers such as methyl t-butyl ether (MTBE), which is widely used as an oxygenate component of gasoline. Approval of methanol blends as vehicle fuels is gradually spreading, but widespread take-up of methanol as a gasoline blendstock outside of China is likely to be contingent on its green credentials (see below).

However, the most promising development for new large scale demand is in the realm of shipping fuels. Methanex has used methanol as a shipping fuel in its fleet of tankers (operated by subsidiary Waterfront Shipping) for some years, but interest in methanol has been galvanized by plans to decarbonise the maritime industry. The International Maritime Organisation (IMO), the UN body that regulates the shipping industry, has set the target of cutting the sector's carbon emissions by 50% in 2050 compared to 2008 levels. Numerous ways of meeting this target have been suggested, including burning green ammonia, but methanol has started to gain momentum after shipping giant Maersk began to focus upon it, arguing that: "it is the most mature from the technology perspective; we can get an engine that can burn it.".

Maersk announced in August last year that it would be building eight large container ships that would operate on methanol, with delivery in 2024-25. Each ship requires around 40,000 t/a of methanol, for a total of 500,000 t/a of new demand just from these eight ships alone, and where Maersk goes, many other shipping companies may follow.

Green methanol

Of course, as with vehicle fuels, Maersk's move is predicated on using methanol from a low carbon source. Green methanol plants have hitherto been fairly few and far between. There is a biofuel-based plant in Sweden using waste from paper manufacture; Enerkem in Canada manufactures methanol from municipal solid waste in the city of Edmonton; and in Iceland, CRI uses geothermal energy to generate electricity to electrolyse water to produce hydrogen which it uses to reduce carbon dioxide to methanol. In the Netherlands, BioMCN used waste glycerol from biodiesel production to make methanol until 2013 when the process became economically untenable. It now has a biogas feed for some of its methanol production, but has been forced to move back to natural gas for most production, which the company is now hoping to replace with hydrogen from renewables. Even so, outside of these and a couple of other waste- or biogas-based plants, most methanol is still currently produced from natural gas or coal.

However, with the cost of renewable energy and electrolysis coming down, especially at a time like the present when oil and gas prices are high, there is increasing interest in using green methanol in a variety of ways. The key to methanol's attraction is its versatility; processes already exist to convert it into gasoline, olefins, esters, glycols, etc. This means that if a low carbon way can be found of producing it, it can simply slot into existing end uses without the need to completely reorganise supply chains.

This magazine has covered lower carbon routes to methanol over the past few years; see e.g. *Nitrogen+Syngas* 363, Jan/Feb 2000, pp40-53. Methanol even offers the prospect of being able to use CO_2 recovered from industrial processes as a feedstock, making downstream products carbon negative or, if used as fuels, at least carbon neutral. The interest in green methanol now almost rivals that of green ammonia, and a number of major projects are now under development, some using biogas, others using electrolysis, still others waste gasification. Most are currently at the pilot or demonstrator plant stage, and no large scale green methanol plants are expected within the next 4-5 years. Longer term, however, if costs and incentives work out, there is almost limitless possibility for green methanol.

A shortage of methanol

For the short and medium term, however, new plants are likely to be gas-based or, in China, coal-based. There are still new methanol plant developments in China, even though there is a huge overhang of unproductive capacity that runs at low utilisation rates there, and more rationalisation of capacity is to be expected. Outside of China, though, new methanol projects are fewer and further between. Geismar 3 in the US will add 1.8 million t/a of capacity, and there are new large scale projects in Malaysia and Egypt, as well as an incremental increase in Saudi Arabia and Russia, and some smaller scale increases in India. Green methanol projects could collectively add another 1.0 million t/a out to 2026. However, Methanex, the largest single company producer, with 9.4 million t/a of capacity, calculates that projected growth in methanol demand over the next 4-5 years will still outpace current plants under construction, leading to tighter methanol markets going forward. Higher oil prices also bode well for methanol producers; methanol end use pricing is traditionally linked to oil pricing, and if oil prices stay ahead of gas costs in advantaged locations such as the US and Middle East, producers there will have a good few years ahead of them. ■

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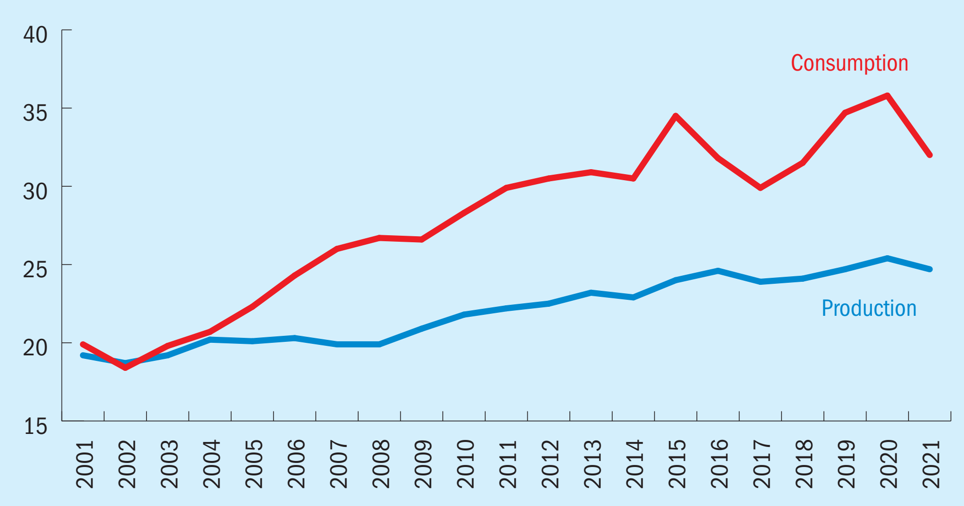
India's urea self-sufficiency drive continues

India's new batch of urea plants are coming on-stream or nearing completion, but can the country regain the self-sufficiency in urea production that it enjoyed in the 1990s?

India is the second largest consumer of urea in the world; in 2021 this amounted to 32 million tonnes, or about 18% of the world's total, and second only to China, which consumed 50 million tonnes. Urea is the key nutrient for India's farmers, and consequently ensuring a secure supply of urea has been a major concern for every Indian government. However, as Figure 1 shows, around the turn of the century, India's urea consumption began to rise faster than domestic production could keep pace with, and since then has widened to an annual gap of 8-10 million t/a, all of which must be imported from overseas. India is now by some way the world's largest importer of urea – the second largest, the USA, imports only 4-5 million t/a by comparison.

India last went through a major urea capacity building programme in the 1990s, during which time capacity kept pace with growing urea demand, but new plant construction stopped in 1995. There were two main reasons for this; firstly, the subsidies being paid to fertilizer companies were starting to claim an ever larger share of the federal budget; and secondly, feedstock availability was beginning to become an issue. Most Indian urea capacity was historically based on naphtha feedstock, but high oil prices led to high naphtha prices and consequently a high subsidy bill to keep urea made from naphtha affordable. To keep bills lower, the government pressured plants to switch to using natural gas feedstock, and all but one plant, which operates partially on naphtha, have now converted. But India's shortage of natural gas meant that the plants often suffered gas supply curtailments, especially during winter when more power was needed and gas was preferentially given to gas-fired power stations.

Fig. 1: **Indian urea production and consumption, 2001-2021, million t/a**



Source: IFA, FAI

Feedstock availability

Feedstock availability became the key constraint on developing new urea capacity during the 2000s and 2010s. Initially it was hoped that exploitation of the offshore Krishna-Godavari basin in the Bay of Bengal, where a major new discovery was made in 2006, would provide India with more than enough gas for all of its needs, but exploitation has proved slower and more difficult than anticipated. To meet its natural gas needs, pipeline projects were also considered, from Iran or Turkmenistan. However, difficulties with transit rights, and especially concerns about Pakistan, with whom India maintains a fractious relationship, meant that these were never really developed either. The only practical solution remaining was liquefied natural gas (LNG).

India's first LNG terminal development was actually begun during the 1990s. Unfortunately, it was in the hands of Enron, and was abandoned half-completed when Enron went bankrupt in 2001. The terminal project, at Dabhol was revived in 2006, but wrangling over contracts prevented its completion until 2013. By then, several other LNG import terminals had been completed; at Dahej in 2004 and Hazira in 2005, and Ennore and Kochi in 2013. A sixth LNG terminal began operating at Mundra in 2020, bringing total regasification capacity to 42.5 million t/a, and four more are planned for completion in the next year or so; at Dhamra and Chhara, as well as two floating storage and regasification units (FSRUs), at Jaigarh and Jafrabad. These will bring total capacity to 60 million t/a.

Overseas production

One way of getting around the lack of feedstock availability in India was to develop capacity overseas in gas-rich locations. Several proposals for an Indo-Iranian urea plant circulated during the 1990s, as well as other potential locations, and more recently there were also projects mooted for the US and Canada, relying on newly abundant shale gas, or at stranded gas locations in Africa. However, so far only one major project has come to fruition; the Oman-India Fertilizer Company (OMIFCO), a joint venture between the government of Oman (50%) and Indian state-owned fertilizer collectives Kribhco and IFFCO (25% each). OMIFCO operates two 2,500 t/d urea plants at Sur on Oman's Indian Ocean coast, with the 1.65 million t/a offtake earmarked 100% for India. A third train has been discussed for several years, to take capacity up to 3 million t/a, but so far talks have foundered on gas pricing and availability.

Coal

Another potential solution for India's urea conundrum was provided by the country's most abundant fossil fuel resource – coal. China had shown that a large scale domestic urea industry could be developed based on coal gasification as a feed, and on the face of it there seemed no reason why India could not do the same. However, India's history with coal gasification had not been a happy one – the two coal-based plants build during the 1970s were plagued by outages and technical issues, and eventually shut down. One of the major differences with China is the high ash content of Indian coal, which can be problematic for some types of gasifiers. Nevertheless, as coal gasification technology evolved, so a more serious look at coal gasification began in the 2000s, especially as oil and gas prices remained higher than coal prices on international markets. A project proposal was eventually developed for the Talcher site, where one of the previous coal gasification urea plants had operated.

New urea capacity

In the meantime, lack of gas over the period 1995-2015 meant that no new urea plants were approved for construction in India, and so what urea capacity increase that did occur was provided via incremental debottlenecking and upgrades of existing plants. There was one exception to this rule; the 1.3 million t/a Matix Fertilizer plant in Bengal, which was built to exploit reserves of coalbed methane in the region. However, when this facility was completed in 2015, the volume of gas that was able to be supplied was only about 35-40% of the plant's requirement, and the plant remained idle until it could be connected to a pipeline from the LNG terminal at Dhamra. Start-up finally occurred in September 2021.

However, as LNG regasification terminals plants began to open during the 2010s, and more gas became available, the Modi government decided to set urea self-sufficiency as one of its targets, announcing its ambitious New Investment Policy in 2013, and in 2017 securing $8.7 billion of funding aiming to end imports of urea within five years. This would be achieved by reviving five mothballed urea plants and setting up two new facilities, bringing 7.5 million t/a of new urea capacity on-stream.

The five plants at existing sites (they were pitched as 'revivals', but in effect entire new plants had to be constructed) included three at: Ramagundam in Andhra Pradesh province; Gorakhpur in Uttar Pradesh; and Sindri in Jharkhand – all sites originally belonging to the Fertilizer Corporation of India Ltd (FCIL), and the fourth at the Hindustan Fertilizer Corporation Ltd Barauni site in Bihar province. All of these new plants are now to be owned and operated by a new state venture, Hindustan Urvarak and Rasayan Ltd (HURL), a joint venture of Coal India (CIL), NTPC and the Indian Oil Corporation (IOCL), in cooperation with Fertilizer Corporation of India (FCIL) and Hindustan Fertilizer Corporation (HFCL). All four will be fed from LNG via pipeline.

The fifth was the Talcher coal gasification plant mentioned earlier – the plant will also use a mix of petroleum coke as feedstock. Talcher Fertilizers Ltd is a joint venture between GAIL, Rashtriya Chemicals & Fertilizers, FCIL and Coal India Ltd. The EPC contract was awarded to Wuhuan Engineering Co. Ltd of China. TFL has been allotted northern part of North Arkhapal mine, Odisha as the captive mine for meeting its coal requirements and petcoke will be sourced from IOCL's Paradip refinery.

Of these five, so far Ramgundam began operations in March 2021. Gorakhpur, Sindri and Barauni are all due to begin operations this year, after covid-related delays. Talcher is now scheduled to start up in September 2023.

New plants

As well as the five government-backed projects, there are two privately funded projects have been approved. The first was the revival by Chambal Fertilizers and Chemicals of its old urea plant at Kota near Gadepan in Rajasthan state, which closed in 2015 due to unfavourable economics. A new 1.27 million t/a replacement plant was completed late last year and commissioned in January 2019.

The government has also approved the establishment of a new brownfield ammonia/urea complex at the Brahmaputra Valley Fertilizer Corp (BVFCL) site at Namrup in Assam, so-called Namrup-IV. A new 860,000 t/a ammonia-urea plant will replace the two older 220,000 t/a and 270,000 t/a units. The new plant will be 52% owned by Rashtriya Chemicals and Fertilizers, 26% by Oil India Ltd, 11% by the state government of Assam and 11% by BVFCL. Here, however, little progress has been made since the agreement in principle in 2018.

Self sufficiency at last?

The start-up of Chambal, Matix and Ramagundam has added 3.8 million t/a of urea capacity to India, and assuming that the four remaining HURL plants also start-up on their current projected timescale, that will be another 5.1 million t/a of capacity by the end of next year. In theory, Indian urea capacity should rise from 26.0 million t/a in 2020 to 33.6 million t/a in 2024, assuming that sufficient natural gas can be imported to operate them all, all year round. As Figure 1 shows, that should take capacity at least to close to the level of current Indian consumption, and while actual production level may be slightly lower, it would nevertheless almost restore India to the self-sufficiency it enjoyed in the 1990s.

But while this should in theory ensure that India can supply all of its domestic needs, whether this works in India's favour economically remains a moot point. For example, it could be argued that a secure domestic supply of urea would avoid having to take from a volatile international market where India is at the mercy of global events - prices have reached $750/t for delivery to Indian ports in the wake of Russia's invasion of Ukraine. However, it is of course predicated on ensuring sufficient supply of LNG, whose price can be equally volatile – at current Asian LNG prices of around $24/MMBtu, that is a base price for ammonia production of nearly $800/t. ■

Nitrogen + Syngas 2022

CRU's Nitrogen + Syngas conference returned to a face to face meeting for the first time in two years at the end of March this year.

Sunset in Berlin across the river Spree.

PHOTO: PXHERE.COM

While the current situation in China is a salutary reminder that covid remains with us, the fact that thanks to widespread vaccination we may finally be moving to living with the virus rather than simply containing it was underlined by the move back to face to face conferences. CRU's Nitrogen+Syngas conference in the Netherlands was actually the last industry meeting that I was able to attend personally, in February 2020, just before lockdown closed in around us. This year it was back to Berlin's unlovely Estrel Centre on the southeast side of the city for a 'hybrid' conference, both virtual and in person, with a packed agenda of nearly 50 papers.

Market updates

The conference began as usual with market updates from CRU's team of analysts. Shruti Kashyap presented the gas price and nitrogen market outlook, dominated of course by events in Ukraine. The disruption to grain exports caused by the conflict has led to record crop prices, but affordability is being squeezed by higher fertilizer prices, leading to demand destruction for phosphates and potash, and switching on the nitrogen side from e.g. ammonium nitrate to ammonium sulphate. It was also possible, she said, that we could see demand destruction for nitrogen if prices remained high.

Russia represented 23% of ammonia and 14% of urea trade in 2021, two third of which had left via the Black Sea, and though the Baltic ports remained open, the OPZ ammonia pipeline across Ukraine was now closed. At the same time, gas prices had broken records in Europe, though had stabilized and were at around $37/MMBtu when the presentation was delivered. These price levels turned Europe into a marginal producer of ammonia, ousting China from that position and leading to idling of capacity across Europe. However, with Europe setting floor prices production could be more sustainable going forward. With 4 million t/a of Russian ammonia supply potentially lost to the market, could other producers cover this? New production is expected this year in the US, and at Ma'aden in Saudi Arabia, and there was the potential for some Trinidadian production to return. However, the price outlook is strong at least until 3Q 2022, falling as new capacity comes onstream into 2023.

On the urea side, India was still active on the spot market and new plants are coming onstream there, but imports are still rising, and urea demand could be boosted by DAP demand destruction. China was expected to keep its urea export restrictions for the time being, leading to a sharp decline in Chinese exports for 2022 – possibly to as low as 3 million t/a as the government prioritises the domestic market. In the medium term, new urea projects outweigh demand growth, especially in India and China, and excess capacity will keep prices lower, though obviously elevated in the short term by the Ukraine crisis.

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Alexander Derricott of CRU explored the challenges of the fertilizer industry's carbon footprint, including the implications of emissions tax schemes. The nitrogen industry generates on average 2.49 tonnes of carbon dioxide equivalent per tonne of ammonia produced, he said, on a par with steel or copper production. This collectively represents 1-2% of global emissions. The industry faces the challenge of cutting emissions while maintaining nitrogen output. This can be achieved by blue and green production; capturing carbon emissions or avoiding them via novel production technologies. Emissions levels are defined by feedstock, but change was coming, Alexander said, pointing to the carbon tax regimes that are now existing or coming in the EU, China and Canada, amongst others.

To complete the first morning, Kevin Rouwenhorst of the Ammonia Energy Association presented an update on ammonia's progress as an energy carrier. He drew attention to a recent report by the International Renewable Energy Agency (IRENA) on ammonia's use as a shipping fuel which forecast that ammonia demand for shipping could reach 183 million t/a by 2050. AEA is also working on a globally harmonised certification scheme for low-carbon ammonia to support the development of a market for low- and zero-carbon ammonia. It will quantify the absolute greenhouse gas emissions associated with ammonia production, and enable prospective producers and consumers to trade ammonia on the basis of certified, transparent, and verifiable emission reductions.

