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Number 381

January | February 2023

nitrogen+syngas

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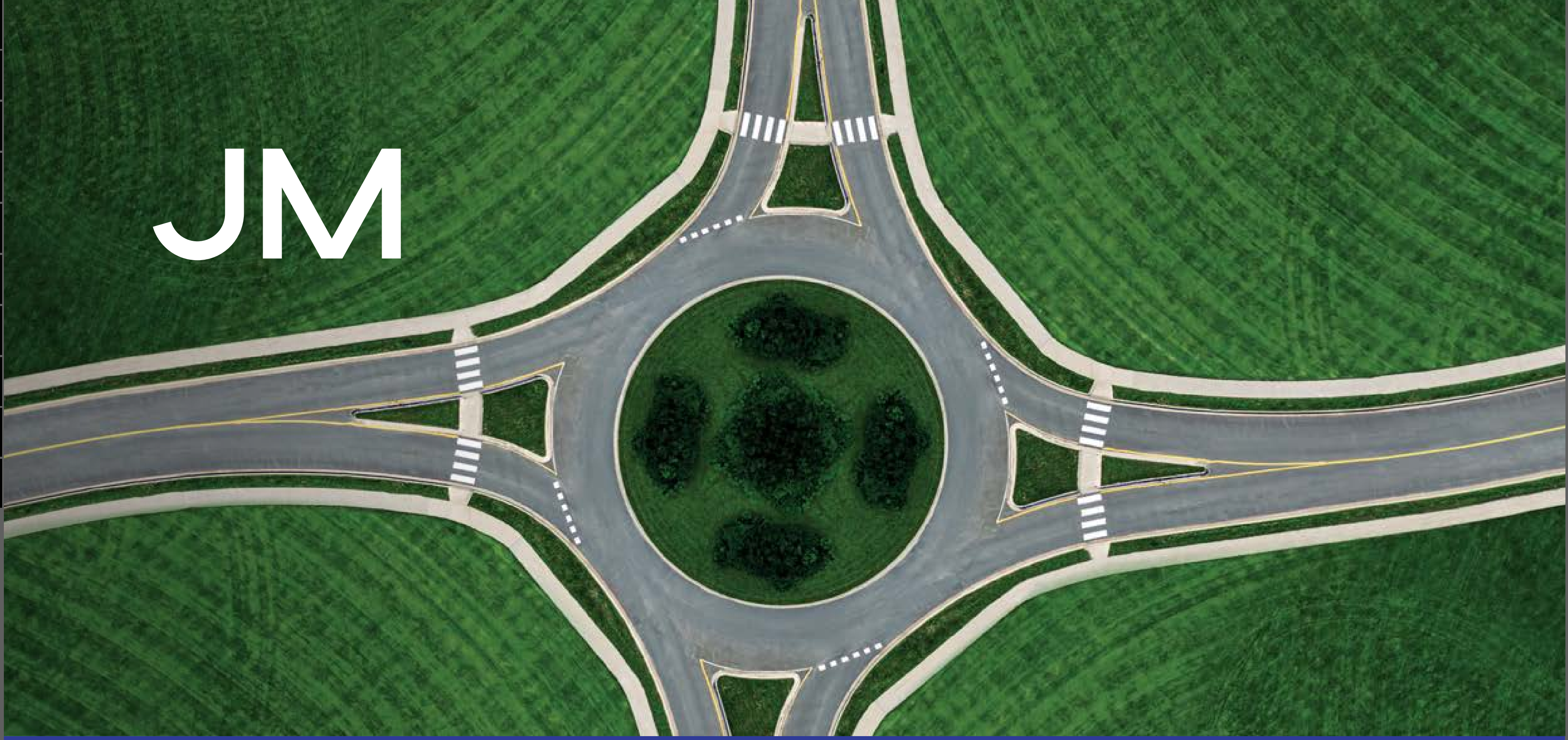
China and the urea market

Europe's natural gas shortage

Methane pyrolysis

Waste to renewable methanol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Cover: La Sagrada Família, Barcelona at night. mr_piboon/iStockPhoto.com

China and urea

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Decentralised methanol

Small-scale modular production

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Published by:
BCInsight

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Missing the boat?

The past year has been a difficult, even disastrous one for Europe's fertilizer producers. High natural gas prices have kept plants shuttered, with 70% of the continent's ammonia production shut down at times. It remains uncertain how much of this will return to production this year, or indeed ever.

At such a time, and given Europe's traditional green focus, it might be thought that this would be the ideal time for the continent to wholeheartedly embrace green ammonia production using renewable power, which is certainly cost effective at current ammonia prices. But according to Yara's CEO, European governments are not providing sufficient incentives for fertilizer producers to invest in green production in Europe, in contrast to the United States. Speaking to Reuters in January 2023, Svein Tore Holsether said; "From a business perspective, it would make a lot more sense to expand into the US, and that's happening across the board now. (We) are at risk of losing both our ability to decarbonise and some of the key industrial players. And that should be a big wake-up call for Europe."

> **"The fundamentals of it being unprofitable to produce ammonia in Europe have remained largely unchanged."**

The reason, according to Holsether, is the US Inflation Reduction Act, passed in August 2022, which offers strong financial incentives for companies to invest in clean energy. Indeed, US state governors were out selling the Act at the recent World Economic Forum (WEF) in Davos, pointing out that it provides up to $370 billion worth of subsidies for clean energy on everything from solar panels to electric cars. European politicians have as much as acknowledged this, complaining about the "aggressive" way that the US is pitching the subsidies to EU businesses. Leaders from the EU-27 countries are meeting February to discuss their joint response, with countries like France urging urgent action to keep European industry alive.

As part of her own reply, President of the European Commission Ursula von der Leyen told chief executives at the WEF that the EU would pass a new Net-Zero Industry Act that will set targets for 2030. The effort will try to increase clean technology funding and fast-track permits for relevant production sites. The EU will also temporarily water down state aid regulations and pump cash into strategic climate-friendly businesses in order "to keep European industry attractive," though some member states fear that this could mainly benefit larger EU members with deeper pockets like von der Leyen's native Germany. As a result, the Commission plans to set up a European Sovereignty Fund to help harder-pressed members, but there is no consensus among finance ministers over how such a common fund will be financed, or over its scale. The appetite for more EU spending in the current economic climate is a limited one.

But the US and EU are not the only players in the new emerging green economy. China too has heavily subsidised its own green technology firms and is accused of poaching companies from Europe and elsewhere with the promise of cheap energy, low labour costs and a more lenient regulatory environment.