Green and blue ammonia

With green ammonia the topic of the day, the first technical session delved into that topic with presentations by several major licensors. Topsoe began, with a run through of ammonia's advantages as a means of transporting hydrogen, as well as direct use as a fuel, especially for shipping. The break-even price remains sensitive to plant capacity; choice of electrolyser technology; cost of electricity; the EPC portion of capex, and the ammonia plant's adaptability to fluctuating power.

Casale's Giovanni Genova also highlighted the fluctuating power input and seasonality of operation that renewables based plants must cope with, which brings new constrains in ammonia plant design. It is necessary to analyse the dynamic of the overall system to guarantee optimal plant configuration as well as reliability and robustness for key equipment. Casale argues that its flexible ammonia synthesis loop allows optimisation of electrolyser and ammonia plant size as well as hydrogen storage, which can be a significant expense.

Deepak Shetty of Stamicarbon described his firm's relatively new green ammonia technology, based on high pressure (300 bar) synthesis, which works well with a high purity electrolysis-based hydrogen feed. Stamicarbon is working on a 200,000 t/a renewables based plant in Kenya at the Oserian Two Lakes Industrial Park, powered by geothermal and solar energy, as well as projects in the US and Europe.

Moving to green ammonia production places different demands on ammonia synthesis catalysts as well. Julie Ashcroft of JM described ongoing technology and catalyst development work that JM has been conducting to meet the technical demands of low-pressure ammonia synthesis and low temperature ammonia cracking, including the development of KATALCO 74-1 GREEN, an ammonia synthesis catalyst optimised for operation at lower

pressure, and KATALCO 27-612, a low temperature ammonia cracking catalyst, which allows for flexibility in operating temperature range for cracking and pressure range for synthesis.

Saipem's Massimiliano Sala suggested that economics of blue ammonia production make it preferable to green for the short to medium term, and that it is possible to achieve a significant CO_2 capture target with small modifications to an existing ammonia process flowsheet. Different alternatives based on available technologies such as steam reforming or autothermal reforming can be used, based on the project targets.

Biomass gasification offers another route to relatively green chemical production, and Yasuhiko Kojima of Toyo reported on work Toyo has been conducting on producing sustainable aviation fuel (SAF) using synthesis based on Velocys' microchannel Fischer-Tropsch technology in Japan. The demonstration plant, using woody biomass, ng was commissioned in June 2020 and a regular domestic flight fuelled by the SAF was conducted in June 2021.

Decarbonising existing plants

Klemens Wawrzinek of Linde argued that in order to achieve emissions targets new green ammonia plants will not be sufficient, but existing plants must also be considered. This means carbon capture and storage – so-called blue solutions. Not only direct emissions but also indirect emissions must be considered, such as power and steam, as these significantly influence the carbon intensity of the product.

> **"In order to achieve emissions targets new green ammonia plants will not be sufficient."**

Ameet Kakoti of Topsoe presented what he described as 'hybrid' plant concepts, which are an important enabler for green ammonia production, revamping a plant to produce up to 10% green ammonia via coupling fuel production with power and fertilizer production could actually encourage and facilitate an increase in the scale of renewable power available, and the hybrid plant can be completely converted to 100% green production by integration of the ammonia loop and renewable technologies over time.

Dan Barnett of BD Energy Systems looked at benchmarking decarbonisation options using a computer model of the syngas plant. The path to decarbonising almost always includes exploring conventional efficiency improvements, he said, and may include the implementation of a green hydrogen package as utilities, and blue scheme improvements with carbon sequestration, each with cumulative energy improvement and decarbonisation gains. In a separate paper, BD Heat Recovery presented work conducted with Petrokemija in Croatia using pinch analysis and HEN integration as techniques for designing retrofit options for a primary reformer furnace. After replacement of an existing APH heat exchanger with an improved design and installation of an additional MP steam coil, energy savings were 0.51 GJ/t NH_3.

Urea technology

Takahiro Yanagawa of Toyo showcase Toyo's new *g-Urea*® process, aiming at carbon neutral urea production using green ammonia made from water electrolysis, nitrogen from air separation and captured CO_2 from waste flue gas or direct air capture, as well as urea production from ammonia and CO_2 generated by biomass and/or municipal solid waste gasification.

Desmet Ballestra have been working on methylene urea – an intermediate in the production of urea formaldehyde resins, but also with potential use as a carrying agent for slow release fertilizers or a coating for urea granules or prills.

Another option for urea downstream production is melamine, and Casale presented their Low Energy Melamine (LEM) process with low urea melt and energy consumptions and easier integration with the associated urea plant due to the generation of anhydrous high-pressure reaction off-gas.

Materials

Stamicarbon makes valves for urea service from corrosion resistant *Safurex*®. Together with valve partner BHDT, the company has now developed a high pressure composite valve, using Safurex in combination with other materials. The design allows for lower and easier valve maintenance, combined with the reliability and performance at a cost-effective price. The new composite valve can also be equipped with wireless sensors for remote monitoring.

VDM Metals detailed field trials conducted at SKW Piestritz in Austria of alloys designed to show excellent resistance to metal dusting conditions as well as relatively easy weldability. VDM Alloy 699XA contains 30% chromium and 2% aluminium, and in addition to its resistance to metal dusting it also exhibits hot strength and creep properties similar to or better those of alloy 601 and a ductility at room temperature comparable to alloy 601. Dissimilar welds with Alloy 800H showed no defects in the weld zone after 18 months.

For nitric acid use, particularly resistant materials are necessary, and Sandvik described its *2RE10*™ material, intended for use where there are problems with 304L type materials due to condensation or evaporation of nitric acid droplets. For process conditions, zirconium is the best choice, and Sandvik also offer a bimetallic tube with an inner layer of zirconium and an outer tube in *2RE10*. If chlorides cause problems, for instance, in cooling water, *SAF2304*™ can be a suitable material, but for cases when a combined resistance to both chlorides and nitric acid is needed, *Sanicro 28* and *SAF 2906* are the best options. In high nitric acid concentrations above 80%, silicon alloyed stainless steel grades have shown the best performance. Sandvik *SX*™, widely used in the sulphuric acid industry, has also performed well in strong nitric acid.

Methanol

The International Methanol Company has conducted an energy efficiency project on its 3,600 t/d methanol plant in Saudi Arabia. With the assistance of Johnson Matthey, the target of 15% improvement in fuel efficiency was exceeded, coupled with a 25% boost to methanol production without increasing the natural gas consumption of the site.

Jens Sehested of Topsoe described his company's research and development work in developing methanol synthesis catalysts, resulting in new discoveries on how the different components in the catalyst formulation matrix influence the performance of the catalyst under industrial conditions, and leading to a new generation of methanol synthesis catalysts.

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Nitric acid

Nitrous oxide abatement remains a key concern in nitric acid manufacture. Umicore has been conducting a project conducted with thyssenkrupp Uhde focusing on the improvement of ammonia combustion efficiency in nitric acid plants and the reduction of N_2O emissions and usage of platinum group metals. The first application of a “twisted wire” catalyst shows noticeable advantages over conventional designs, including significant cost reductions and lower CO_2 equivalent emissions.

Thyssenkrupp Uhde also discussed using the Organic Rankine Cycle or Kalina Cycle technology to make use of low caloric energy from a nitric acid plant, rather than dispersing it in cooling water. More than 800 kW of electrical power can be produced from the low caloric heat of a typical 1,000 t/d dual pressure nitric acid plant. It can also be used as a revamp option.

KBR’s N_2O abatement process employs a catalytic reactor upstream of the tail gas expansion unit in a nitric acid plant. At an operating temperature range of 350°C to 660°C the process achieves more than 95% removal efficiency by use of a proprietary catalyst. By operating at a higher temperature the energy efficiency of the expander is also increased,

Krastvetmet presented data from testing different catalytic systems for ammonia oxidation. Nitrous oxides may be reduced by 25-30% by changing the catalyst design at the same level of ammonia oxidation efficiency. Krastsvetmet has developed a process for single pressure nitric acid plant revamping using tertiary nitrous oxide reduction on iron exchange zeolite catalyst which removes both nitrous oxides and NOx with over 98% efficiency.

Johnson Matthey described a solution using in-burner destruction of N_2O via a ceramic catalyst developed by Yara (YARA 58-Y1) to achieve more than 90% abatement. The operating conditions immediately below the catalyst create mechanical challenges that must be overcome, as described in the presentation.

Operating improvements

Several papers tackled operational improvements to plants. Koch Engineered Solutions presented computational fluid dynamic modelling cast studies to highlight the challenges related to reformer revamping and new, stringent NOx emission requirements, as well as operational issues due to poor combustion performance or an increase in existing reformer capacity, and solutions for revamping reformers, providing guidelines for air balancing, accurate reformer CFD modelling, reformer layout, and burner design.

Alfa Laval examined the pros and cons of syngas boiler design to recover process heat, aiming to optimise process and mechanical dimensions and minimise the amount of expensive construction materials. Engro Fertilizers discussed the discovery of a hairline crack was observed on the main Natural Gas Feed Line towards the Primary Reformer at their plant in Pakistan. The site team were able to install a box to contain the leak, avoiding an expensive shutdown.

Finally, two papers from Fatima Fertilizers discussed emergency scenario planning for a vintage ammonia-urea plant, including layers of protection enhancement and an upgrade to the emergency shutdown system, as well as work on dealing with a methanator feed tube leak during start-up, tackled with assistance from Topsoe remote monitoring of the converter via their *ClearView* advanced monitoring tool. ■

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47 48 49 50 51 52

Nitrogen project listing 2022

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

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
AUSTRALIA							
Clough, Saipem	Topsoe	Perdaman	Karratha, WA	Ammonia	3,500	DE	2025
Clough, Sapiem	Saipem	Perdaman	Karratha, WA	Urea	2 x 3,100	DE	2025
Daelim	KBR	NeuRizer	Leigh Creek, SA	Ammonia	1,600	CA	2025
Daelim	Stamicarbon	NeuRizer	Leigh Creek, SA	Urea	2,850	CA	2025
Technip FMC	Topsoe	Strike Energy	Garaldton, WA	Ammonia	2,400	DE	2026
Technip FMC	Saipem	Strike Energy	Garaldton, WA	Urea	4,200	DE	2026
BANGLADESH							
MHI, CNCIC	Saipem, TKFT	BCIC	Ghorasal Polash	Urea	2,800	UC	2023
BELARUS							
n.a.	Stamicarbon	Grodno Azot	Grodno	Urea	+90	RE	On Hold
BRUNEI							
thyssenkrupp Uhde	thyssenkrupp Uhde	Brunei Fertilizer Ind.	Sungai Liang	Ammonia	2,200	C	2022
thyssenkrupp Uhde	Stamicarbon, TKFT	Brunei Fertilizer Ind.	Sungai Liang	Urea	3,900	C	2022
CANADA							
Black & Veatch	Stamicarbon	Confidential	n.a.	Urea	+300	RE	2024
CHINA							
n.a.	Casale	Fujian Shen Yuan	Fuzhou	Ammonia	1,200	UC	2022
n.a.	Casale	Jiangsu Jinmei	Xuzhou	Ammonia	2,000	UC	2022
n.a.	Casale	Chongqing Yihua	Chongqing	Ammonia	900	UC	2022
n.a.	Casale	Oriental Energy	Binhai	Ammonia	900	UC	2023
n.a.	Casale	Hubei Yihua	Yichang, Hubei	Ammonia	2,000	UC	2023
n.a.	Casale	Shanxi Qingshui	Yulin, Henan	Ammonia	2,000	UC	2023
n.a.	Saipem	Shanxi Qingshui	Yulin, Henan	Urea	3,300	UC	2023
n.a.	Casale	Anhui Haoyuan	Fuyang, Anhui	Ammonia	1,540	UC	2024
n.a.	Casale	Henan Jindadi	Luohe, Henan	Ammonia	1,800	UC	2024
n.a.	Casale	Jiangsu Huachang	Zhangjiagang	Ammonia	1,800	UC	2024
n.a.	Casale	Henan Shenma Nylon	Pingdingshan	Ammonia	1,200	UC	2024
n.a.	Stamicarbon	Confidential	Dongping, Shandong	Urea	2 x 2,330	DE	2024
n.a.	Casale	Henan Xinlianxin	Jiangxi	Ammonia	2,000	UC	2022
n.a.	Stamicarbon	Henan Xinlianxin	Jiangxi	Urea	2,330	UC	2024
DENMARK							
n.a.	Topsoe	Vestas	Jutland	Ammonia	15	CA	2023
n.a.	n.a.	CIP	Esbjerg	Ammonia	910	FS	2026
EGYPT							
thyssenkrupp Uhde	thyssenkrupp Uhde	NCIC	Ain Sokhna	Ammonia	1,200	UC	2022
thyssenkrupp Uhde	Stamicarbon, TKFT	NCIC	Ain Sokhna	Urea	1,050	UC	2022
thyssenkrupp Uhde	thyssenkrupp Uhde	NCIC	Ain Sokhna	Nitric acid	500	UC	2022
thyssenkrupp Uhde	thyssenkrupp Uhde	NCIC	Ain Sokhna	Ammonium nitrate	635	UC	2022
thyssenkrupp Uhde	thyssenkrupp Uhde	NCIC	Ain Sokhna	CAN	835	UC	2022
Tecnimont	KBR	EHC	Ain Sokhna	Ammonia	1,320	CA	2023
n.a.	Stamicarbon, TKFT	Abu Qir Fert	Abu Qir	Urea	+445	RE	2025

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

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
GERMANY							
n.a.	Topsoe	First Ammonia	n.a.	Ammonia	300	P	2024
HUNGARY							
n.a.	Casale	BorsodChem	Kazincbarcika	Nitric acid	660	UC	2022
INDIA							
Engineers India Ltd	Topsoe	HURL	Ramagundam	Ammonia	2,200	C	2021
Engineers India Ltd	Saipem	HURL	Ramagundam	Urea	3,850	C	2021
n.a.	Casale	Zuari AgroChem	Goa	Ammonia	1,050	RE	2022
TechnipFMC/L&T	Topsoe	HURL	Sindri	Ammonia	2,200	UC	2022
TechnipFMC/L&T	Saipem	HURL	Sindri	Urea	3,850	UC	2022
TechnipFMC/L&T	Topsoe	HURL	Barauni	Ammonia	2,200	UC	2022
TechnipFMC/L&T	Saipem	HURL	Barauni	Urea	3,850	UC	2022
TOYO	KBR	HURL	Gorakhpur	Ammonia	2,420	UC	2022
TOYO	TOYO	HURL	Gorakhpur	Urea	3,850	UC	2022
TOYO	KBR	Deepak Fert & Chem	Taloja	Ammonia	1,500	CA	2023
thyssenkrupp Uhde	thyssenkrupp Uhde	Deepak Fert & Chem	Vadodara	Nitric acid	250	UC	2023
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Nitric acid	900	UC	2024
n.a.	Casale	Deepak Fert & Chem	Gopalpur	Ammonium nitrate	970	UC	2024
Wuhuan Engineering	KBR	Talcher Fertilizers	Talcher	Ammonia	2,200	UC	2025
Wuhuan Engineering	Stamicarbon	Talcher Fertilizers	Talcher	Urea	3,850	UC	2025
IRAN							
PIDEC	Casale	Masjid Soleyman	Masjid Soleyman	Ammonia	2,050	UC	On Hold
PIDEC	TOYO	Masjid Soleyman	Masjid Soleyman	Urea	3,250	UC	On Hold
PIDEC	Topsoe	Hengam Petrochemical	Assaluyeh	Ammonia	2,050	UC	2022
PIDEC	Saipem, TKFT	Hengam Petrochemical	Assalyueh	Urea	3,500	UC	2022
Namvaran	KBR	Kermanshah Petchem	Kermanshah	Ammonia	2,400	UC	2023
Namvaran	Stamicarbon	Kermanshah Petchem	Kermanshah	Urea	2,000	UC	2023
Hampa	Casale	Zanjan Petrochemical	Zanjan	Ammonia	2,050	UC	2024
Hampa	Stamicarbon	Zanjan Petrochemical	Zanjan	Urea	3,600	UC	2024
ISRAEL							
Saipem	Topsoe	Haifa Chemicals	Mishor Rotem	Ammonia	300	DE	2023
n.a.	KBR	Haifa Chemicals	Mishor Rotem	Nitric acid	+35%	RE	n.a.
NIGERIA							
Saipem	Topsoe	Dangote Fertilizer Ltd	Agenbode	Ammonia	2,200	C	2021
Saipem	Saipem/TKFT	Dangote Fertilizer Ltd	Agenbode	Urea	3,850	C	2021
Saipem	Topsoe	Dangote Fertilizer Ltd	Agenbode	Ammonia	2,200	C	2022
Saipem	Saipem/TKFT	Dangote Fertilizer Ltd	Agenbode	Urea	3,850	C	2022
n.a.	n.a.	OCP	n.a.	Ammonia	3,300	P	2025
NORWAY							
n.a.	Topsoe	Barents Blue	Markoppneset	Ammonia	3,000	DE	2026
OMAN							
n.a.	KBR	Oman Oil	Salalah	Ammonia	1,000	FS	n.a.

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1 t/d of hydrogen = 464 Nm^3/h
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52

Contractor	Licensor	Company	Location	Product	mt/d	Status	Start-up date
POLAND							
thyssenkrupp Uhde	thyssenkrupp Uhde	Grupa Azoty	Pulawy	Nitric acid	1,000	UC	2022
thyssenkrupp Uhde	thyssenkrupp Uhde	Grupa Azoty	Pulawy	Ammonium nitrate	1,300	UC	2022
thyssenkrupp Uhde	thyssenkrupp Uhde	Anwil SA	Wloclawek	Nitric acid	1,265	UC	2022
thyssenkrupp Uhde	thyssenkrupp Uhde	Anwil SA	Wloclawek	Ammonium nitrate	1,200	UC	2022
n.a.	Casale	Grupa Azoty	Kedzierzyn	Urea	780	RE	2023
RUSSIA							
n.a.	KBR	Kemerovo Azot	Kemerovo	Nitric acid	500	C	2021
Casale	Casale	Togliatti Azot	Togliatti	Urea	2,200	UC	2022
Tecnimont	Stamicarbon	KuibishevAzot	Togliatti	Urea	1,500	UC	2022
GIAP	Casale	KuibishevAzot	Togliatti	Nitric acid	1,350	UC	2022
GIAP	Casale	KuibishevAzot	Togliatti	Ammonium nitrate	1,500	UC	2022
CNCCC	Topsoe	ShchekinoAzot	Pervomayskyy, Tula	Ammonia	1,500	UC	2022
CNCCC	Stamicarbon	ShchekinoAzot	Pervomayskyy, Tula	Urea	2,000	UC	2022
NIIK	Casale	JSC Metafrax	Gubakha	Ammonia	1,000	UC	2022
NIIK	Casale/MHI	JSC Metafrax	Gubakha	Urea	1,700	UC	2023
n.a.	Stamicarbon	Acron	Novgorod	Urea	2,000	UC	2023
n.a.	Stamicarbon	Acron	Novgorod	Urea	+1,100	RE	2024
Tecnimont	KBR	EuroChem	Kingisepp	Ammonia	3,000	UC	2024
Tecnimont	Stamicarbon	EuroChem	Kingisepp	Urea	4,000	UC	2024
Uralchem	Stamicarbon	Uralchem	Perm	Urea	+900	RE	On Hold
n.a.	Casale	KuibishevAzot	Togliatti	Nitric acid	1,575	CA	2024
n.a.	Casale	KuibishevAzot	Togliatti	Ammonium nitrate	2,300	CA	2024
SAUDI ARABIA							
Daelim	thyssenkrupp Uhde	Ma'aden	Ras al Khair	Ammonia	3,300	UC	2022
n.a.	Topsoe	Neom	Neom	Ammonia	3,500	DE	2025
SOUTH KOREA							
thyssenkrupp Uhde	thyssenkrupp Uhde	Hu-Chems	Yeosu	Nitric acid	1,150	UC	2023
n.a.	KBR	Hanwha	Yeosu	Nitric acid	1,200	UC	2024
TURKEY							
Tecnimont	Stamicarbon	Gemlik Gubre	Gemlik	Urea	1,640	UC	2023
Tecnimont	n.a.	Gemlik Gubre	Gemlik	UAN	500	UC	2023
UNITED STATES							
Black & Veatch	Stamicarbon	Confidential	n.a.	Urea	+660	RE	2023
n.a.	Casale	Coffeyville Resources	Coffeyville, KS	Urea	1,100	RE	2023
n.a.	Stamicarbon	Confidential	n.a.	Urea	+1,180	RE	2025
n.a.	Stamicarbon	Confidential	n.a.	Urea	1,500	CA	2025
n.a.	KBR	Monolith Materials	Hallam, Nebraska	Ammonia	830	CA	2025
n.a.	Topsoe	Air Products	Ascension, LA	Ammonia	n.a.	P	2026
UNITED ARAB EMIRATES							
n.a.	n.a.	ADNOC	Ruwais	Ammonia	3,000	P	n.a.
UZBEKISTAN							
n.a.	Casale	Ferkensco	Yangiyer	Ammonia	1,500	DE	2025
n.a.	Casale	Ferkensco	Yangiyer	Urea	1,800	DE	2025

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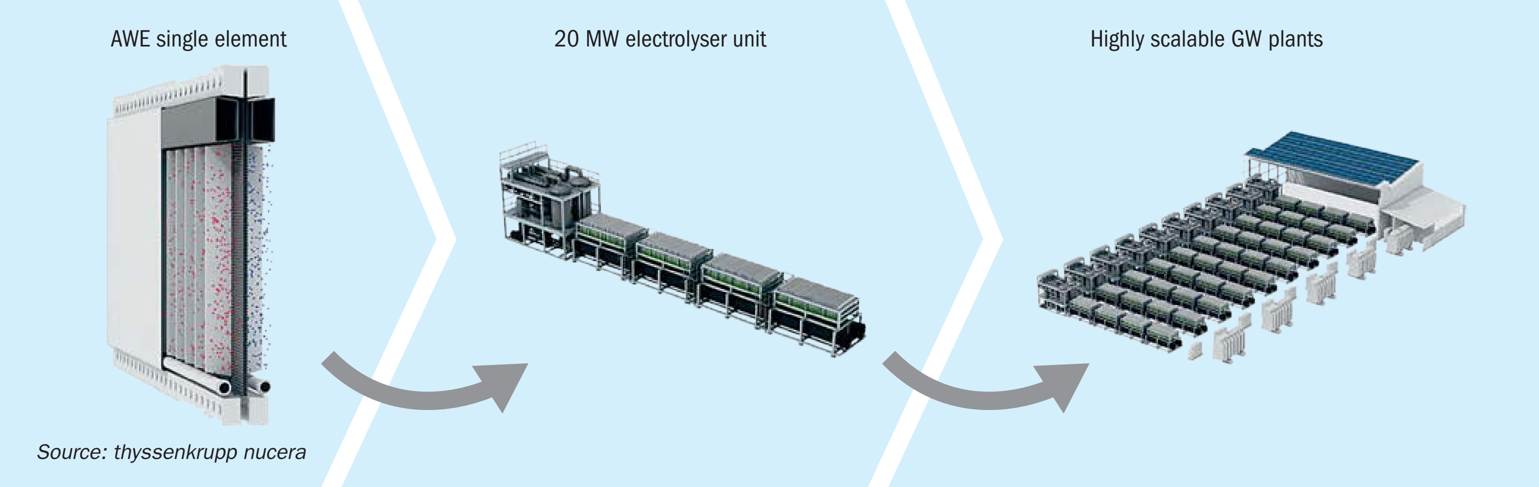
Ready for large-scale decarbonisation

Erika Niino-Esser of thyssenkrupp Industrial Solutions explains the importance of thyssenkrupp's technologies for sustainable hydrogen and ammonia value chains in the global energy transition, and how they are contributing to a climate-neutral world. Several novel green hydrogen projects are also highlighted.

Fig. 1: **Schematic design of an electrolysis cell (left), a 20 MW module (middle) and a 200 MW water electrolyser (right) from thyssenkrupp nucera**



Source: thyssenkrupp nucera

How is thyssenkrupp contributing to a climate-neutral world? Well, both companies thyssenkrupp nucera and thyssenkrupp Uhde have chemical engineering DNA and jointly offer technologies for the whole sustainable hydrogen and ammonia value chain, which are necessary for the global energy transition.

thyssenkrupp nucera offers world-leading technologies for high-efficiency electrolysis plants. The company, a joint venture with Industrie De Nora, has extensive in-depth knowledge in the engineering, procurement, and construction of electrochemical plants and a strong track record of more than 600 projects with a total rating of over 10 GW already successfully installed.

With its water electrolysis technology to produce green hydrogen, the company offers an innovative solution on an industrial scale for green value chains and an industry fuelled by clean energy – a major step towards a climate-neutrality.

Water electrolysis

Water electrolysers are electrochemical devices where purified water as well as electricity is fed to produce hydrogen and oxygen. The most mature and commercially available technologies are alkaline water electrolysis (AWE) and polymer electrolyte membrane (PEM). Other types of water electrolysis use solid oxide electrolyser cell (SOEC) and anion exchange membrane (AEM) technologies.

thyssenkrupp nucera offers alkaline water electrolysis and has developed modules with a standard size of 20 MW. Schematic designs of this 20 MW module as well as its key component, the electrolysis cell, are shown in Fig. 1.

During operation of the electrolyser, a mixture of demineralised water and electrolyte is fed into the electrolysis cell. When green electricity is applied, water is split into green hydrogen and oxygen. This chemical reaction inside the cell element is illustrated on the left side of the figure. The design of the cell element is based on thyssenkrupp nucera's knowledge and experience in chlor-alkali electrolysis.

By increasing the number of these cell elements, shown in the middle of Fig. 1 as four electrolyser stacks within the 20 MW module, a larger amount of hydrogen and oxygen can be produced. In the next step, both gases are purified in the process unit section inside the module. One 20 MW module can produce a maximum of 4,000 Nm^3 of hydrogen per hour with a high purity of 99.9 vol-%. Oxygen is usually a by-product in this process, which can be vented into the atmosphere.

By scaling up the alkaline water electrolyser, thyssenkrupp nucera was not only able to reduce the footprint of its plant, but it has also achieved a significant cost reduction. Picturing the current situation where electrolysers of several hundred MW are needed, the number of 20 MW modules can be increased as shown on the right of Fig. 1. These large-scale water electrolysers are key for reducing the CO_2 emissions, especially in hard-to-abate industrial sectors such as the steel or chemical industries.

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Hydrogen and ammonia value chain

Further technologies complementing the hydrogen value chain are provided by thyssenkrupp Uhde, which owns a huge portfolio of chemical and process technologies. These include carbon capture and utilisation technologies, such as methanol, synthetic gases, and fuels. For enabling large-scale and at the same time sustainable chemical production, the in-house technologies have been adjusted to utilise green routes and green hydrogen as the basis. These green routes as well as the industrial sectors with huge potential for decarbonisation are presented in Fig. 2.

High hopes particularly lie on the value chain for green ammonia, where thyssenkrupp Uhde has been one of the market-leading players for about 100 years. Whereas conventional ammonia production relies on grey hydrogen based on steam methane reforming of natural gas, the feedstocks for green ammonia consist of green hydrogen produced by water electrolysis using renewable energy sources. The nitrogen required for the ammonia synthesis is produced by an air separation unit. thyssenkrupp's modularised and standardised green ammonia plant designs can be developed for different plant capacities, ranging from 50 and 6,000 t/d.

Ammonia is not only an intermediate product for fertilizer production but is also a promising hydrogen carrier when it comes to global trading. The transportation of ammonia is state-of-the-art, and the existing infrastructure can be utilised for distribution. The most cost-effective solution is direct use of ammonia by the end-user, but it is also possible to convert the ammonia back into hydrogen and nitrogen. This process is called ammonia cracking and represents the reverse reaction of ammonia production. Due to the familiarity with the process, thyssenkrupp Uhde is developing this technology for large-scale applications with the aim of being market-ready by 2025. The plant for ammonia cracking can be operated with renewable energy sources in order to regain the green hydrogen.

Green hydrogen projects

With thyssenkrupp's capabilities to provide the whole hydrogen and ammonia value chain, there are several existing and novel projects that can be highlighted as listed below.

CF Industries in USA

At the world's largest ammonia production complex, hosting six ammonia plants and several fertilizer plants, CF Industries in Donaldsonville is going to partially decarbonise its current ammonia production. Many of these plants have been delivered by thyssenkrupp and are based on the proven Uhde® ammonia process. The new installation of thyssenkrupp's 20 MW water electrolyser will produce green hydrogen by utilising renewable energy and will enable an annual production of 20,000 t of green ammonia by 2023.

Element One / NEOM green hydrogen project in Saudi Arabia

Another 20 MW water electrolyser will be installed at NEOM in the Kingdom of Saudi Arabia, which is expected to start up in 2023. The project, also known as "Element One" represents a milestone project and is funded by the German government.

The same location is ideally placed for utilising both solar and wind energy and is therefore optimal for a high-capacity factor for the water electrolysis.

Targeting a production of 650 t/d of green hydrogen from 2026, a thyssenkrupp water electrolyser of more than 2 GW will be engineered, procured, and fabricated. NEOM Green Hydrogen Company, consisting of NEOM, ACWA Power and Air Products, will operate the facility for sustainable hydrogen and ammonia production.

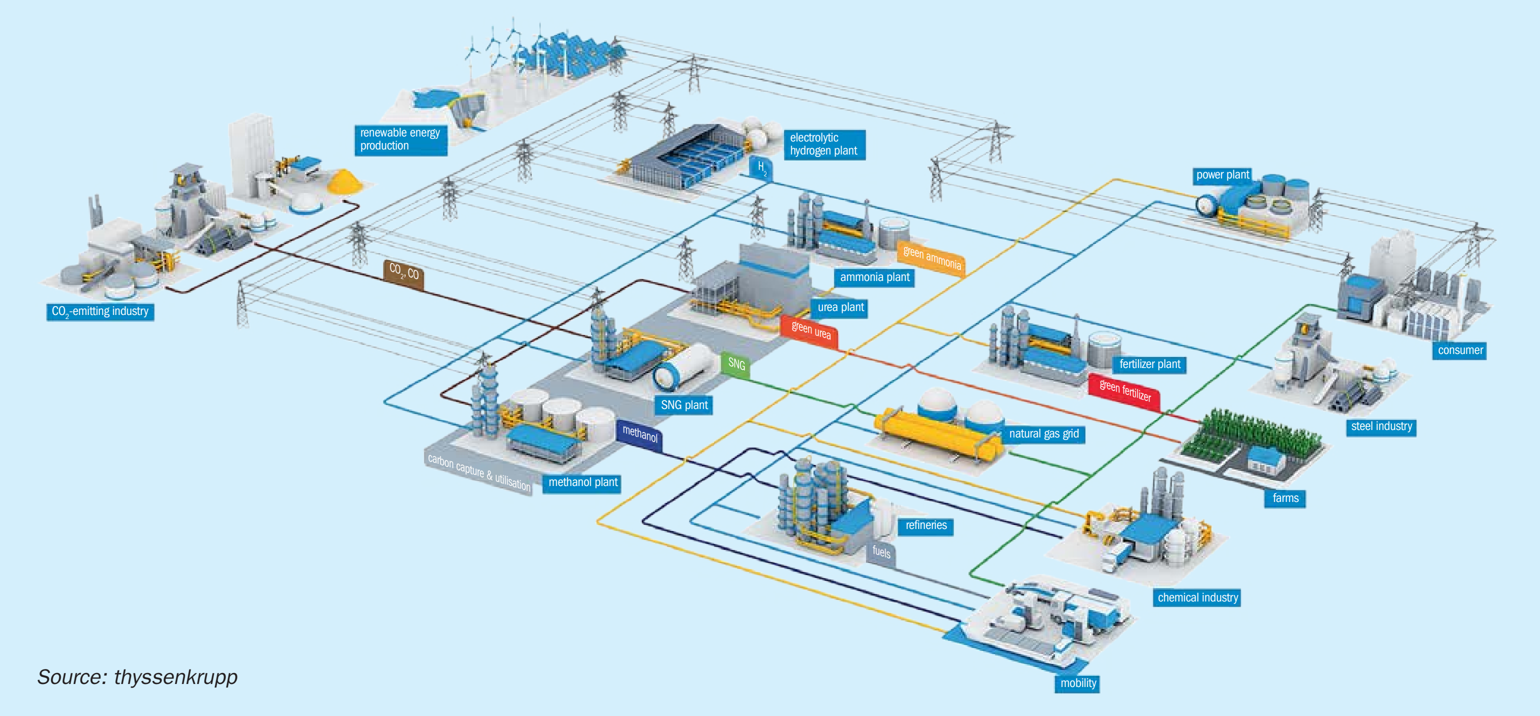
Air Products in the USA

Due to ambitious regulations in California, there is huge potential to decarbonise the transportation sector and neighbouring state Arizona has the ideal conditions for the production of low-cost renewable energy.

Air Product's hydrogen facility in Casa Grande, Arizona, will provide around 10 t/d of green hydrogen via thyssenkrupp's technology from 2023. A 40 MW water electrolyser will produce the clean gas, which will be liquefied by Air Products' proprietary technology.

The production site will also include a terminal for Air Products to distribute the

Fig. 2: **Hydrogen value chain by thyssenkrupp**



Source: thyssenkrupp

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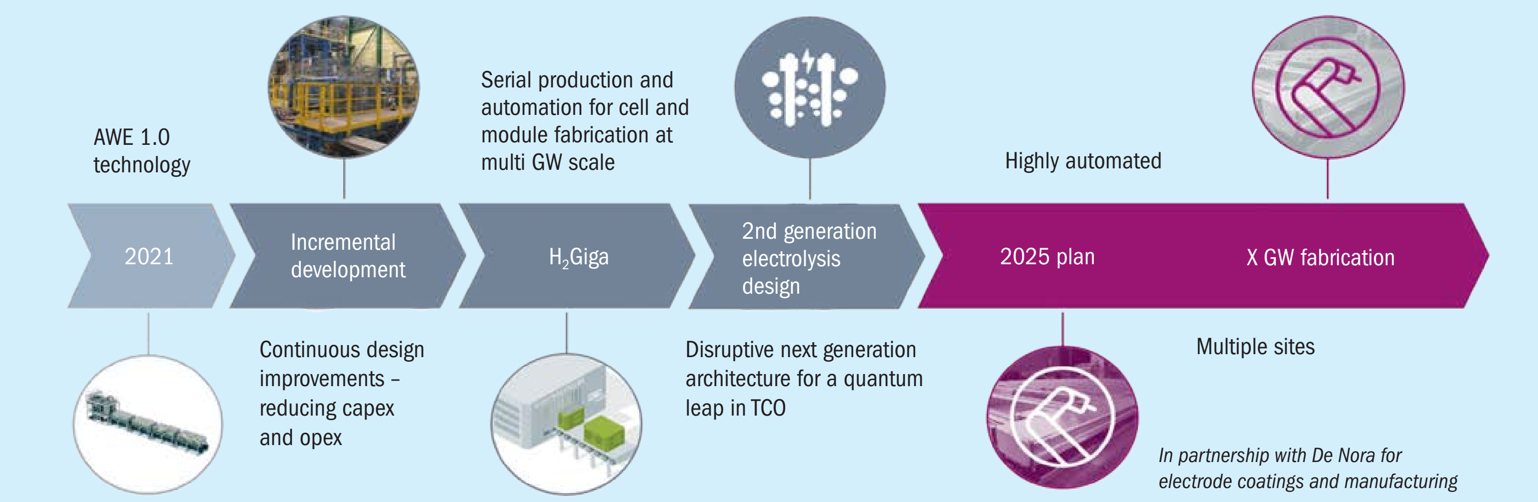
Fig. 3: **Product roadmap for thyssenkrupp nucera's alkaline water electrolysis technology as of April 2022**



Source: thyssenkrupp

product for the mobility market in California and other locations in the US. This represents a second joint project with the strategic partner Air Products.