The race to attract new green investment may be a headache for policymakers around the world, but it can only be good news for the future of the planet. As for European ammonia producers, the jury is still out. Svein Holsether said that: "the fundamentals of it being unprofitable to produce ammonia in Europe have remained largely unchanged," since last October.

Richard Hands, Editor

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Price Trends

Market Insight courtesy of Argus Media

NITROGEN

Ammonia prices registered another week of losses at the start of January, with supply options continuing to outweigh demand in most regions. Prices have been falling steadily for the past twelve weeks, as the market rebalances after production curtailments across Europe for much of 2022. Steady falls in gas pricing over the past few weeks have put production costs firmly below today's import price, with European production now scheduled to ramp up at many plants this month.

The weaker sentiment was backed up by a \$55/t drop in the monthly Tampa contract, but limited spot trade was reported following the announcement at the beginning of the first week of January. Recent market drivers include January Tampa price settles at \$975/t c.fr – Yara has settled the Tampa contract price with Mosaic at \$975/t c.fr for January – a \$55/t fall from December and the lowest price since July 2022. The new contract represents a Trinidad netback of around \$935/t f.o.b.

European natural gas prices fell sharply again in the first week of January, with TTF month-ahead prices dropping to \$20/MMBtu on 4 January – the lowest level for nearly a year. The current TTF price of \$22/MMBtu reflects an ammonia production cost of around \$830-840/t for February, excluding carbon costs.

Export availability out of Saudi Arabia may be lower in January. Sabic will have a turnaround at one of its ammonia plants this month but details have not been confirmed. Ma'aden's plants are running currently but there are reports that the producer may take some capacity offline at one of its three ammonia facilities next week.

Urea prices fell as the year began as producers fought for liquidity and the market remains weak. Egyptian prices fell by \$40/t in a matter of days to \$495/t f.o.b, while prices in the Middle East and southeast Asia fell to around \$440/t f.o.b. In end-user markets prices slumped also – US prices fell through the course of the first week of January by \$30/t, Brazil by \$15/t and many European markets by around \$20/t.

With India out of the market for January there is a clear overhang of supply in Russia, the Middle East and both north and west Africa for January-loading cargoes. Export controls continued to curb activity around the edges of the market. Indonesia is unlikely to be able to sell any fresh urea during January, while supply of ammonium nitrate has been curtailed by Russia's export quotas. But most market participants are bearish.

Recent market drivers include India's apparent decision to delay its next purchase tender until end-January, and the removal of European import duty – cargoes are again flowing to European markets from the Middle East, southeast Asia and the US, forcing north African producers to cut prices in early January to stay competitive.

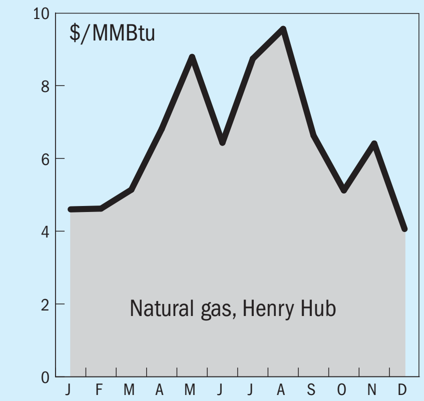
Table 1: **Price indications**

Cash equivalent	mid-Dec	mid-Oct	mid-Aug	mid-Jun
Ammonia (\$/t)				
f.o.b. Black Sea	n.m.	n.m.	n.m.	n.m.
f.o.b. Caribbean	975-1,025	1,100-1,200	1,050-1,095	925-950
f.o.b. Arab Gulf	820-900	890-990	915-1,030	880-970
c.fr N.W. Europe	975-1,020	1,140-1,240	1,165-1,250	1,000-1,085
Urea (\$/t)				
f.o.b. bulk Black Sea	420-530	n.m.	n.m.	n.m.
f.o.b. bulk Arab Gulf*	420-485	546-631	570-680	535-650
f.o.b. NOLA barge (metric tonnes)	495-520	550-585	465-585	570-595
f.o.b. bagged China	440-485	580-620	475-530	525-625
DAP (\$/t)				
f.o.b. bulk US Gulf	660-710	756-808	803-836	822-888
UAN (€/tonne)				
f.o.t. ex-tank Rouen, 30%N	575-600	683-693	605-609	583

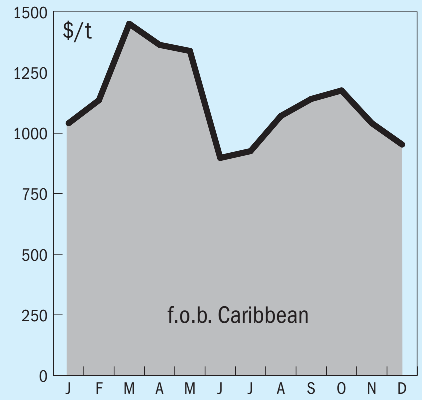
*Notes: n.a. price not available at time of going to press. n.m. no market. * high-end granular.*

END OF MONTH SPOT PRICES

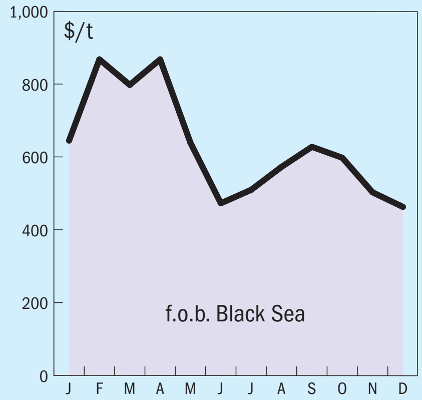
natural gas



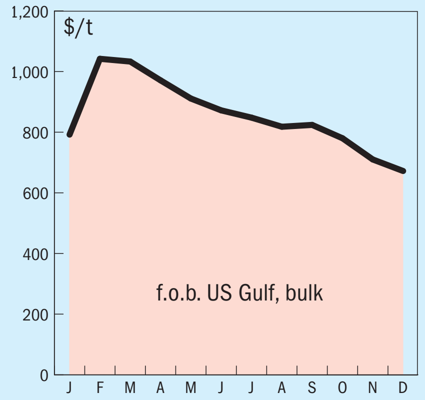
ammonia



urea

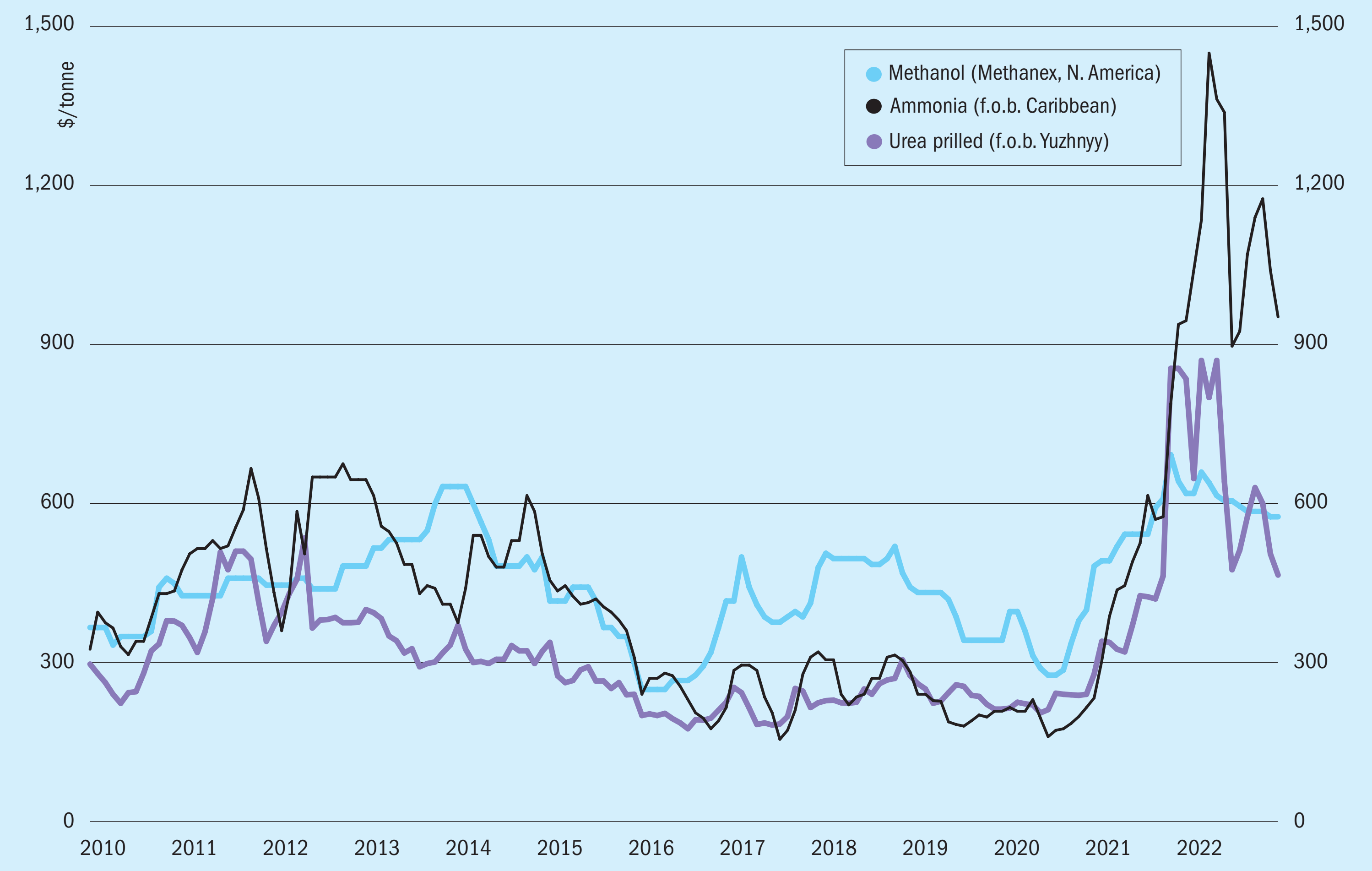


diammonium phosphate



Market Outlook

Historical price trends $/tonne



Source: BCInsight

AMMONIA

- The market is anticipated to correct lower throughout the rest of the first quarter. Once a clearer picture over seasonal fertilizer demand in Europe emerges, this could stabilise downward momentum.
- Lower gas prices in Europe, albeit still at the $20/MMBtu level, mean that European producers will be able to produce below current import prices of $925/t c.fr, and ammonia prices may fall. At present, around 50% of European ammonia production remains closed. However, gas prices remain high and volatile and a cold snap could see prices climbing again, especially if demand revives.
- Tampa prices have also trended lower, but concerns remain about navigation restrictions due to water levels on the Mississippi River following a very dry 2022. Difficulties getting fertilizer upriver to farms could lead to price rises again as demand picks up for the spring application season.

UREA

- Importers and traders seem united in sentiment that a floor in the urea price is still some distance from being found, and are trading accordingly, exacerbating market softness. Break even production costs are well below latest trades, so little support will be found there. Prices have fallen back to below the level in Q3 2021.
- Low demand is contributing to the bearish market. Farm demand will rise later in the first quarter across much of the northern hemisphere but it is far from certain that this will be enough to return prices to today's levels. Stock levels remain high.
- Delayed tendering from India is another contributing factor, and Indian buyers may want to see how far prices will fall before re-entering the market.

METHANOL

- Methanol prices have been more stable than ammonia and urea over the past few months, neither rising as high nor falling as far. Downstream demand into chemical derivatives like formaldehyde and acetic acid has fallen in major markets, leading to methanol prices sinking. Nevertheless, there has been an uptick in pricing in January on tight demand and good fundamentals in downstream markets.
- MTO demand has been slack in China, as new ethylene capacity has put pressure on Chinese MTO margins, but producers have been able to buy at a discount from Iran to keep operational. At the same time, however, Chinese coal prices have been high for some time, constricting the domestic methanol supply.
- The Chinese Lunar New Year is traditionally a time when markets are quiet, but market players are looking towards the impact of the relaxation of China's covid regulations on increasing demand in China, which represents more than half of all methanol demand. Higher yuan rates against the dollar have also supported higher Chinese c.fr prices.
- There was short supply elsewhere in Asia, exacerbated by a maintenance shutdown at PT Kaltim Methanol Industri in Indonesia and an unplanned outage at Ar Razi in Saudi Arabia.

Nitrogen Industry News

CHINA

Stamicarbon secures largest ever Chinese urea project

Stamicarbon has won a contract for a large-scale urea project in China. The urea plant, with a production capacity of 3,800 t/d, will be the largest ever licensed by Stamicarbon in the country. The customer, the plant's location and the value of the contract have not been disclosed.