Shell in the Netherlands

A large-scale water electrolyser with a capacity of 200 MW will be installed for the large-scale project "Hydrogen Holland I" in the port of Rotterdam. This will represent a major hydrogen hub in central Europe to contribute to the energy transformation. After engineering, procurement, and fabrication of the 200 MW water electrolyser plant, the expected start-up of the plant is 2024. The source of renewable energy will be offshore wind coming from the farm Hollandse Kust (Noord). The produced green hydrogen can be transported through a pipeline with a length of around 40 km to Shell's Energy and Chemical Park Rotterdam. With the aim of being climate neutral, reusable construction materials will be utilised where possible, and solar panels will be incorporated in the outside walls of the plant. The factory will be open to selected visitors once fully operational.

Hydrogen lead projects in Germany

thyssenkrupp is involved in all three hydrogen lead projects funded by the German Federal Ministry of Education and Research (BMBF). These projects are called H_2Mare, TransHyDE and H_2Giga, and have been initiated for the implementation of the National Hydrogen Strategy.

The aim of the H_2Mare project is to explore green hydrogen generation and other power-to-X products utilising offshore wind energy directly at sea. The direct coupling of offshore wind energy and water electrolysis will minimise production costs. thyssenkrupp is involved in the sustainable production of synthetic fuels, methane, green ammonia, and green methanol at sea for H_2Mare and conversion technologies such as ammonia cracking in TransHyDE. In the latter project several technologies for hydrogen transportation will be developed, evaluated, and demonstrated. Even though Germany will produce hydrogen within the country, a large amount needs to be imported from wind- and sun-rich regions. Therefore, an efficient infrastructure for transporting hydrogen is required.

In the H_2Giga project, the automated and serial production of water electrolysers will be enabled. Even though thyssenkrupp nucera has already built up an annual supply capacity of 1 GW of electrolysers in Germany, this is clearly just the beginning of an influential and far-reaching development process. Within four years by 2025, thyssenkrupp will expand the manufacturing capacity to 5 GW with this project.

The path forward

The product roadmap showing how thyssenkrupp nucera is going to further develop its cell elements for alkaline water electrolysers in the upcoming years is presented in Fig. 3.

The design of the current electrolysis cell is called "AWE 1.0 technology". It is based on thyssenkrupp's chlor-alkali experience and cell elements of this design already allow a manufacturing capacity of 1 GW. Continuous improvement and qualification are also taking place at the test plant for water electrolysis with a capacity of 2 MW, which has been in operation since April 2018. The test facility is called Carbon2Chem® and is located in Duisburg, Germany. With years of operational experience, the product has a high quality and is also highly reliable during dynamic operation.

The previously mentioned H_2Giga project aims for serial and automated production of cells as well as modules at GW scale. At the same time, the new cell design "AWE 1.x technology" will be developed to further reduce both capex and opex. The research outcome of H_2Giga will be implemented jointly with Industrie De Nora to have the automated cell and module manufacturing operational from 2025.

In parallel, a second-generation electrolysis cell called "AWE 2.0 technology" will be developed in the next four to five years. Major improvements in stack design will be implemented and can include any type of disruptive technologies in the field of water electrolysis. For the implementation of "AWE 2.0 technology" a further increase of the cell manufacturing capacity is planned, with expansion into multiple regions being considered.

Conclusion

thyssenkrupp owns a strong portfolio of chemical and process technologies, which includes large-scale water electrolysers and ammonia production plants. With these technologies being market-ready, both thyssenkrupp Uhde and thyssenkrupp nucera are ready for decarbonisation on a large scale. The large-scale green hydrogen and chemical projects with up to 2 GW capacity are just the beginning, with more to follow. ■

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Highly optimised ammonia synthesis catalysts

Ammonia synthesis catalysts have seen major improvements over the last 100 years, and they are highly optimised with respect to activity, thermal stability, and poisoning resistance. Improving such catalysts even further requires a deep understanding of their structure and the impact of different parameters on performance. Clariant, Johnson Matthey and Topsoe report on their studies and developments in ammonia synthesis catalysts.

CLARIANT

AmoMax® 10 Plus: From fundamental understanding to industrial application

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Ammonia synthesis is one of the oldest catalytic reactions carried out on a large scale, and a tremendous amount of research effort has been put into catalyst optimisation over the last 100 years. The most common strategy for catalyst optimisation utilises incremental improvements based on empirical studies, e.g., high throughput preparation and testing. Although this approach has led to considerable improvements, its limitations are evident. As a leading catalyst manufacturer, Clariant believes that a deep understanding of the catalyst structure and underlying mechanisms are crucial, to allow thinking outside of the box and to surpass the limitations of purely empirical research. Clariant's approach follows a rational catalyst design based on a deep understanding of its structure and how different parameters impact the catalytic performance. In order to study the catalyst behaviour under realistic operating conditions, an in-situ catalyst characterisation at high pressure and temperature is necessary. Such studies require highly sophisticated equipment and expertise. Clariant has partnered up with two Max Planck institutes, CEC and FHI, to study the relationship between composition, structure, and performance of iron oxide catalysts in context of the reduction mechanism. Applying the learnings from these studies, a new catalyst that provides unprecedented performance benefits was designed: AmoMax® 10 Plus.

Characterisation of model catalysts

Ammonia synthesis catalysts are commonly based on iron oxides, i.e., magnetite (Fe_3O_4) or wüstite ($Fe_{1-x}O$). The catalytically active species α-Fe is produced by reducing the iron oxide precursor inside the converter. Thus, to optimise the catalyst's structural properties, it is crucial to understand the reduction mechanism. Compared to magnetite, wüstite-based catalysts contain less oxygen, making them easier to reduce.

In order to study the reduction mechanism in detail, three different wustite-based model catalysts were prepared:

- Pure $Fe_{1-x}O$
- $Fe_{1-x}O$ promoted with K_2O and Al_2O_3
- $Fe_{1-x}O$ promoted with K_2O, Al_2O_3, and CaO

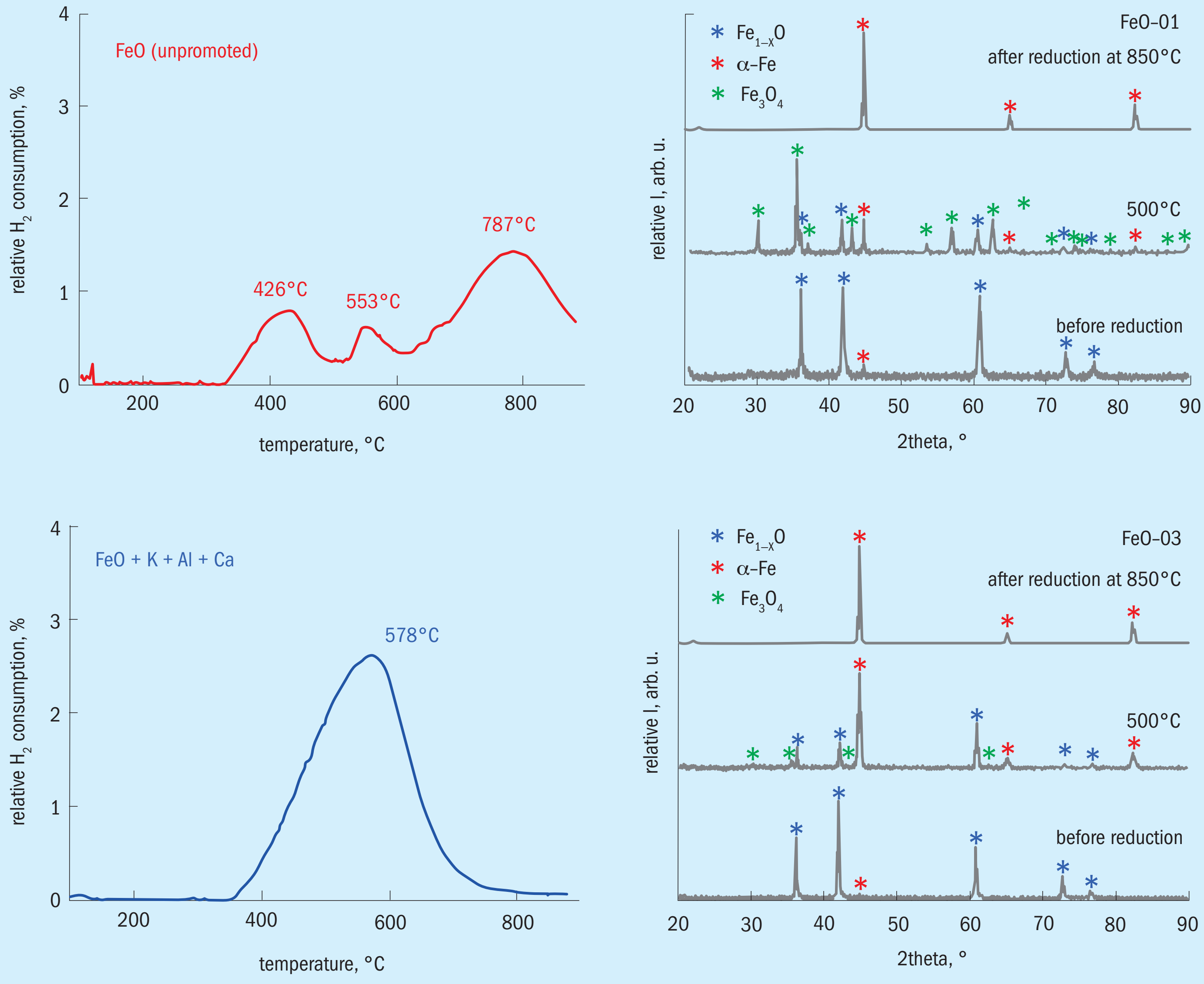
Temperature-programmed reduction (TPR) was performed on these catalysts and an industrial wustite-based catalyst. In addition, the catalysts were studied by X-ray diffraction (XRD) before and after reduction at different temperatures. The results for two of the model catalysts are illustrated in Fig. 1.

The results show that the reduction behaviour strongly depends on the promoter composition: While the unpromoted catalyst shows three distinct reduction peaks, the promoted catalyst shows only one large reduction peak. XRD shows large amounts of magnetite in the unpromoted catalyst after partial reduction at 500°C, while very little magnetite is found after partial reduction of promoted wüstite.

Based on these results, a reduction mechanism is proposed (Fig. 2): Wüstite can either be reduced directly to iron or disproportionate to magnetite and iron. The magnetite phase generated by thermal disproportionation is then reduced to iron, either directly or via intermediate reduction to wüstite. While disproportionation leads to large, catalytically inactive bulk iron, direct reduction results in high surface nanoplatelets, a prerequisite for high catalytic activity. Certain promoters stabilise the metastable wüstite, thereby preventing disproportionation.

The pressure during reduction has a significant impact on the catalyst's microstructure. However, in-situ studies are commonly performed at low pressure. In order to bridge this "pressure gap", a sophisticated experimental setup for high-pressure quasi in-situ transmission electron microscopy (quasi in-situ TEM) was developed at FHI. Consequently, quasi in-situ TEM experiments were performed on the triply promoted wüstite catalyst in order to study the structural changes

Fig. 1: **TPR profiles and XRD results with two model catalysts**[1]



Source: Reference 1

during reduction under high-pressure conditions (10 bar). Fig. 3 shows the same particle before reduction (left) and after partial reduction at 365°C (right). After partial reduction, the wüstite core is surrounded by a porous layer of nano-sized iron platelets. In addition, some magnetite is found. These observations corroborate the proposed reduction mechanism, where even with the promoted system, small amounts of magnetite are formed during the early stages of reduction due to the disproportionation of wüstite.

When designing a catalyst, it is important to understand the correlation between structure and performance. To shed light on these correlations, the catalytic performance was tested at 90 bar and 400°C in a fixed bed lab-scale reactor. In addition, the BET

Fig. 2: **Proposed reduction mechanism of wüstite (modified illustration)**[1]

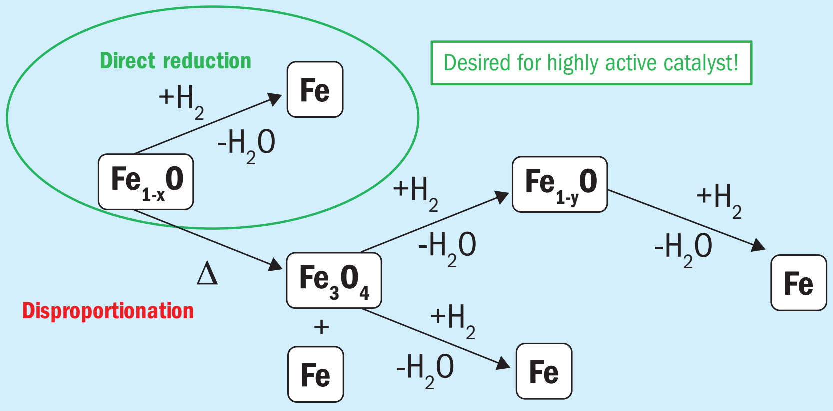


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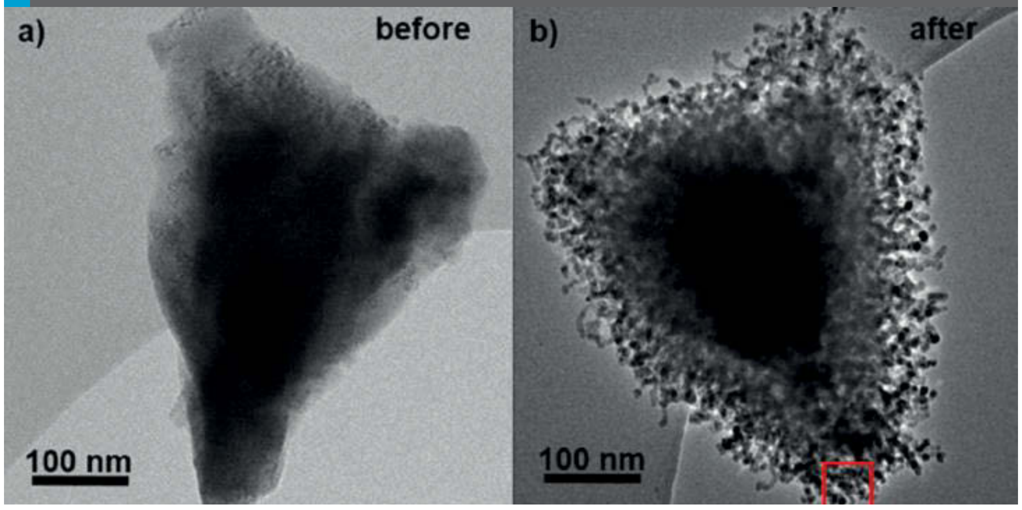
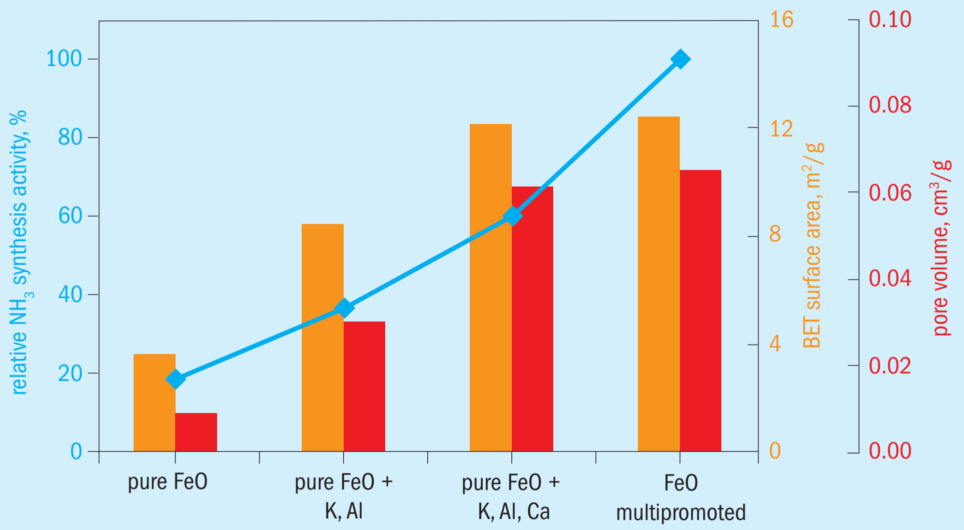
Fig. 3: **Quasi in-situ TEM images of triply promoted wüstite before reduction (left) and after partial reduction at 365°C (right)**[1]



PHOTOS: REFERENCE 1

Fig. 4: **Relative NH_3 synthesis activity at 400°C and 90 bar, BET surface area, and pore volume**[1]



Source: Reference 1

surface area and pore volume of the spent samples were measured by N_2 physisorption. The results are summarised in Fig. 4.

A clear correlation was observed between BET surface area, pore-volume, and catalytic activity for unpromoted wüstite doubly promoted wüstite, and triply promoted wüstite: With increasing surface area and pore volume, the catalytic activity increases. These observations further corroborate the proposed reduction mechanism: The chosen promoters stabilise wüstite, inhibiting the disproportionation and favouring direct wüstite reduction, which leads to the formation of iron nanoplatelets. These platelets provide a high surface area, which is correlated with high catalytic activity. Interestingly, the multi-promoted industrial wüstite catalyst is considerably more active than the triply promoted model catalyst, but it does not have a significantly higher surface area or pore volume. This indicates that there are other effects of promoters that are not related to generating and maintaining a high surface area. Such effects can include an electronic promotion or the generation of specific crystallographic defects.

In summary, a strategy can be formulated that allows a highly active wüstite catalyst to be generated based on the proposed reduction mechanism: The catalyst must be designed to favour direct reduction over disproportionation, thereby creating high-surface-area iron nanoplatelets (Fig. 5).