The contract covers technology licensing, the plant's process design package (PDP), and the supply of proprietary equipment in Safurex®. The urea plant will be integrated with a dual-line melamine plant, making Stamicarbon's know-how on coupling urea and melamine plants of vital importance to the project. The urea plant will have the capacity to provide 1,133 t/d of feed to the coupled melamine plant and manufacture 1,560 t/d of urea prills and 1,100 t/d of urea granules. This will allow the plant to serve three critical industries in China – being configured to produce urea prills, potentially urea granules, and even diesel exhaust fluid (DEF).

"We are proud to be part of this remarkable project that will bring forward best-in-class urea and melamine production in China," said Pejman Djavdan, Stamicarbon's managing director. "It is a genuinely solid project with an innovative concept that is bound to add value to the community and the region at large.

Green ammonia plant for Mongolia

Topsoe says that it has been chosen by Mintal Hydrogen Energy Technology as technology provider for a new green ammonia plant in Baotou, Inner Mongolia. The new plant will be the first dynamic green ammonia plant in China, using the technology to adapt to the inherent fluctuations in power output from wind turbines. Renewable power from the turbines will be connected directly to the electrolysis unit, making it more cost-effective than using hydrogen storage, according to Topsoe. The first phase will have a maximum capacity of 1,800 t/d (390,000 t/a), with production expected to begin in 2025. Using wind to generate green ammonia will replace approximately 850,000 t/a of coal feed and so help reduce more than 2 million t/a of CO_2 from being emitted to the atmosphere.

Dajun Yang, Managing Director China, Topsoe, said: "We are thrilled to be chosen for this amazing project by Mintal Hydrogen, and we look forward to support with our know-how and hardware. Being chosen to contribute to this ground-breaking project is clear evidence of our ability to deliver state of the-art solutions and to support the energy transition and reduction of greenhouse gas emissions also in China."

THAILAND

MHI to study ammonia co-firing at Thai power plant

Mitsubishi Heavy Industries (MHI) has signed a Memorandum of Understanding (MoU) with Thai companies BPP and EGCO Group, as well as Japanese energy supplier JERA to jointly collaborate in a feasibility study on ammonia co-firing at a coal-fired thermal power plant operated by BLCP, an independent power producer in Thailand and a joint venture between Banpu Power Public Company (BPP) and Electricity Generating Public Company (EGCO Group). The plan envisages that MHI, with support from its power solutions brand Mitsubishi Power, conduct a study on the supply of ammonia burners, boiler facilities, and equipment necessary for ammonia co-firing. JERA will examine the procurement and transportation of ammonia fuel, and JERA and Mitsubishi Corporation will investigate the port facilities, along with ammonia receiving and storage facilities. BLCP, MHI, Mitsubishi Corporation, and JERA will also jointly conduct studies and develop plans to achieve up to 20% ammonia co-firing, supporting reductions in CO_2 emissions and decarbonisation. Thailand has said that it is committed to reaching carbon neutrality by 2050, and net zero greenhouse gas emissions by 2065, and plans to strengthen cooperation with Japan regarding decarbonisation technologies for fuels such as ammonia and hydrogen.

MOROCCO

Ammonia storage tanks for OCP

Proton Ventures and consortium partners Société Chérifienne de Matériel Industriel et Ferroviaire (SCIF) and Engineering & Group IPS have been awarded a turnkey contract by Office Chérifien des Phosphates (OCP) to design and build two refrigerated ammonia storage tanks at the Jorf Lasfar phosphate complex in Morocco. The project will be completed in 3Q 2024 and will enable OCP Group to increase their production in order to meet higher demand for ammonium phosphates. The scope of works includes the design, procurement, construction and start-up of an anhydrous ammonia storage, refrigeration and transfer system to the new fertilizer production units at OCP Jorf Lasfar chemical complex, Morocco.

Paul Baan, CEO of Proton Ventures said: "It has been an honour to be selected for a new storage project at Jorf Lasfar. Proton Ventures' ammonia storage track record and capabilities in combination with an efficient collaboration with our partners SCIF and EMPI are prerequisites for a successful project."

UNITED STATES

Topsoe selected as technology provider for clean ammonia project

Topsoe has been chosen by Ascension Clean Energy (ACE), a joint venture project led by Clean Hydrogen Works (CHW), Denbury Carbon Solutions and Hafnia, for its planned world-scale low carbon ammonia plant. The huge $7.5 billion project is aiming to produce 7.2 million t/a of low carbon ammonia in Louisiana, using Topsoe's *SynCOR*™ autothermal reforming (ATR) technology, and the project expects to achieve up to 98% percent carbon capture, corresponding 12 million t/a of CO_2 equivalent. The project will be sited on the west bank of the Mississippi River in Louisiana's Ascension Parish, near existing infrastructure, with direct access to the river. A final investment decision is expected in 2024, with completion targeted for 2027.

Peter Vang Christensen, Senior Vice President Technology, Topsoe, said: "Low carbon solutions are vital if we are to succeed with the energy transition, and this project will have a positive impact in leading the way for large scale decarbonisation of our global energy infrastructure. We are delighted to have been selected to support this project that will showcase not only Topsoe's world leading technology, but also ACE's role in the transition to decarbonised fuels."

Stamicarbon to conduct feasibility study on urea project

Stamicarbon has signed an agreement for a feasibility study with KeyState Natural Gas Synthesis, a company based in north-central Pennsylvania, to become its urea and DEF (diesel exhaust fluid) technology licensor. This project is expected to produce hydrogen, automotive-grade urea, and ammonia, while capturing and permanently storing carbon dioxide emissions associated with hydrogen production. The project is one of Pennsylvania's first to use carbon capture and storage (CCS).

Pejman Djavdan, CEO of Stamicarbon said; "From the beginning, [KeyState CEO] Perry Babb inspired us with his enthusiasm and drive for this unique project. We are therefore very proud to be selected as the licensor for the urea and DEF technology. This novel combination of Stamicarbon technology with KeyState's carbon capture approach will result in an excellent precedent for low-carbon projects in Pennsylvania and other states in the United States. We look forward to continuing our successful cooperation and entering the next project phase as soon as possible".

JAPAN

Approval for ammonia storage and regasification barge

Japanese classification society ClassNK has issued an approval in principle for an ammonia floating storage and regasification barge (A-FSRB) jointly developed by NYK Line, Nihon Shipyard Co., Ltd. (NSY), and IHI Corporation (IHI). It is the first such approval for A-FSRBs handling ammonia as cargo.

The barge jointly developed by NYK Line, NSY, and IHI is an offshore floating facility that can receive and store ammonia that has been transported via ship as a liquid, warm and regasify ammonia according to demand, and then send it to a pipeline onshore. According to the companies, it offers the advantages of shorter construction time and lower costs in comparison to the construction of onshore storage tanks and regasification plants. In fact, the A-FSRB is expected to speed up the adoption of fuel ammonia and contribute to its wider use as a lower-environmental-impact next-generation fuel.

Currently, there are no international regulations for floating storage and regasification facilities when the cargo is ammonia, and it is expected that the unique requirements of ammonia will have to be reflected in the design. Therefore, the companies and ClassNK conducted a comprehensive risk identification of various contingencies and worked to identify technical issues from the initial study stage. The risk identification was conducted using the gap analysis method, which identified differences between conventional ships and offshore floating facilities (heavy oil, LNG, etc.) and evaluated the impact of such differences. Based on its review and the risk identification results, ClassNK issued the approval in principle for the A-FSRB.

JERA looking towards ammonia supply agreements with Yara, CF Industries

Japan's biggest power generator JERA has signed ammonia supply memoranda of understanding (MOUs) with CF Industries and Yara, as it aims to co-fire ammonia in its power plants in order to reduce emissions. JERA plans to use a 20% ammonia fuel mix at all its coal-fired power plants by 2035, and to develop technology to use 100% ammonia in the 2040s as part of Japan's target to achieve carbon neutrality by 2050.

JERA agreed with Yara and separately with CF Industries to look at the possibility of buying up to 500,000 t/a of clean ammonia for the 20% co-firing operations at the Hekinan Thermal Power Plant Unit 4 in Japan. JERA has agreed to study "potential supply options, including an equity investment alongside CF Industries to develop a greenfield clean ammonia facility in Louisiana, as well as a supplementary long-term offtake agreement from CF Industries' Donaldsonville Complex in Louisiana", according to CF Industries. Yara and JERA also plan to collaborate on blue ammonia production in the US Gulf and to produce more than 1 million t/a, according to Yara.

Air Liquide technology selected for low-carbon ammonia project

Air Liquide's technology has been selected for Japan's first demonstration project owned and operated by INPEX Corp to produce low-carbon hydrogen and ammonia. Air Liquide's autothermal refomrming technology will be used at the Kashiwazaki Clean Hydrogen and Ammonia Project in the Hirai area of Kashiwazaki City, Niigata Prefecture. Air Liquide says that, when combined with carbon capture, autothermal reforming can achieve higher energy efficiency, lower investment cost and a simplified single train production process to facilitate carbon capture of up to 99% in highly integrated industrial facilities.

UNITED ARAB EMIRATES

Uhde and ADNOC to cooperate on ammonium 'cracking' plants

Thyssenkrupp Uhde and ADNOC have signed a memorandum of understanding to explore a long-term partnership to create new markets for hydrogen and promote global clean energy value chains. The MoU will focus on a joint project development of large-scale ammonia cracking, to extract hydrogen from ammonia after transportation. This will be based on Uhde reformer technology, which is used in over 130 large-scale chemical plants across the world. The agreement will also lead to the exploration of opportunities in the clean energy value chain for the supply and shipment of clean ammonia from the UAE to large-scale ammonia cracking facilities globally.

Musabbeh Al Kaabi, Executive Director, Low Carbon Solutions and International Growth Directorate at ADNOC said: "We are committed to strengthening our position as a reliable supplier of lower carbon-intensive energy, creating new revenue streams and growing the global market for hydrogen. In doing so, we will work with like-minded partners, such as thyssenkrupp to deliver tangible solutions that contribute to the decarbonization of the energy sector."

Dr. Cord Landsmann, CEO of thyssenkrupp Uhde added: "Clean ammonia is the best way to transport hydrogen by ship, and together with ADNOC, we will deliver the last piece of the puzzle for global green hydrogen trade at large scale."

Separately, ADNOC subsidiary the Abu Dhabi Chemicals Derivatives Company, also known as Ta'ziz, has signed an agreement to develop a low-carbon ammonia plant with the capacity of about 1 million t/a at its Ruwais site. Ta'ziz has signed a shareholder agreement with Fertiglobe, South Korea's GS Energy and Japan's Mitsui for the project, which will be in the Ta'ziz Industrial Chemical Zone. Site preparation is under way, and start-up is expected in 2025.

"This is a significant milestone in the development of our low-carbon ammonia business and further strengthens the UAE's hydrogen value proposition," said Ta'ziz's acting chief executive Khaleefa Al Mheiri. "We are building on the collective strengths of our partners and shareholders to develop the first-of-its-kind large-scale, low-carbon ammonia project in the Middle East and North Africa."

OMAN

Ammonia plant inaugurated

OQ, formerly the Oman Oil Company, officially inaugurated its new ammonia plant at Salalah on January 15th 2023. Speaking at the ceremony, Kamil al Shanfari, Executive Director of OQ's projects in Salalah, said: "OQ's ammonia plant is integrated with the methanol plant and was designed to retain the hydrogen-rich purge gas generated by the methanol plant as feedstock. The demand for ammonia products in the global markets is witnessing constant growth leading to higher returns and rendering the project highly feasible. The ammonia is being used as a key ingredient in the production of fertilizers and is an important intermediate chemical in the manufacturing of synthetic resins, detergents, coolants, synthetic fibres, and polyurethanes, among other applications. Ammonia is also used in the production of green hydrogen, which is a key component of the OQ Energy Transition agenda," Al Shanfari added.

GERMANY

Yara to expand ammonia import capacity

Yara International says that it plans to modify its ammonia terminals in Germany, enabling them to handle up to 3 million t/a of ammonia. According to Yara, this equates to roughly 530,000 t/a of hydrogen and will help speed up the hydrogen economy in Germany. The company operates two deep-sea terminals for ammonia in Brunsbüttel and Rostock, Germany. The Rostock terminal currently handles 600,000 t/a and has Germany's largest ammonia storage capacity, according to Yara.

"Vice-Chancellor of Germany Dr. Robert Habeck and other German leaders have been crystal clear in their ambitions to ramp-up the hydrogen economy. As a response, I'm proud to say that Yara has identified a substantial potential to increase ammonia imports to Germany in line with growing market demand", said CEO of Yara International, Svein Tore Holsether.

"By summer 2023 our export terminal in Brunsbüttel will be modified to import as well. In addition, the terminal in Rostock can increase the imported volumes. In total Yara would be able to deliver 3 million tonnes of clean ammonia if demand is there. With additional tank capacity we can expand our import capacity much further", said Yves Bauwens, Plant Manager in Brunsbüttel.