Development of AmoMax® 10 Plus

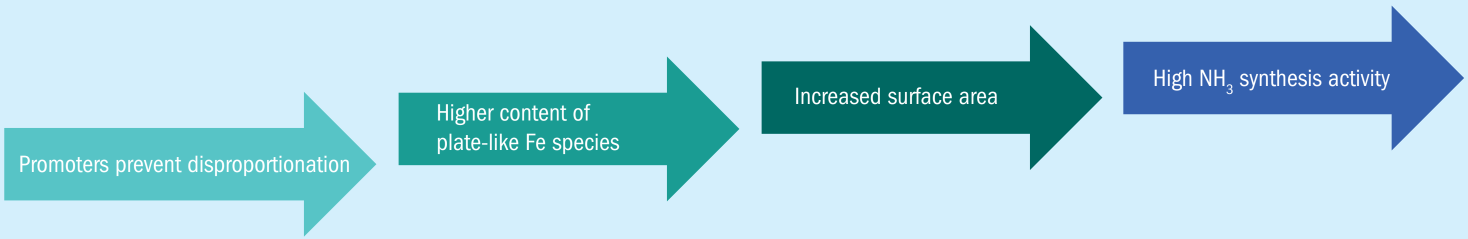
Design approach

The last section has provided some insights into the investigations to understand the correlations between catalyst composition, microscopic structure, and performance parameters. Equipped with these learnings, it is possible to design a catalyst by adjusting the recipe for optimised performance. Applying this rationale design approach as illustrated in Fig. 6, Clariant optimised the composition of AmoMax® 10, a highly active catalyst with more than 100 references around the world, to obtain a next-generation catalyst with unprecedented performance: AmoMax® 10 Plus.

Reduction behaviour

One of the main advantages of wüstite-based catalysts compared to classical magnetite-based catalysts is that they are more easily reduced while releasing a lower amount of water due to their lower oxygen content. This is already the case with Clariant's current generation wüstite catalyst, AmoMax® 10, Fig. 7 shows that AmoMax® 10 Plus is even more easily reduced, with a roughly 10°C lower reduction temperature compared to

Fig. 5: **Scheme illustrating the impact of promoters on activity based on the proposed reduction mechanism**



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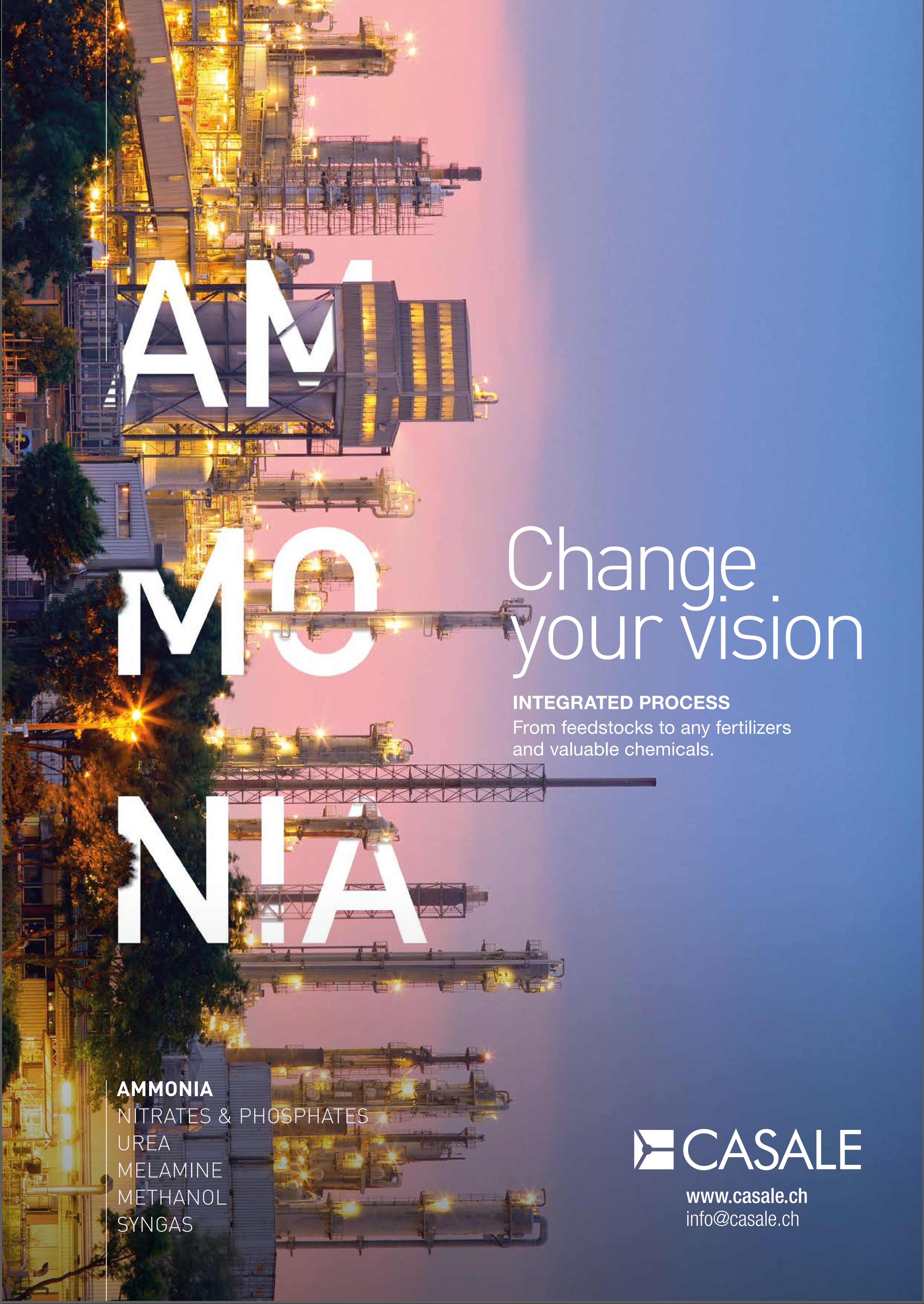
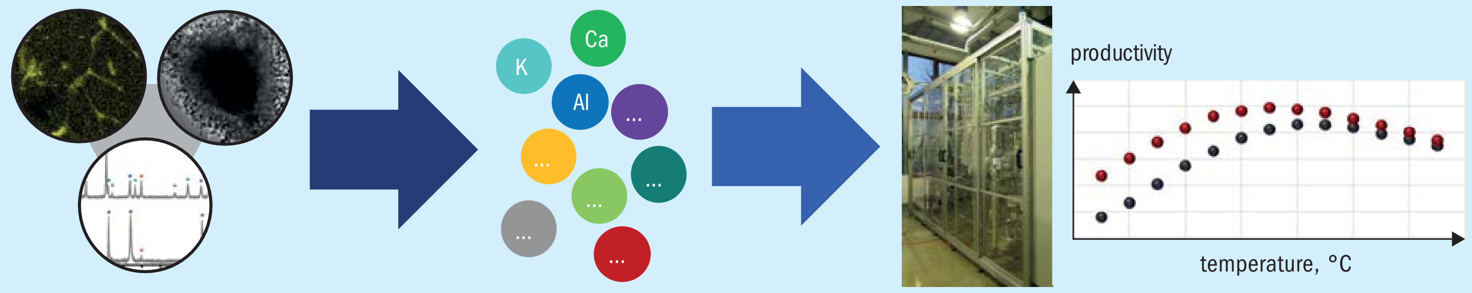


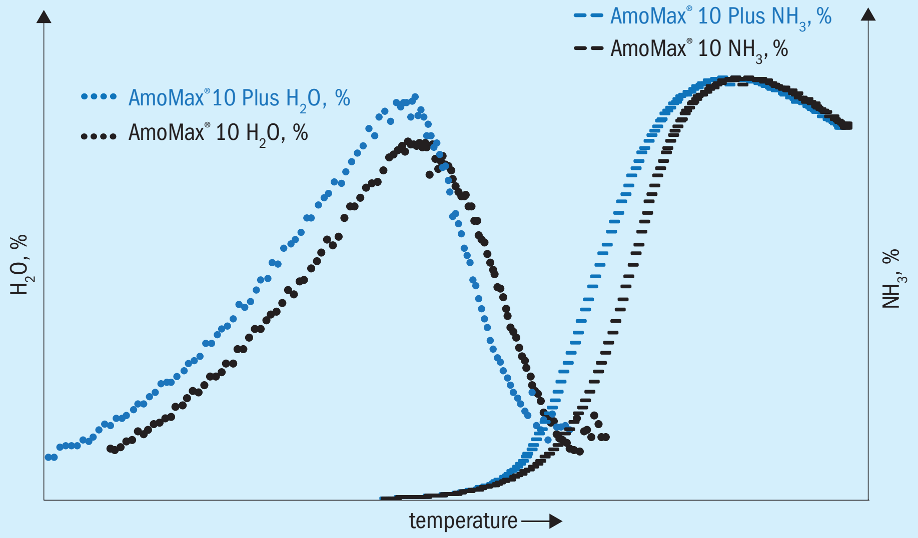
Fig. 6: **Rational approach to designing an ammonia synthesis catalyst by understanding the structure-activity correlations**



Source: Clariant

AmoMax® 10 at 90 bar. This faster reduction leads to a lower light-off temperature due to an earlier onset of NH_3 production. A faster reduction and lower light-off temperature are highly beneficial because they can save considerable time during start-up.

Fig. 7: **Reduction profiles and NH_3 production with AmoMax® 10 and AmoMax® 10 Plus at 90 bar**



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Catalytic performance

A crucial performance parameter for ammonia synthesis catalysts is their resistance to poisoning, particularly by oxygenates such as H_2O, O_2, CO, and CO_2. The most common poison is H_2O, which is released during catalyst reduction but can also be present in small concentrations (usually below 10 ppm) in the feed gas. In addition, the catalyst may be exposed to high water concentrations during certain unexpected events. It is not uncommon that one or more of these events occur over the catalyst lifetime of 15+ years. The water resistance during NH_3 synthesis was tested in a bench-scale reactor by dosing 80 ppm water into the feed gas at a pressure of 100 bar. Fig. 8 shows the performance of AmoMax® 10 and AmoMax® 10 Plus under these conditions. Clearly, AmoMax® 10 Plus is considerably more active under poisoning conditions, especially at low temperature where the poisoning effect of water is typically the strongest. At 400°C, AmoMax® 10 Plus provides a productivity boost of nearly 200%.

Due to the high expected lifetime of 15+ years, stable long-term performance is a crucial feature of an ammonia synthesis catalyst. Therefore, rapid aging tests were performed in order to study the long-term thermal deactivation of the catalyst. After each heat cycle (520°C, 150 bar), the NH^3 productivity was measured at 400°C and 100 bar. The performance over eight heat cycles is illustrated in Fig. 9. Both AmoMax® 10 and AmoMax® 10 Plus exhibit very high thermal stability, but AmoMax® 10 Plus is roughly 8% more active overall.

Value creation

The higher activity of AmoMax® 10 Plus enables a lower loop pressure and a lower recycle ratio, which results in considerable energy savings. The expected savings

Fig. 8: **Relative NH_3 production with AmoMax® 10 and AmoMax® 10 Plus at 100 bar, with 80 ppm H_2O**

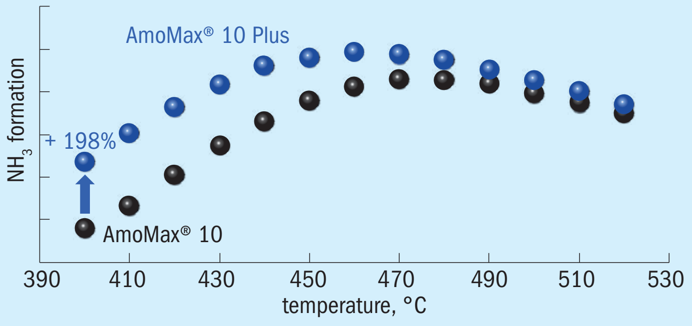

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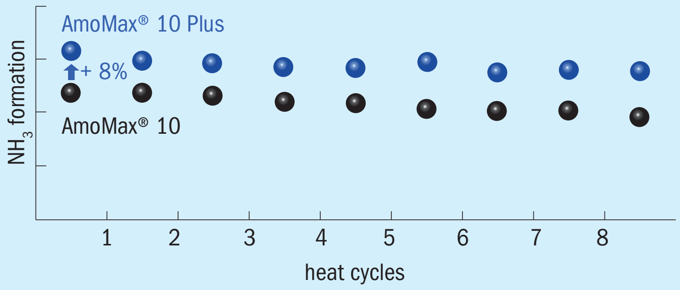
Fig. 9: **Relative NH_3 production with AmoMax® 10 and AmoMax® 10 Plus in rapid aging experiment with heat cycles (520°C, 150 bar) and test cycles (400°C, 100 bar)**



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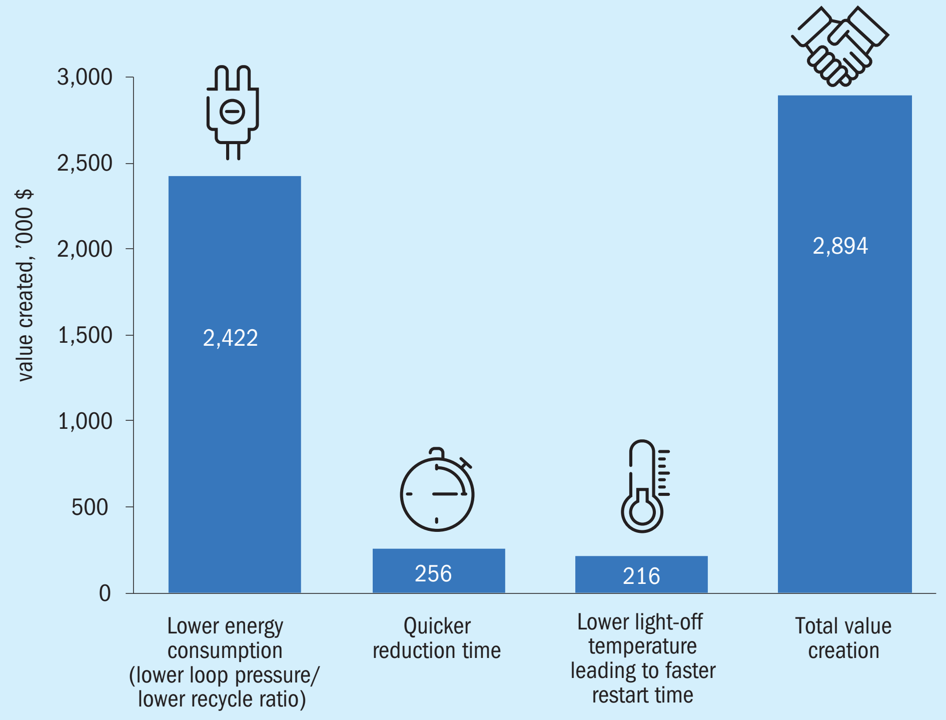
compared to a benchmark magnetite catalyst were calculated for a typical 1,600 t/d ammonia plant over a lifetime of 15 years, assuming natural gas costs of $4.0/million Btu and an ammonia price of $220/t (Fig. 10). Most of the total savings are due to lower energy consumption, which is estimated to be 0.15 GJ/t of ammonia. The easier reduction and lower light-off temperature are expected to generate the additional value of nearly $0.5 million. All in all, the expected value creation over 15 years adds up to nearly $3 million.

Fig. 10: **Value created by AmoMax® 10 Plus in a typical 1,600 t/d NH_3 plant over a lifetime of 15 years, compared to benchmark magnetite catalyst**



Source: Clariant

Acknowledgments

We acknowledge Prof. Robert Schlögl, the Max Planck Institute for Chemical Energy Conversion (CEC), and the Fritz Haber Institute of the Max Planck Society (FHI) for their crucial contributions that helped elucidate the reduction mechanism of wüstite-based ammonia synthesis catalysts.

Reference

1. Folke J. et al.: "Promoter effect on the reduction behavior of wüstite-based catalysts for ammonia synthesis", Catalysis Today (2021).

JOHNSON MATTHEY

High activity ammonia synthesis catalyst and its role in the transition to a low carbon economy

T. Davison

There is an increasing focus internationally on reducing greenhouse gas (GHG) emissions to limit the effects of global warming, resulting in the introduction of ever more stringent emissions limits and the rapid development of new low carbon technologies. In countries with emissions trading schemes there is an extra incentive to reduce the carbon footprint of plants, especially in Europe where carbon prices have risen considerably in early 2022. The high gas prices currently being seen in some regions are also an effective driver to increase plant efficiency in order to drive down opex costs. For new plant designs the focus in green and blue ammonia flowsheets as an effective way of addressing these issues and these technologies are key to achieving GHG reduction targets, whereas for existing conventional plants the change will be more gradual, with revamps or replacement over time to low carbon alternatives.

Away from the established markets for ammonia in fertilizers and chemical production, which will continue to grow, there is also projected to be a large emerging market for ammonia as a hydrogen transport vector. A lot of investment is rightly going into green hydrogen production as a source of fuel, but hydrogen itself is not the best choice as an energy vector, having a low energy density and being difficult to store and transport. Due to this, the feasibility of using other compounds as hydrogen transport vectors has become a topic of discussion. Ammonia is currently considered a front-runner as a hydrogen transport vector due to a high hydrogen density (120 kg H_2 per m^3 at -33°C, 1 atm)[1] and existing infrastructure for storage and transportation associated with the mature fertilizer and chemicals industry. Ammonia can also be used as a fuel itself, either as pure ammonia or partially decomposed ammonia along with the option to fully decompose to hydrogen for use in fuel cells or energy generation. Plants to service this market will be blue or green ammonia designs and are projected to make up the majority of the new ammonia plants being built in the mid to long term.