Thyssenkrupp Uhde plans to double sales

Thyssenkrupp's plant engineering unit Uhde says that it plans to double sales to around €2 billion ($2.2 billion) in the mid-term and is open to taking on co-owners to accelerate growth, according to the division's chief executive. Thyssenkrupp's Uhde division, which employs about 5,000 staff, plans and builds ferilizer, petrochemical, coking and polymer factories, wants to focus its business around sites for the production of ammonia, which is becoming more relevant as a carrier of green hydrogen.

SAUDI ARABIA

SABIC licenses sustainable ammonia technology

SABIC Agri-Nutrients has signed an agreement with Icelandic company Atmonia ehf., for SABIC to license Atmonia's sustainable ammonia technology within Saudi Arabia, Bahrain, Kuwait and Oman. Atmonia is developing catalysts for nitrogen electrolysers, allowing the production of ammonia in a single step process using water, nitrogen and clean electricity. The company says that the capital cost for production infrastructure is very low compared to current technology, allowing for low ammonia production costs, provided that sustainable electricity is also available at low cost (eg, from dedicated solar farms). The process they are developing occurs at ambient temperature and pressure, enabling intermittent operations, suitable for intermittent renewable power sources such as solar and wind and distributed production, further lowering cost and the emissions.

Munif Al-Munif, General Manager T&I at SABIC AN commented "This agreement demonstrates SABIC AN's confidence in Atmonia's ability to reach its development goals and launch the product. SABIC AN is fully committed towards the climate change challenge by production of sustainable fertilizer in the future, but today 1-2% of the global anthropogenic carbon emissions are from ammonia production. Furthermore, sustainably produced ammonia represents a promising carbon free energy carrier, or eFuel, with the potential to avoid up to additional 3% of anthropogenic emissions due to shipping emissions. Application of ammonia in aviation and for electrical grids are receiving increasing attention and interest. Application of sustainable ammonia as fertilizer and fuel are key steps to achieve a carbon neutral future."

MALAYSIA

Petronas divests stake in urea plant

Petronas Chemicals Group Bhd (PetChem) has agreed to divest its 25% stake in Petronas Chemicals Fertiliser Sabah Sdn Bhd (PCFS) to SMJ Sdn Bhd, a wholly owned Sabah state government company. PetChem holds a 100% interest in PCFS, sited at Sipitang in Sabah province, which has a production capacity of 1.9 million t/a of ammonia and urea.

"The divestment is part of PetChem's strategic effort to position itself as a preferred partner in shaping and delivering the aspiration of PetChem's and SMJ's to sustain and grow the petrochemicals business in the state of Sabah," the company said in a stock exchange filing. The divestment is expected to be completed in 2023.

RUSSIA

Resumption of Russian ammonia exports discussed

A deal to resume Russian ammonia exports via Ukraine looked imminent at the end of November, according to the UN's aid chief. Martin Griffiths, Under-Secretary-General for humanitarian affairs and emergency relief at the UN's Office for the Coordination of Humanitarian Affairs (OCHA), told Reuters on 30th November that a deal was "quite close" and could happen within a week.

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"[If] we do not do fertilizers [exports out of Russia] now, we will have a food availability problem in a year. So, it is hugely important, almost more important than grain," said Griffiths. "Everybody understands that the operation of the ammonia pipeline from Russia through Ukraine to the port of Odessa... it can be started within a week or two."

The closure of the Russian pipeline and the Black Sea ports on the 24th February last year resulted in the loss of around 200,000 tonnes/month of Russian ammonia exports to the global market (*Fertilizer International* 507, p8). Buyers in Morocco, Turkey, Bulgaria, and India, who previously relied heavily on Russian ammonia, have been forced to find alternative suppliers.

Speaking to the *Financial Times* in mid-December, Russian ferilizer billionaire Dmitry Mazepin called on global commodity traders to back a deal to resume Black Sea ammonia shipments.

A UN- and Turkish-brokered deal between Russia and Ukraine in July last year – subsequently renewed in November – opened the way for exports of previously blockaded Ukrainian grain. This agreement also included a pledge to restart exports of ammonia, according to Mazepin.

He told *Financial Times* that he had personally discussed the plan with Russian president Vladimir Putin at a meeting in November: "I asked for help, through diplomatic channels, to once again revisit those agreements that were signed in Istanbul regarding the grain deal to open ammonia."

The proposal from Mazepin, the founder and former owner of Russian nitrogen producer Uralchem, involves restarting the pipeline connecting the company's massive TogliattiAzot (TOAZ) ammonia production complex in Russia to the Ukrainian port of Yuzhny.

Mazepin said ammonia exports via Ukraine could resume immediately with about 80 percent of output going to African countries. "We are ready to resume pumping," he said.

UZBEKISTAN

ACWA Power to develop green ammonia project

ACWA Power, a Saudi developer, investor, and operator of power generation, water desalination and green hydrogen plants worldwide, has signed heads of terms agreements to develop a green hydrogen and ammonia pilot project in Uzbekistan with the country's Ministry of Energy and state-owned chemical company Uzkimyosanoat.

Uzbekistan's first green hydrogen project will be an integrated facility and is set to be connected to an existing ammonia plant in Chirchiq, 45 kilometres from the capital Tashkent. The project is expected to generate 3,000 t/a of green hydrogen. ACWA Power says that it will oversee the full value chain of integration to the existing infrastructure, which is expected to improve the on-stream time of the facility and reduce its dependence on natural gas. The company has plans for an accelerated development timeline for this facility and is targeting a commissioning date of December 2024.

Mohammad Abunayyan, Chairman, ACWA Power, said: "Uzbekistan has emerged as one of the most exciting growth countries for ACWA Power in recent years and is our biggest destination for investment outside of Saudi Arabia."

A second project involves a feasibility study for the development of a 500,000 t/a green ammonia plant. This project would reduce Uzbekistan's dependence on natural gas by 600 million m^3/year, and would cut carbon dioxide emissions by 1.5 million t/a. The study will be completed by the end of 2024.

KAZAKHSTAN

Ammonium nitrate complex for KazAzot

Técnicas Reunidas has won an engineering contract to develop an ammonium nitrate plant at Aktau in Kazakhstan. The Spanish company has been selected by state owned fertilizer producer JSC KazAzot through a front-end engineering design open book estimation. Construction of the $1 billion complex will be undertaken by Técnicas Reunidas through an engineering, procurement and construction contract, once the FEED is finalised and financing is closed.