High activity ammonia synthesis catalysts can be effectively utilised in all of these scenarios to optimise synthesis loop operation. For existing plants, either as a standalone catalyst replacement or as part of a wider revamp, utilising a high activity ammonia synthesis catalyst over a standard one enables loop operation at the most efficient conditions and can thereby reduce the comparative consumption of the plant. In new blue ammonia plants, where the catalytic stages operate at similar conditions to conventional grey ammonia plants, the same benefits can be realised by incorporating the high activity synthesis catalysts at the design stage. For green ammonia plants the number of catalytic stages is limited as electrolysers

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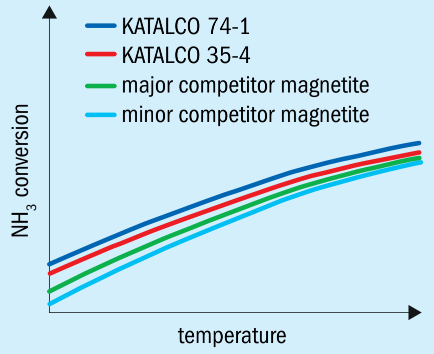
are used to generate hydrogen rather than conventional steam methane reforming and water gas shift, but Johnson Matthey has solutions for both the deoxygenation stage and the ammonia synthesis stage at the full range of operating pressures for projects currently being developed.

The catalyst

KATALCO™ 74 series catalysts were initially developed for used in the AMV and LCA processes, which required the highest activity catalyst for their low pressure (80 bar) synthesis. As this increased activity compared to conventional magnetite catalysts is applicable over the whole range of ammonia synthesis converter pressures however, more recently it has been adopted for high pressure synthesis loops. This increase in activity, illustrated in Fig. 1, and an increased ease of reduction are achieved by incorporation of cobalt oxide as a promotor and differing, re-optimised levels of the other structural and electronic promotors compared to standard magnetite catalysts. The cobalt has the effect of increasing the rates of nitrogen adsorption and ammonia desorption from the surface of the catalyst, hence increasing the rate of the overall synthesis reaction.

A number of studies[2-5] into the location of cobalt in ammonia synthesis catalysts have looked at the reasons for the positive effect on catalyst reduction and activity. In these studies, cobalt oxide is found as a solid solution dissolved in the magnetite phase. The incorporation of cobalt into the iron lattice distorts the structure of the fused iron catalyst, generating layers of cobalt spinels which typically produce smaller iron crystallites on reduction, as shown in Fig. 2. This is a significant factor in generating the high activity of the material.

Fig. 1: **Comparison of magnetite catalyst performance**



Source: Johnson Matthey

This catalyst is robust and stable, with the high activities relative to conventional magnetite catalysts sustained over long catalyst lifetimes. Johnson Matthey has a long list of references for these KATALCO 74 series catalysts, all showing high activities maintained for long lifetimes with a number of plants operating for over 20 years on the same charge.

Existing plants

The optimal operation of a synthesis loop and its corresponding plant is dependent on a number of factors. Plants located in areas with a cheap supply of natural gas will often want to prioritise increasing ammonia make over the efficiency of the plant, although the shift to focus more on plant emissions may shift these operators to focus more on plant efficiencies and the reduction of emissions. Plants with more expensive feedstocks and in areas with more stringent regulations on emissions and in carbon trading schemes will tend to want to focus on maximising the efficiency of the plant, which is what this article will focus on.

Increasing efficiency and reducing the energy consumption of the synthesis loop is a balancing act, trying to minimise the cumulative requirements of compression, refrigeration, and recirculation. As the loop pressure increases the compression duty goes up, but the refrigeration duty decreases and as the reaction equilibrium is more favourable more ammonia is produced over the converter and the recycle rate and hence recirculation duty also drops. The reverse is also true and when the operating pressure deviates too much from the optimal position in either direction the overall energy consumption rises substantially, so to maximise efficiency the aim is to operate close to this pressure for minimum energy consumption. However, this minimum will differ from plant to plant – depending on the design and age of the plant, the compressor design and how it is driven, whether there have been any retrofits and even the age and performance of installed catalysts in the front end can have an impact.

Case study 1

A modern 2,200 t/d thyssenkrupp Industrial Solutions (tkIS) plant has a three-bed design using two converters with an HP steam boiler in between bed 2 and bed 3. By using KATALCO 74-1 instead of KATALCO 35-4 in the design the loop pressure can be reduced by 4% while maintaining the same production rate, efficiently saving compression energy and reducing

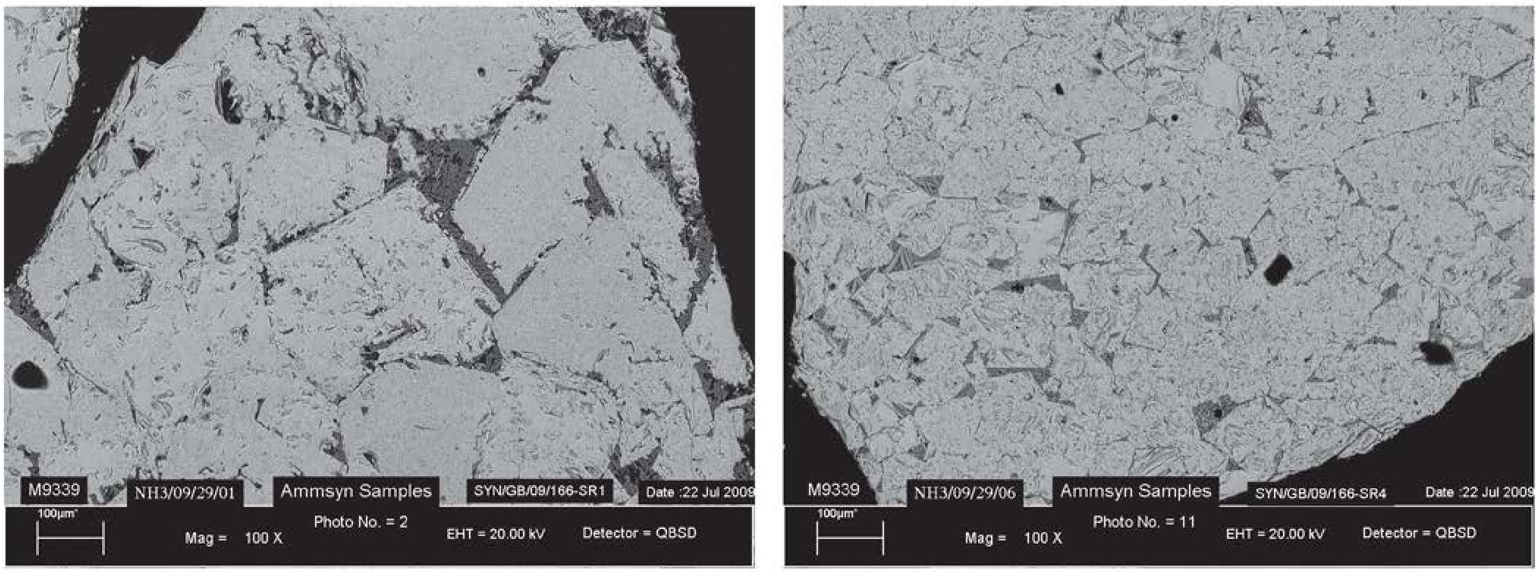
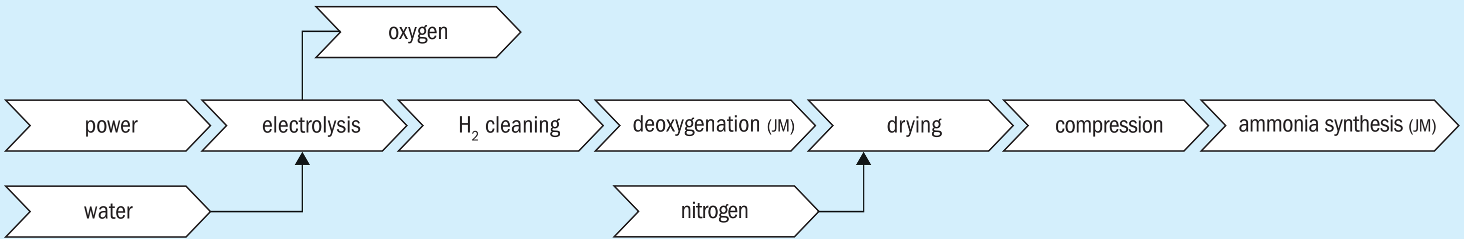


Fig. 2: Microscopy images of standard and cobalt promoted magnetite.

Fig. 3: **Typical schematic of a green ammonia process**



Source: Johnson Matthey

the overall consumption of the plant, along with its associated emissions. This plant has now been up and running for five years and is performing well, with previous data sets showing an exit ammonia concentration of above 22%, well above the required performance at a loop pressure of 192 barg – 15 bar below the flowsheet pressure and enabling them to produce significantly more than the nameplate production rate whilst still operating efficiently.

Case study 2

High activity catalysts are most beneficial when installed in beds with difficult duties – for example, high inlet ammonia, lower hydrogen and nitrogen partial pressures. In some plants it may be beneficial to target these particular beds for replacement with high activity catalyst rather than replacing the whole quota of beds. A retrofit of a converter on a European plant reinforces this – the first bed is installed with a KATALCO 35 series catalyst, as the duty is relatively easy, but as the reaction becomes more inhibited and the bed temperatures need to be lower the high activity KATALCO 74 series catalyst is used in the second and third beds to maximise the reaction rate. This configuration, along with the changes to the converter internals, has allowed the plant to gain a significant benefit with respect to the pressure the loop must operate at to meet production requirements. At the end of the previous charges' lifetime the converter inlet pressure was >300 barg and it was achieving an outlet ammonia concentration of just under 16%, the new charge with KATALCO 74 series catalyst in beds 2 and 3 and new internals achieved an outlet concentration of 22% at <230 barg, far greater conversion at a substantially lower pressure. This reduction brings the pressure down close to that minimum in terms of loop power consumption, substantially increasing the efficiency of the back end of the plant.

Revamps

The scope for low carbon solutions via revamps is dependent on the final product manufactured on the site – if the ammonia is fed to a urea plant, then the majority of the carbon dioxide recovered in the CO_2 removal stage will be used as feedstock for urea production. In this case there is potential for carbon capture and storage (CCS) only from the flue gas exit the primary reformer and any surplus CO_2 not required for urea production. If the plant is producing merchant ammonia or the site is manufacturing ammonium nitrate, etc. then more of the carbon can be captured and sequestered with potential CCS on both the flue gas from the primary reformer and the CO_2 stream from the CO_2 removal stage. Concurrently with installing CCS technology many plants will look to make other improvements during a revamp project including debottlenecking and opex reductions, where a high activity ammonia synthesis catalyst such as KATALCO 74-1 can be utilised in conjunction with other upgrades to get the most out of the plant.

Clean ammonia production

Blue ammonia

Blue ammonia will be a key technology in the drive to low carbon ammonia and energy, whilst carbon dioxide is still produced by the process, it is produced in a form which can be captured and sequestered. This technology is closer to a conventional "grey" ammonia plant and as such in the short term is more viable for the bulk of the large-scale new ammonia plants, whereas green ammonia technology at this scale will likely become more prominent in the mid to long term. As the major differences between existing "grey" ammonia plants and blue ammonia flowsheets are around the reforming section, the conditions within the synthesis loop will be within the bounds of currently operating plants. Both KATALCO 35 series and the high activity KATALCO 74 series catalysts have proven strong performance at these conditions – in particular the KATALCO 74 series catalysts can be used to maximise activity within the ammonia synthesis reactor and optimise loop performance.

Green ammonia

With improved electrolyser technology, falling renewable energy costs, and the drive to reduce carbon emissions, green ammonia is looking increasingly favourable as a viable alternative to SMR based production. The majority of projects in development are based on updated AWE or PEM (proton exchange membrane) type electrolysers, with a general configuration similar to that shown in Fig. 3, a process schematic showing the building blocks of a typical green ammonia process.

One of the big considerations for these plants is how best to match the input power to the desired ammonia production rates. To effectively decarbonise the system the power generated must come from renewable or decarbonised energy production, but most renewable energy production methods have large fluctuations in output, for example wind and solar energy both fluctuate greatly depending on the weather. There are various methods in development to mitigate these effects, but despite this there will be more fluctuation in the flow of syngas to the synthesis loop compared to a conventional "grey" ammonia plant, so this will need to be factored into the design of the equipment in the loop to ensure that it is robust and adaptable to these conditions.

The green ammonia technologies in development fall into two major categories – designs with high pressure synthesis loops and those that have low pressure ammonia synthesis at the electrolyser operating pressure. The low pressure plants tend to be at a smaller scale or modular in design, with multiple modules to achieve the desired capacity. The high

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pressure plants may also have a modular approach in terms of the electrolysis section, with the potential to add more capacity over time but they have a large ammonia synthesis loop operating at high pressures (from 130 to over 300 barg). Some of the projects focussing on the smaller/modular plants are designing for ammonia production at the operating pressure of the PEM electrolyser to reduce the need for compression. These projects are looking at ammonia synthesis at significantly lower pressures than existing large-scale ammonia production, from some as low as 20 barg to around 45 barg, with relatively low conversion per pass of ammonia in the synthesis reactor due to the less favourable equilibrium conditions.

For the high synthesis pressure type designs the conditions within the loop are similar to conventional ammonia plants or with even higher pressures so the reaction equilibrium is relatively good and conventional catalysts are suitable for this duty, with KATALCO 74-1 GREEN a superior choice to deliver high performance in the centralised synthesis loops. In the UK as part of National Net-Zero Project a Green Ammonia Demonstrator (Fig. 4) was designed, built, and commissioned at the Science & Technology Facilities Council (STFC) Rutherford Appleton Laboratory in Oxfordshire in 2018. This unit was loaded with JM's high activity KATALCO 74-1 GREEN ammonia synthesis catalyst. The aim of the project was to be a small-scale demonstrator for the world's first roundtrip application of green ammonia for energy storage Power-to-Ammonia-to-Power (P2A2P). The project was part of the Siemens-led Decoupled Green Energy project and is now entirely operated by STFC.

To assess the viability of ammonia synthesis at the low pressures associated with the small, modular green ammonia units in development, testing of KATALCO 74-1 GREEN catalyst was undertaken down to pressures of 25 barg. This testing and associated modelling confirmed that KATALCO 74-1 GREEN still shows high activity at these low pressures and Johnson Matthey's in-house models provide a good measure of the reaction dynamics even in this operating envelope. Due to the low pressures the equilibrium conversion is significantly lower than in conventional ammonia synthesis reactors so the outlet ammonia concentration from the reactor is lower (likely <10 mol-% NH_3) and a higher recycle rate would be necessary compared to the higher pressure loops.


PHOTO: JOHNSON MATTHEY

Fig. 4: Green ammonia demonstrator plant in which KATALCO 74-1 was installed.

Summary

Ammonia production continues to be of utmost importance internationally, both in its existing markets of fertilizer and chemicals production and the emerging market of green ammonia as a hydrogen vector and fuel. For existing production facilities the challenge is to expand production sustainably whilst reducing plant emissions and requires a focus on operating efficiency, achieved through revamps (including carbon capture and storage) and the use of high performance catalysts such as KATALCO 74-1 to optimise this efficiency.

For new blue and, in particular, green ammonia plants servicing the emerging clean ammonia energy market the focus is on improving the efficiency of the process, aiming to get the operating costs closer to those for the conventional grey ammonia plants. While the majority of the scope for this cost reduction is around the design and intensification of the electrolysers, use of the high activity KATALCO 74-1 GREEN catalyst in these flowsheets can aid in optimisation of the loop and subsequently bringing operating costs down. For the green ammonia flowsheets with low pressure loops, KATALCO 74-1 GREEN catalyst has been tested down to 25 bar and still shows reasonable activity even at these low pressures.

References

1. Manglik, R., Heat Transfer and Fluid Flow Data Books, Genium Publishing Corporation, Table 4-1. Physical Properties of Common Liquids at Atmospheric Pressure. Retrieved from Knovel
2. Rabina, P.D., Kuznetsov, L.D., Enikeev, E.Kh. and Ivanov, M.M., Kinet. Katal., 8, 167, (1967); Artyukh, T., Rusov, M.T. and Boldyreva, N.A. Kinet. Katal., 8, 1319, (1967)
3. Kalenczuk, R., Applied Catalysis A, 112, 149, (1994)
4. Kalenczuk, R., Catalysis Letters, 33, 255, (1995)
5. Wang, W-X., Zhao, H.-Q., Wen, J.-M., Li, F. and Wang, D.-M., Applied Catalysis A, 122, 5, (1995)

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TOPSOE

Magnetite matters: optimising a time-tested catalyst for improved conversion and efficiency

M. Feddersen

The manufacture of ammonia is a huge global market, likely to amount to approx. $90 billion by 2026. In fact, many people would consider the modern ammonia process to be one of the most important industrial chemistry reactions ever developed. It paved the way for the widespread availability of ammonia fertilizer, helping give rise to significant increases in yields from agriculture, and a resulting growth in prosperity and a world population boom. Besides its importance as a fertilizer and a building block for other nitrogen fertilizers, ammonia is also an important feedstock for various chemicals and in future could become an important energy vector.

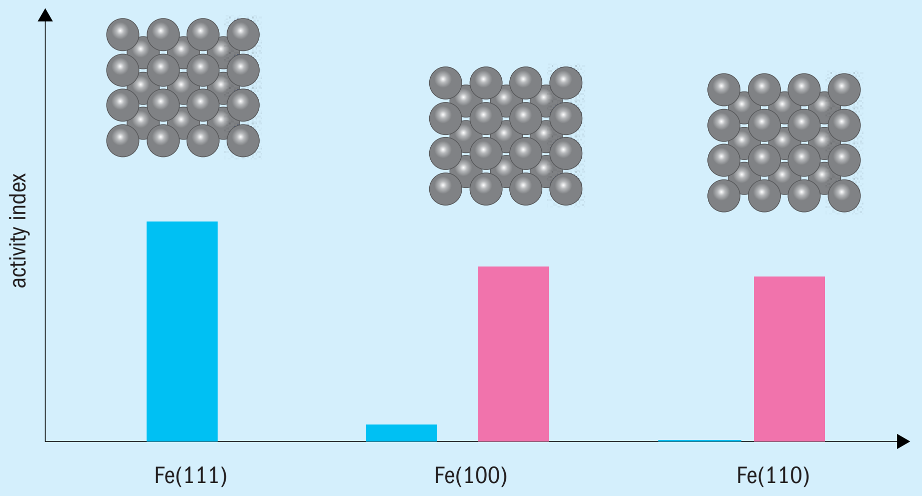
World ammonia production in 2019 was 235 million tonnes, so even any slight changes, improvements and efficiency gains in the production process can have significant effects. When implementing and streamlining a relatively mature technology, operating margins matter and can be crucial for profitability.

The catalysts used for ammonia synthesis will influence the operating economics of the plant throughout its service life. They should last for 15 to 20 years before any replacement is needed, so it is essential to make the right choice. The wrong choice can have extremely costly consequences because there is no way to replace the catalyst without considerable production loss as a result of the extensive downtime required to complete a catalyst change out.

The Haber-Bosch process for producing ammonia marked the beginning of using promoted magnetite catalysts to synthesise ammonia. Now, more than a century later and despite the emergence of several alternative catalysts, magnetite is still the preferred catalyst for many ammonia producers. Continued technical developments to maximise the amount of ideal iron crystal morphology and to optimise the unique promoter dispersion have now resulted in the availability of the most active magnetite catalyst ever.

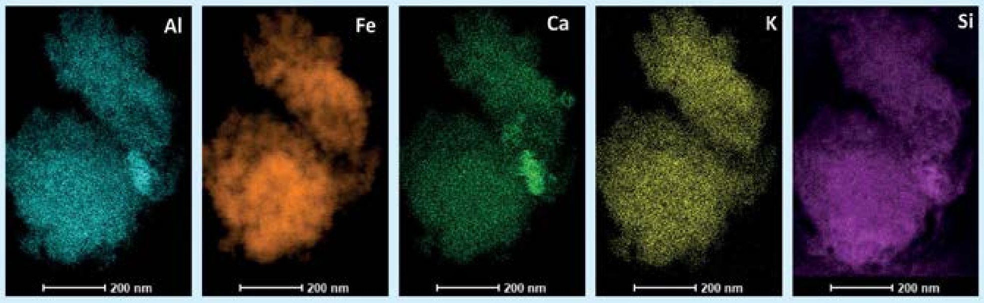
Solutions based on magnetite catalysts provide exceptionally long service lives – so long, in fact, that people involved in selecting this specific catalyst will probably only do it once in their entire professional career.

Fig. 1: **Illustration of the different iron surfaces, and their activities without promotion and with optimal promotion**



Source: Topsoe

Fig. 2: **Scanning electron microscope pictures of alumina, calcium, potassium and silica promotor distribution on magnetite iron surfaces**



Source: Topsoe

A number of alternative formulations and technology approaches for ammonia synthesis catalysts have also appeared over the years.

A catalyst using ruthenium on a carbon carrier system and involving a special process design was the talk of the ammonia industry about 25 years ago. Only a handful of these installations ever actually materialised because there were challenges with side-reactions such as methanation and the catalyst was also very sensitive to poisoning. Furthermore, the scarcity of ruthenium and the complexity of the production process resulted in very high catalyst costs that prevented the process from being commercially viable.

A few years later, in about 2005, an iron catalyst based on a promoted wüstite phase began to appear commercially. This catalyst was a result of a Chinese development initiative and has since won a significant market share.

In order to compare the different characteristics and advantages of magnetite-based and wüstite-based catalysts, it is important to understand what makes a good ammonia synthesis catalyst with a long service life. These features include:

- high activity;
- high catalyst stability;
- good stabilisation of pre-reduced versions.

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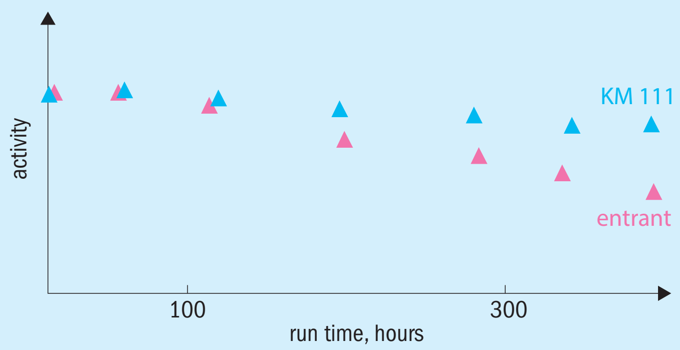
Fig. 3: **Ageing experiments on commercially available magnetite- and wüstite-based ammonia synthesis catalysts**



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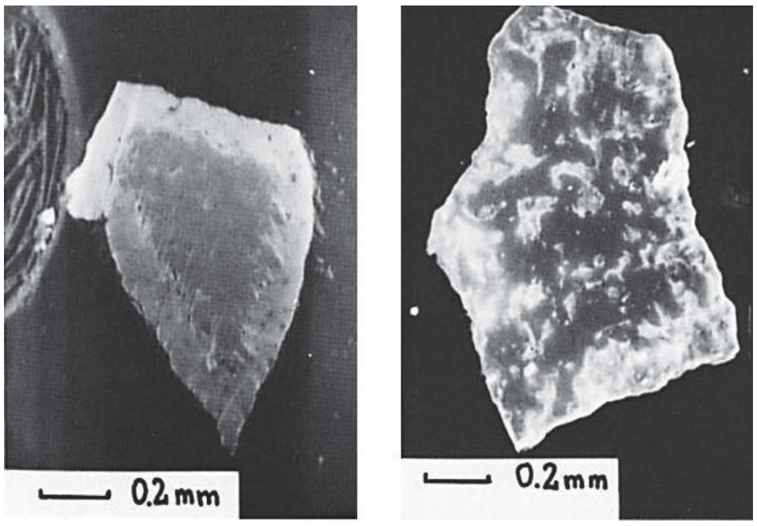

Fig. 4. Fast reaction (left) compared with inhibited reaction (right). Image obtained from ref 2.

Activity and balance

Achieving high catalyst activity requires not only the right amount and distribution of the promotors on the iron surface, but also the presence of a significant number of the highly active Fe(111) sites. The open iron surfaces of these sites make it easier for the gas reactants to access the catalyst surface, which in turn means they exhibit a much higher ammonia synthesis activity than the Fe(100) and Fe(110) sites, which feature a more closed iron structure.

Magnetite in itself does not have any preference for any of these sites, so it is merely something that can be controlled and optimised by selecting the right conditions during manufacture of the catalyst.

Some of this can be compensated for by the appropriate use of the most suitable promoters, but it can still never reach the full activity level of the Fe(111) sites, as illustrated in Fig. 1

The importance of promotor distribution

The use of structural promoters (such as Al, Ca, Si and Mg) significantly reduces the sintering of the active iron sites during the operation, and this in turn results in a very high catalyst stability and stable production rates of the industrial unit.

However, in order to achieve the best possible promotion effects, the individual promoters must be distributed very consistently throughout the iron surface. On magnetite, this is made possible by using the right specialist techniques while the catalyst is being fabricated. The even distribution of the different promoters is shown in Fig. 2.

Broadhurst *et al.*[1] describe the promoter distribution on wüstite catalyst and conclude that it is very difficult to get an even promoter distribution on wüstite-based catalysts, and that this will lead to increased deactivation rates.

In order to investigate this further, the Topsoe research and development department carried out a number of ageing experiments on magnetite and wüstite-based catalysts.

The resulting effect on the deactivation rates is illustrated in Fig. 3, where ageing of the magnetite and wüstite-based catalysts has been carried out at 500°C and with a gas composition reflecting normal industrial conditions with a hydrogen/nitrogen ratio of 3. The experiments ran at a pressure of 20 Mpa.

The accelerated ageing shows that the magnetite-based material loses only 10% of activity during the test, whereas the wüstite based material loses substantially more at 30% of its SOR activity.

Stability of pre-reduced ammonia synthesis catalyst

A loading of ammonia synthesis catalyst will normally consist of a pre-reduced layer for the first bed and oxidic catalyst for the lower beds. The oxidic catalyst in the lower beds will then have to be reduced in situ over a number of days, in conjunction with the start-up.

There are plants where pre-reduced catalyst is installed in all the catalyst beds in order to save start-up time and to reduce the amount of ammonia-containing water generated during the catalyst reduction. A plant can normally save two to three days of catalyst reduction time and thereby gain a significant amount of extra ammonia product during this period.

Manufacture of the pre-reduced catalyst is done in a separate step after the oxidic catalyst has been produced. Most catalysts are pre-reduced at the same facility as the oxidic catalyst, but in some cases it is carried out by third parties.

It is critical that this reduction step is completed in a way that ensures maximum activity is achieved because this is where the crucial pore structure of the catalyst is created. This means that heating rates and water content must be carefully controlled and monitored during the pre-reduction process.

Raiser and Baranski[2] carried out a detailed investigation of this, and Fig. 4 shows pictures of the influence on the water content during reduction. When the reaction is fast, the reduction occurs in a narrow zone that moves progressively from the outer surface to the unreacted dense centre (left). When the reaction is inhibited, perhaps due to the presence of high concentrations of water, there is an uneven profile of reduction degrees throughout the iron particles (right).

After full reduction has been achieved, a separate passivation step needs to be completed. Without the right passivation, the handling and loading of the catalyst will be at risk because the catalyst may begin to heat up when it comes into contact with air.

Such heating up can result in significant delays of the loading activity and will also, in most cases, require that the reactor is blanketed by nitrogen. The result will most assuredly be a catalyst activity that is lower than expected, so this catalyst should be discarded if possible.

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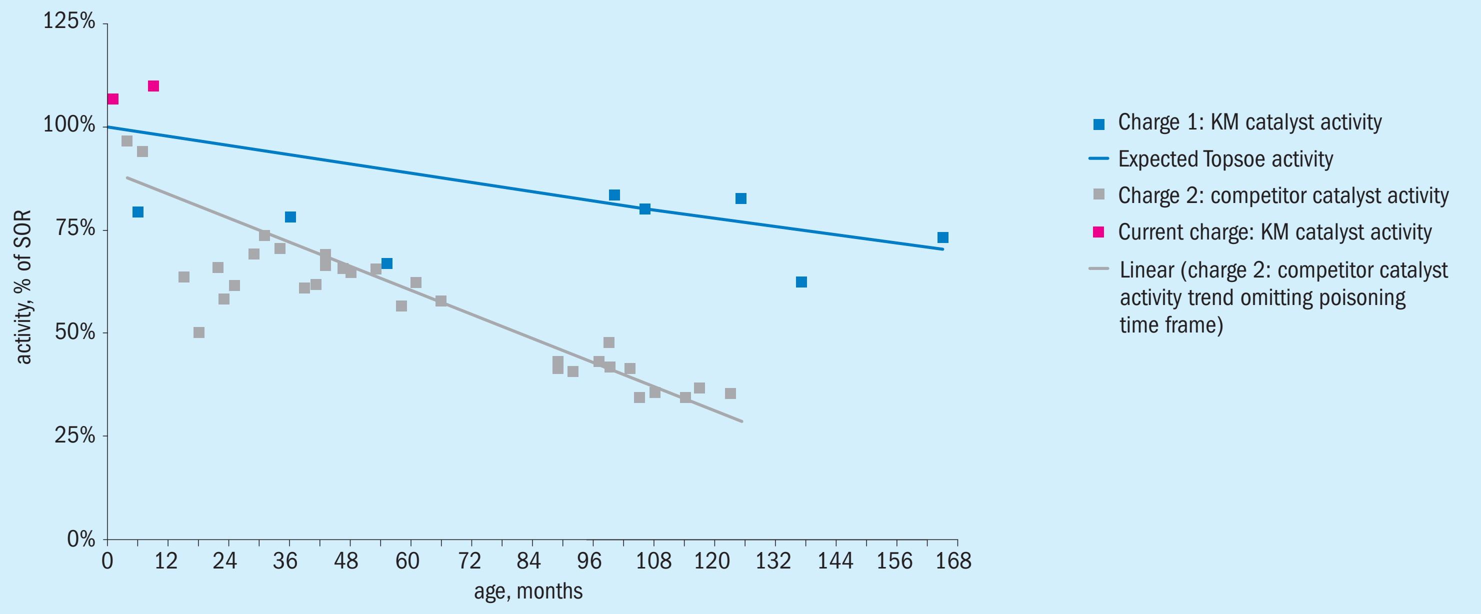
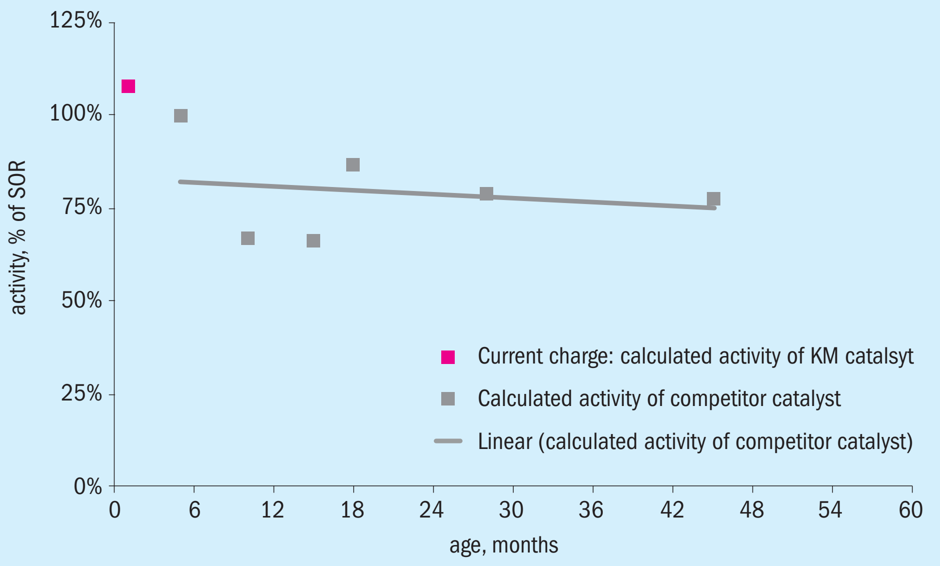
Fig. 5: **Activity comparison between magnetite-based KM1 and wüstite-based catalyst in an industrial unit**



Source: Topsoe

Fig. 6: **Comparison of KM 111 activity with activity of a wüstite-based catalyst**



Source: Topsoe

From research investigations to practical experience

So how does magnetite perform in practice in real world industrial units?

After more than 13 years of operation with the Topsoe KM magnetite-type catalyst, a plant located in North America switched over to a wüstite-based catalyst (Fig. 5). This catalyst showed much faster deactivation than had been encountered with the previous KM charge, and after ten years of operation the plant decided to replace it and to return to using the KM magnetite-based catalyst. The first 12 months of operation confirmed the very high activity level of the new Topsoe catalyst.

Industrial feedback and years of research by Topsoe into the magnetite phases and appropriate promoters resulted in the launch of the KM 111 and the pre-reduced KMR 111 catalysts in 2014.

Since their introduction, these ammonia synthesis catalysts have been installed in more than 70 ammonia plants worldwide. This currently represents 25% of all plants for which Topsoe has provided catalyst solutions for ammonia synthesis. A recent example of a KM 111 installation is in a US ammonia plant, where it replaced a wüstite catalyst (Fig. 6). The three-bed reactor installed in this plant uses a pre-reduced catalyst in the first bed and KM 111 as the catalyst in in the second and third beds.

The wüstite-based catalyst was replaced four years after installation due to mechanical issues in the ammonia converter. The plant decided to install magnetite-based KM 111 on account of its lower deactivation and higher activity properties.

Conclusion

Selecting the right type of ammonia synthesis catalyst can have a big impact on plant economics. Magnetite-based catalysts have been considered the ideal choice for use in ammonia synthesis converters for well over a century. With the recent developments within iron surface sites and promoter compositions, they continue to be selected throughout the industry due to their positive impact on plant reliability and plant economics. ■

References

1. Broadhurst P.V., Lunn M.D., Young K., Ward R.M., Lynch F.E.: "The chemistry within your catalyst, Part 4. Ammonia synthesis", Nitrogen+Syngas magazine issue, page 22 (Sep/Oct 201).
2. Reizer A., Baranski A.: "The topochemistry of the reduction of an iron catalyst for ammonia synthesis", Appl. Catal. 9, (1984), 343 Fig.1 Illustration of the different iron surfaces, and their activities without promotion and with optimal promotion (1984).

PHOTO: H-TEC SYSTEMS

Fig. 1: Electrolysers from H-TEC SYSTEMS at a wind farm in Northern Germany.

The potentials of power-to-X and green fuels

Florian Gruschwitz of MAN Energy Solutions takes a look at the current investment decisions influencing green hydrogen projects on the path to decarbonisation, reviews technologies that are available today, and discusses what it will take to ramp up a global green hydrogen economy.

There is no doubt that green hydrogen is a key element on the path to decarbonisation. Nor is there even the least surprise these days that green hydrogen, and power-to-X in general, has gained so much popularity and public attention. For good reason, this will not be a flash in the pan.