The new world scale complex will have the capacity to produce 660,000 t/a of ammonia, 577,500 t/a of urea, 395,000 t/a of nitric acid and 500,000 t/a of ammonium nitrate and will become the largest combined fertilizer production complex in the Kazakhstan. Técnicas Reunidas says that it will be a reference in its sector at an international scale due to the minimisation of environmental impact and substantial efficiency improvements, including a high level of integration with existing facilities and optimising the use of natural resources.

Syngas News

UNITED STATES

Fulcrum starts up waste to fuel plant

Fulcrum BioEnergy says that it has successfully produced low-carbon synthetic crude oil using landfill waste as a feedstock at its Sierra BioFuels Plant, the world's first commercial-scale landfill waste-to-fuels plant. Located outside of Reno, Nevada, Sierra will produce approximately 11 million gallons of renewable, low-carbon transportation fuels each year from approximately 175,000 t/a of landfill waste.

"This accomplishment is a watershed moment for Fulcrum and opens the door for our plans to transform landfill waste around the world into a low-carbon transportation fuel in a way that will have a profound environmental impact," said Eric Pryor, Fulcrum's President and Chief Executive Officer. "After more than a decade of dedication and perseverance, successfully creating a low-carbon fuel entirely from landfill waste validates the strength of our process and our partners' unwavering belief in and support for our business model. As we continue to work to address global environmental challenges and advance our development program, we aim to replicate our success at Sierra with cost-efficient net-zero carbon plants nationally and ultimately around the globe."

The plant uses JM and BP's innovative *FT CANS* technology to convert syngas from gasified waste into synthetic fuel. JM and BP signed their first licence with Fulcrum to use their technology in 2018. Noemie Turner, VP technology development and commercialisation at BP, said: "We're excited that commercial-scale use of our Fischer Tropsch technology built on a foundation of top-class research and development, in collaboration with our technology partner, Johnson Matthey could help support the decarbonisation of the transport sector." ■

SWEDEN

Ørsted moves ahead with green methanol project

Ørsted says that it has taken a final investment decision to build Europe's largest green methanol plant, FlagshipONE, to supply green fuel for the shipping industry. Topsoe will provide engineering, procurement and fabrication for the project, including pre-assembled modules for the facility and free-standing equipment such as the methanol reactor and distillation columns, as well as licensing its eMethanol synthesis technology. The plant will be built in Örnsköldsvik in Northern Sweden and is expected to be in operation in 2025. The facility will produce approximately 50,000 t/e ear of green methanol from renewable energy and biogenic CO_2. This is enough to fuel a large ocean going vessel or several ferries, according to the company.

Sundus Cordelia Ramli, member of Liquid Wind's Board of Directors and CCO for Power-to-X at Topsoe, said: "The shipping industry is one of the single biggest emitters of CO_2, accounting for 3% globally. It makes us proud to be part of this consortium that brings together very capable players to actively bring down this figure. We look forward to bringing our tried and tested methanol technology into this innovative context and to support decarbonisation of the shipping industry alongside Ørsted, a leader in renewable energy."

Anders Nordstrøm, COO at Ørsted P2X, said: "Ørsted is determined to lead the green transformation of society, and that's exactly what we're doing by constructing a project like FlagshipONE. We believe that e-methanol will play a key role in bringing down the carbon emissions from the maritime industry, and alongside key partners like Topsoe, we're working hard to make that vision come true"

FRANCE

Test runs for power-to-hydrogen-to-power demonstrator

ENGIE Solutions, Siemens Energy, Centrax, Arttic, the German Aerospace Center (DLR) and four European universities, together forming the Hyflexpower consortium, have announced the successful completion of the first stage of a research project on renewable energy. Located at the Smurfit Kappa Saillat Paper Mill in Saillat-sur-Vienne, this program aims to demonstrate that green hydrogen can serve as a flexible means of storing energy which can then be used to power an industrial turbine. The hydrogen is produced on site with an electrolyser and used in a gas turbine with a mix of 30-vol.% hydrogen and 70 vol.-% natural gas for power generation. The partners describe it as the world's first industrial-scale power-to-X-to-power demonstrator, and expect to conduct trials this year that will continue to increase the hydrogen ratio up to 100%.

Commenting on the end of the initial testing phase, Gaël Carayon, Project Director at ENGIE Solutions, said: "Ambitious projects like this one require taking partnerships to the next level and being united in a joint mission to make decarbonisation a reality. Hydrogen will play a crucial role in the interaction between renewables and electricity storage and generation. ENGIE Solutions is proud to participate to this unique project."

NORWAY

Tjelbergodden to shut down for three months

Equinor says that it plans to close its Tjeldbergodden methanol plant from the second week of February until the end of April this year while installing a mercury removal unit. The unit will enable the plant to better handle the condensate from its feed from the offshore Dvalin petroleum field, which contains higher amounts of mercury than the plant's current systems are designed for. Tjelbergodden is Europe's largest methanol plant, accounting for around 25% of the continent's production and has an annual capacity of around 900,000 t/a. It is co-owned by Equinor and ConocoPhillips.

GERMANY

Sustainable aviation fuel from methanol

Sustainable aviation fuels are intended as drop-in replacements for fossil fuel aviation fuel without major modifications to the engines and infrastructure. However, most current SAFs are used in a blend with conventional jet fuel, with the drop-in rate typically limited to a maximum of 50%. Consequently the German Federal Ministry of Digital Affairs and Transport (BMDV) has launched a two and a half year study with a budget of €5.2 million with the aim of developing a process that, in addition to producing a 100% drop-in capable SAF, also allows the process route used for this to be as selective as possible, with minimal additional CO_2 emissions and with a high degree of integrability into existing structures or new installations. The starting point of the process is sustainably produced methanol.

In addition to catalyst development, process development, plant integration and the design of a demo plant, the project also includes techno-economic and ecological analysis as well as accompanying support for the certification and analysis of the new aviation fuels. It brings together a consortium including BASF Process Catalysts, refiner OMV Germany, standards company DLR, testing laboratory ASG, and thyssenkrupp Uhde, the latter of which is developing the technology, optimising the process steps in terms of reaction control and efficiency, integrating the individual processes into an economical and sustainable overall process, designing the demonstration plant and calculating the total investment cost for a commercial plant.