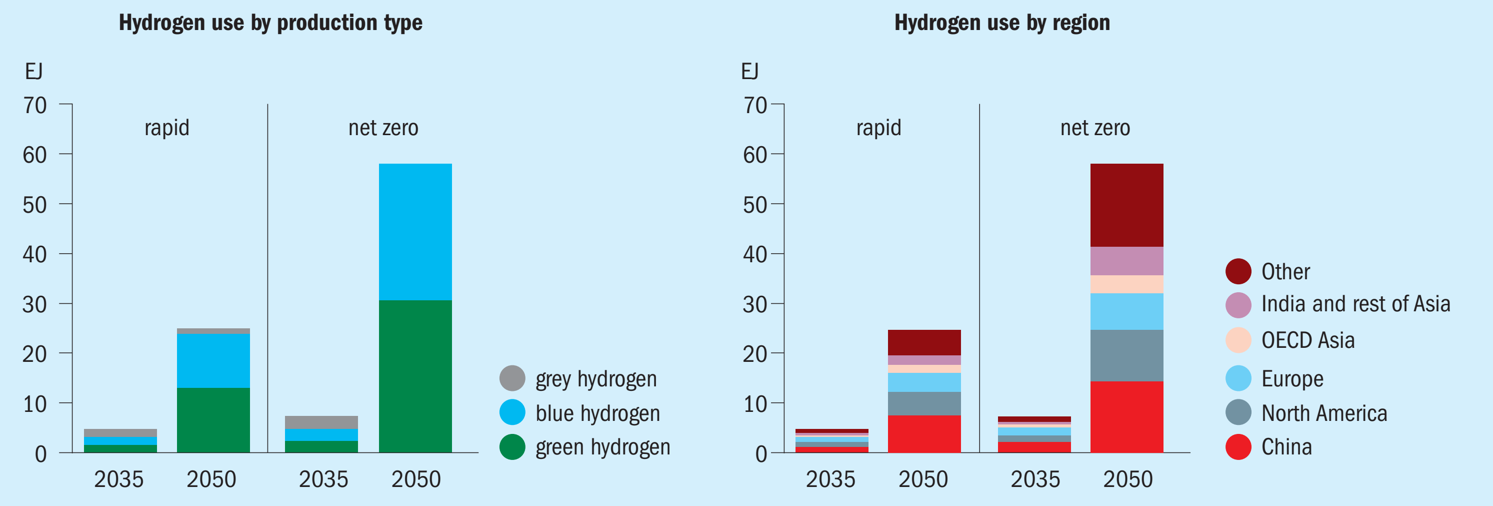
Strong drivers like the EU's 'Fit-for-55' programme, which targets reducing net greenhouse gas emissions by at least 55% by 2030, underline the reality that decarbonisation has now become a serious target and many countries have already published ambitious hydrogen strategies. Companies like MAN Energy Solutions can already provide the necessary key technologies along the power-to-X and green hydrogen value chain and have serious involvement through significant investments aimed at further extending the base of necessary technologies.

Mature technologies, for instance for e-fuel production, are available that enable the use of existing infrastructure, but much remains to be done in order to create more viable business cases. It can be shown how derivative fuels, or e-fuels, can successfully complement green hydrogen in its elemental form and be an important enabler in the ramp-up to a green hydrogen economy.

One thing is clear: elemental green hydrogen will not be a one-size-fits-all solution. Instead, there will be a multi-option scenario where pragmatic approaches will aim at maximum efficiency, whilst at the same time ensuring that a solid base and ramp-up path for long-term transition to green hydrogen is created (Fig. 2).

To get the full picture, it is helpful to look at the topic from two perspectives: firstly, viewing power-to-X in the context of how it can play an important role in reaching decarbonisation targets; and, secondly, looking at the main hurdles, but also success criteria, in getting a green hydrogen economy ramped up at a global level.

Fig. 2: **Hydrogen use by production type and use by region**



Source: BP Energy Economics 2020

If we agree that decarbonisation is an underlying imperative in order to save the planet, then a policy comprising four elements can be identified, beginning with replacing fossil-fuelled power generation with renewable energy sources. The use of green hydrogen and employing e-fuels (based on green hydrogen) are two further elements. And the fourth, for the hard-to-abate carbon sources, is carbon capture and storage technologies, again combined with power-to-X technologies.

These four elements may be viewed as a type of 'decision tree' such that, when addressing an application that acts as a considerable carbon source today, all four means of decarbonisation need to be assessed in the order shown to find the 'best fit' – i.e., the most effective way to achieve decarbonisation considering all current, boundary conditions.

Needless to say, decarbonisation is reliant upon an abundant availability of renewable energy. Accordingly, extending the capacity of renewable energy generation is of paramount importance. The first question in the quest for decarbonisation is therefore: 'Is direct electrification possible?'. This means, first of all, replacing all fossil-fuelled power generation with renewable energy. However, natural-gas-fuelled power plants, for example, may be tolerated as 'back-up' or 'peakers' as they facilitate the maximum use of renewable energy in the grid while simultaneously ensuring maximum reliability and grid stability.

Continuing through the 'decision tree', for applications that cannot be directly electrified as of yet or even in the longer term, the use of green hydrogen could be a good option and many examples exist. However, following the Pareto principle, which specifies that 80% of consequences come from 20% of the causes, some prominent areas especially suited for decarbonisation can be identified, such as steel production where production with green hydrogen instead of coal would cut carbon emissions considerably.

Another good example of a sector ripe for decarbonisation with green hydrogen is within processes that already require large amounts of hydrogen today. Here, 'grey' hydrogen is currently used and produced by steam methane reforming. One such example is fertilizer production where ammonia as a main feedstock requires large amounts of hydrogen.

Which leads us to the third stage in the 'decision tree' when neither direct electrification nor the use of green hydrogen as a molecule is possible. In such instances, e-fuels may be a solution. Derivative fuels or e-fuels in this context are carbon-neutral fuels based on green hydrogen. This includes synthetic methane, methanol or 'e-Kerosene' – or ammonia produced from green instead of grey hydrogen, which provides a carbon-free option.

As such, derivative fuels could play an extremely important role: acting as a bridge technology and replacing their fossil twin, leading to carbon-neutrality; as a carrier medium for green hydrogen; or even as 'green' feedstock as for the prior-mentioned 'green' ammonia for fertilizer production. One of the great advantages in derivative fuels is their direct applicability today.

But even if we picture a fully electrified, green hydrogen and e-fuel-powered world, we must not forget that there are still applications or processes that intrinsically emit larger amounts of carbon. One very prominent example is cement production where, during the calcination process, large amounts of CO_2 chemically bound within limestone are released. Pilot projects have already demonstrated, in order to reach the targeted 'net zero' for atmospheric emissions, that these carbon emissions can be captured, liquefied, and stored in subsea locations. Another method of reaching 'net zero' would be to use this CO_2 to produce methanol as a chemical feedstock. In this way, carbon can be bound again as part of a cycle.

MAN power-to-X solution

MAN Energy Solutions is already a forerunner in power-to-X technology. In 2013, the company commissioned the methanation reactor for Europe's first and for a long time most powerful power-to-gas plant on a 6 MW scale for Audi AG. Since then, MAN has consistently developed PtX technology and today offers turnkey plants with a capacity of 50 MW and more.

This MAN power-to-X solution is a sustainable solution for synthetic fuel production and long-term energy storage. It responds to the fundamental challenges of decarbonisation. The direct use of synthetic fuels allows the decarbonisation of sectors which currently rely on fossil fuels, such as marine, aviation or certain industrial processes.

Renewable energy is used to run an electrolyser, for example a PEM or an alkaline

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electrolyser, which breaks water down into hydrogen and oxygen. The hydrogen is then put into a methanation reactor with carbon dioxide, resulting in synthetic natural gas (SNG). The carbon dioxide can be obtained either by carbon capture from in-house or adjacent industrial processes or power generation using amine scrubbing, pressure swing absorption or membrane separation. The SNG can be stored, used directly, or injected into the existing gas infrastructure.

Hydrogen production by electrolysis

PEM electrolysis is a process by which electricity is used to split water into hydrogen and oxygen. It consists of a proton-permeable membrane, a cathode, and an anode. When water is added to the electrodes, the external voltage causes a catalytic effect, splitting the water. The hydrogen ions diffuse through the membrane.

To generate 1 kg of hydrogen, ~8.9 kg of water is required. In addition, ~7.9 kg of oxygen with a purity of 99.95% is produced. This corresponds to the purity required for further use in technical and medical applications. Water of tap water quality is required for electrolysis. The power requirement for 1 kg of green hydrogen is ~53 kWh.

H-TEC SYSTEMS is a subsidiary of MAN Energy Solutions and currently offers electrolysers with a nominal electrical output of up to 1 MW (Fig. 3). All H-TEC SYSTEMS solutions are integrated, scalable, and containerised. An electrolysis capacity of 1 MW provides enough hydrogen to fill a car tank up to 90 times per day in 24-hour operation. These module sizes are particularly suitable for pilot projects and small industrial customers. The electrolyser consists of 110 kW stacks, which can be replaced, if necessary, thus extending the service life of the plant. The maximum total electrolysis capacity is currently 10 MW but will be expanded to 150 MW in the future with the new product "Hydrogen Cube Systems" (HCS). These are 2-MW modules which make it possible to cater to applications with a high hydrogen demand.


PHOTO: H-TEC SYSTEMS

Fig. 3: PEM electrolyser by H-TEC SYSTEMS.

H-TEC SYSTEMS electrolysers have an integrated water treatment and deionisation system. Therefore, only water that meets industrial standards (tap water) is necessary as a feedstock for electrolysis. In arid areas, additional water generation may be necessary e.g., with desalination plants.

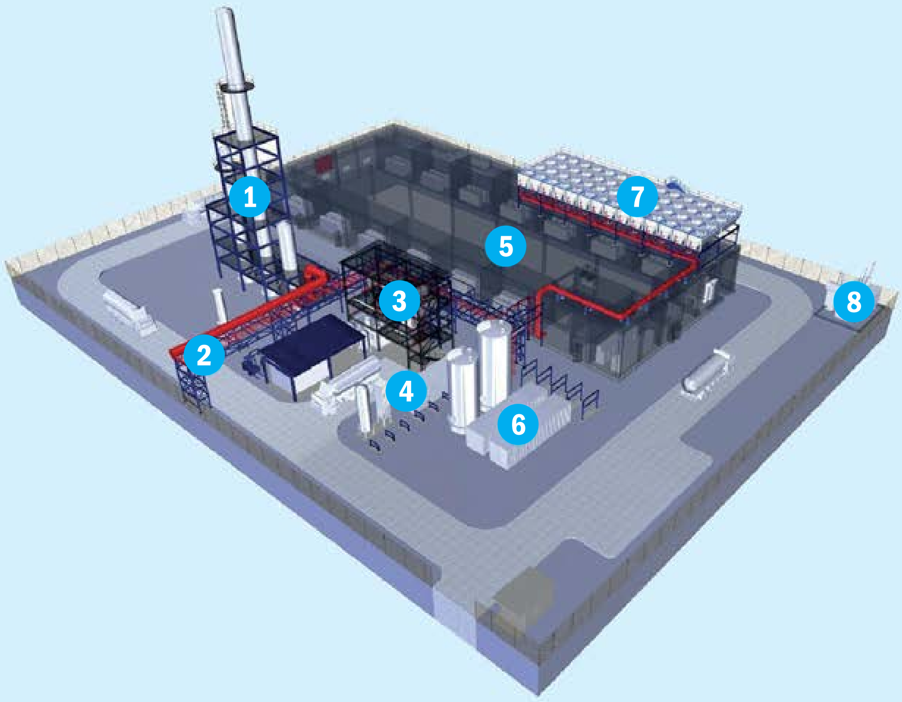
SNG production by methanation

Methanation, or the Sabatier process, is a chemical reaction in which carbon dioxide is converted to synthetic methane. It is an exothermic reaction that has to be accelerated by nickel catalysts. The chemical efficiency is ~83%.

From 1 kg of H_2, ~2 kg of SNG and ~4.5 kg of water are produced with the addition

Fig. 4: **Model of a complete 50 MW Power-to-Gas plant by MAN Energy Solutions**

1. Amine gas treatment/CO_2 separation
2. Main plant media interface (gas grid, water, O_2, etc.)
3. Methanation unit including SNG treatment
4. Control air unit
5. Electrolysis building
6. Water treatment and storage tanks
7. Cooling system
8. Step-down transformer (optional)



Source: MAN Energy Solutions

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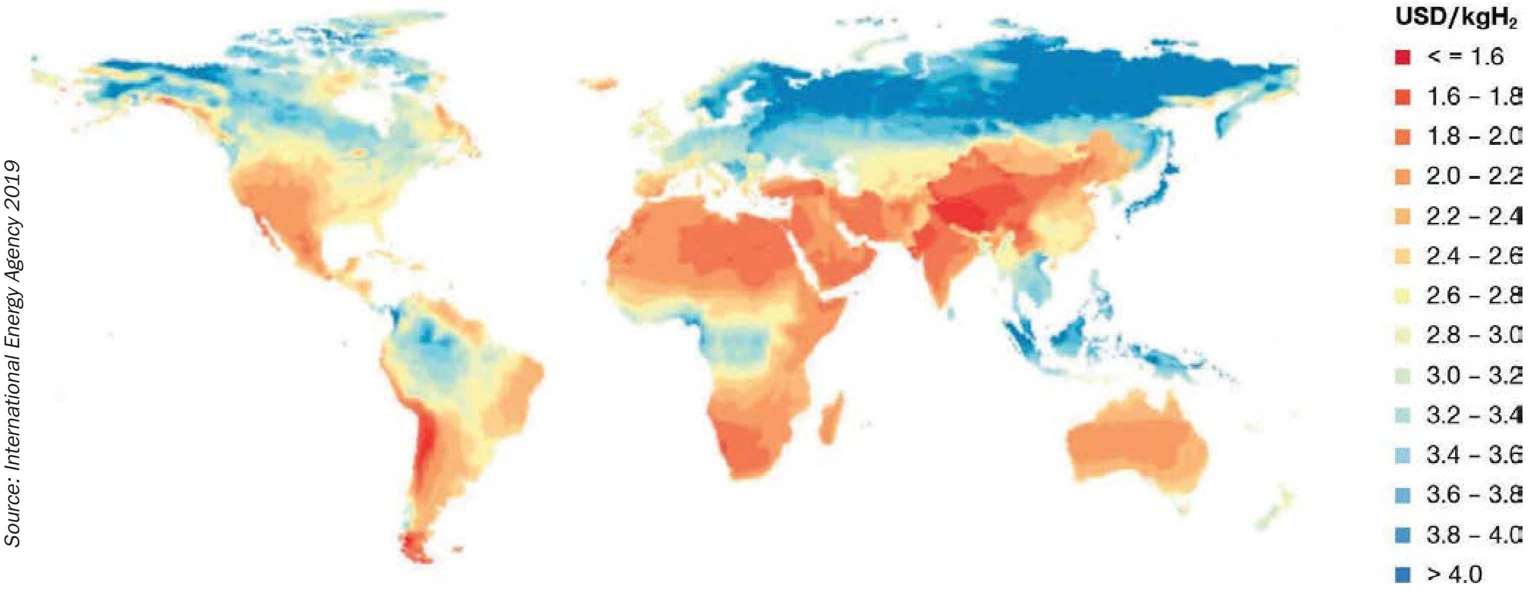

Source: International Energy Agency 2019

Fig. 5: Hydrogen costs from hybrid solar PV and onshore wind systems in the long term.

of CO_2. This is a chemical reaction that takes place without additional energy in the form of electricity. The equipment associated with the methanation reactor, such as pumps, requires electricity, so a total of ~27.3 kWh is required to produce 1 kg of SNG.

The reactor is a boiling water reactor in which process temperatures range from 270-600°C. The process by-products are water and saturated steam at a temperature of 270°C. If this is integrated into other production processes, the methanation process can achieve an overall efficiency of 95%. The outlet pressure is 20 bar(g).

Two reaction stages are necessary for high methane purity (>95%) in MAN methanation technology. This is due to the thermodynamic equilibrium that occurs between the two reaction sides. Water is separated in an intermediate stage between the two reaction stages. This means that, in the second stage, the equilibrium is shifted further to the product side and thus the highest gas purity can be achieved.

Since this is an exothermic reaction, external cooling is necessary to allow the chemical process to proceed in a controlled manner. There is no risk of damage to the equipment due to excessive temperatures. In addition, cooling influences the thermodynamic equilibrium in a positive manner and thus contributes to the final high product purity. Continuous cooling increases efficiency (a greater mass of reactants can be converted into products), requiring a smaller reactor and less catalyst material. The overall system is more compact than adiabatic process concepts, which require a total of three to five process steps with intermediate cooling to achieve a methane purity of >95%.

Fig. 4 shows a model of a complete 50 MW power-to-gas plant by MAN Energy Solutions.

The challenges

In conclusion, a carbon-neutral world, the desired “net zero”, to avoid further climate change is within reach and without having to completely change the world, the products we use, nor our way of life. Green hydrogen and power-to-X are key elements in this transition. The question then is: how do we ramp up the green hydrogen economy? For this, we will have to consider the whole value chain: the production of green hydrogen and derivatives, its transport to its application, and of course the application itself where, as in the case of direct reduction ovens for ‘green steel’ production, some considerable investments will be needed.

Accordingly, all parts of the value chain need to be pushed and ramped up simultaneously. Large, industry-wide programmes like Germany’s ‘H_2Giga’ initiative are helping to scale up electrolysis to industrial levels with accompanying cost-reductions. However, the cost reduction of green hydrogen production alone does not make for a feasible business case when green fuels have to compete with their fossil twin without integrating the external cost of additional carbon introduced to the atmosphere. Thus, respective carbon taxation is needed as well as, at least for the ramp-up phase, smart ‘Carbon Contracts for Difference’ schemes like the German ‘H_2Global’ to finally make larger power-to-X projects bankable.

Fig. 5 shows hydrogen costs from hybrid solar PV and onshore wind systems in the long term.

Setting up a global hydrogen economy is necessary to leverage renewable-energy potential in regions where it cannot be otherwise used and in order to not cannibalise renewable energy capacities in regions with high demand. This would also help to bring sustainable prosperity to more parts of the world and could solve strong global (inter)dependencies in energy trading.

Large-scale off-takers such as steel production have to be created, for example, in line with EU Important Projects of Common European Interest (IPCEI) projects. Even if they had to rely on ‘blue hydrogen’ in a starting phase, this means that investments could be made and hydrogen pipeline infrastructures created. Subsequently, as soon as green hydrogen production was at scale, a ‘switch’ to green hydrogen would be possible with all the major investments made up to that point in time. As such, it’s acceptable for many of the first, large power-to-X projects to rely on derivative fuels since ocean transport of elemental hydrogen is a challenge. E-fuels can complement a green hydrogen economy, are an enabler for larger electrolyser plant setups, and can resolve the chicken or egg dilemma until hydrogen grids become available to provide inexpensive transport, storage, and distribution options.

Seen from an industry perspective, we can say that we are ready and eager to shape the future. We are taking the risk and investing in the transformation of our portfolios and to provide the necessary technologies. Now we need the necessary political action in order to ramp up a global green hydrogen economy and to convert decarbonisation targets into reality. ■

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
47 48 49 50 51 52

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1 47
2 48
3 49
4 50
5 51
6 52
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
47 48 49 50 51 52