Contract signed for green hydrogen plants

HH2E has signed an agreement with Noway's Nel Hydrogen Electrolyser AS for a front end engineering and design study and a letter of intent for two 60 MW electrolyser plants in Germany. The FEED will commence after a firm purchase order is made, and the parties intend to conclude a contract for electrolyser equipment within the first half of 2023. The two 60 MW plants will be among the largest green hydrogen production plants in Europe. Both facilities are in the first phase and can be significantly expanded. The hydrogen will be used for industrial applications, transportation, and heat. In total, HH2E is aiming for 4 GW of electrolyser capacity in Germany by 2030.

"One of the prerequisites for reaching our growth ambitions is the sufficient availability of high-quality electrolysers in Europe, such as those that Nel will supply. We are very happy and confident with Nel's technology and experience", says Alexander Voigt, Co-founder and board member of HH2E.

SAUDI ARABIA

Methanol plant expansion set for Q1 2023 completion

Saudi Methanol Chemicals Co. (Chemanol) says that the work on its $80 million methanol plant expansion project in Jubail will be complete at the end of the first quarter of 2023. In a filing with the Saudi Stock Exchange, the company said that front-end engineering and design work on the facility was 95% complete. The work was initially due to be finished by the end of 2022, but it faced delays due to the late submission of required information from manufacturers, according to the firm. The expansion will increase capacity at the plant by 100,000 t/a to 330,000 t/a.

AUSTRALIA

Green methanol plant for Tasmania

Spanish energy company Iberdrola has announced plans to invest more than $1.1 billion in a new green methanol plant. It is partnering with developer ABEL Energy to build a green hydrogen and green methanol production plant at Bell Bay in northern Tasmania, which will have a capacity to produce 200,000 t/a of green methanol in its first phase for use as marine fuel. The project, called Bell Bay Powerfuels, would increase to 300,000 t/a in its second phase, making it one of the largest projects of its kind in the world.

A major player in renewable energy with an objective of exceeding 60,000 MW of renewable capacity by 2025, Iberdrola is developing 60 renewable and green H_2 initiatives in eight different countries. It has acquired Infigen Energy, Australia's leading renewable energy company, and plans to invest between $2-3 billion in the country with the aim of reaching 4,000 MW of renewables capacity in the coming years. Last year, Iberdrola acquired the rights to the world's largest onshore wind farm at Mount James, with an installed capacity of 1,000 MW.

OMAN

Shell signs agreement for synthetic methane production

Shell Oman has signed a letter of intent with Oman's Ministry of Energy and Minerals to explore the deployment of liquified synthetic gas (LSG) in Oman. LSG is methane produced from renewable hydrogen and captured carbon dioxide, which is then liquefied. This low-carbon fuel can be directly introduced to existing gas networks and infrastructure, including LNG plants such as Oman LNG.

Shell has also taken a 35% stake in Green Energy Oman (GEO), a consortium that is developing the country's largest renewable green hydrogen project in the Al Wusta and Dhofar governorates. The hydrogen will be produced from up to 25 GW of solar and wind energy. Other members of the consortium include OQ, InterContinental Energy, EnerTech Holding Company, KSCC and Golden Wellspring Wealth for Trading. Worley is providing concept feasibility study services for the project. ■

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People

Henk van Duijn is now President and CEO of the International Fertilizer Development Centre.

The International Fertilizer Development Centre (IFDC) has appointed **Henk van Duijn** as President and Chief Executive Officer (CEO) as of January 1st 2023. Van Duijn brings more than 30 years of experience in agriculture and international development, with a focus on Europe, Africa, and Asia. Prior to his selection as IFDC President and CEO, van Duijn served as Vice President, Corporate Services, and Chief Operations and Finance Officer at IFDC. Before that, he headed the 2SCALE program (2019-2021) and served as CEO of Bopinc (2014-2019). As a diplomat and civil service director in the Netherlands, van Duijn led the design, startup, and implementation of large-scale interdisciplinary programs as well as national and international public-private partnerships in Europe, Africa, and Asia. He holds a master's degree in Land and Water Management from Wageningen University & Research.

Outgoing IFDC President and CEO Albin Hubscher will retire after four years of leading the organisation to a renewed commitment to soil health. He was instrumental in formulating IFDC's plan to develop a global innovation centre that will design and scale next-generation soil health and plant nutrition innovations. Hubscher praised his successor, saying, "Henk's reputation for leading organizations to achieve great things precedes him in this appointment. I am confident that he will continue to build IFDC's momentum as a thought leader in soil health and fertilizer technology, for which he has already been a prime force."

The AFA board of directors has unanimously approved the appointment of **Saad Abou El Maaty** as AFA Secretary General. El Maaty has a experience in managing, executing, and rehabilitating a several of major entities in the petroleum and fertilizer sectors, most recently as a Chairman & CEO of Abu Qir Fertilizers and Chemical Industries Co. He has also served on various regional and international bodies as, variously; AFA chairman, IFA board member and IFA ambassador representing Egyptian fertilizer producers, as well as being a member of the board of governors for the Arab Water Council, and serving on the Board of Directors for several companies. ■

Calendar 2023

JANUARY

30 – 1 FEBRUARY
Fertilizer Latino Americano,
RIO DE JANEIRO,
Brazil
Contact: Argus Media Ltd
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MARCH

6-8
Nitrogen+Syngas Conference 2023,
BARCELONA,
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Chancery House,
53-64 Chancery Lane,
London WC2A 1QS, UK.
Tel: +44 (0)20 7903 2444
Fax: +44 (0)20 7903 2172
Email: conferences@crugroup.com

APRIL

17-19
Syngas 2023,
BATON ROUGE,
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Tel: +1 225 706 8403
Email: betty@syngasassociation.com
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MAY

22-24
Nitrogen+Syngas USA,
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Chancery House,
53-64 Chancery Lane,
London WC2A 1QS, UK.
Tel: +44 (0)20 7903 2444
Fax: +44 (0)20 7903 2172
Email: conferences@crugroup.com

22-24
IFA Annual Conference,
PRAGUE, Czech Republic
Contact: IFA Conference Service,
49 Avenue d'Iena,
Paris, F75116, France.
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

JUNE

8-9
NH3 Event,
ROTTERDAM, Netherlands
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Karel Doormanweg 5,
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Tel: +31 10 4267275
Email: info@nh3event.com

11-14
IMTOF 2023, LONDON, UK
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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 53 54 55 56

Plant Manager+

Problem No. 65 High urea concentration in carbamate recycle

This UreaKnowHow.com round table discusses the process upset condition of a high urea concentration in the ammonium carbamate recycle. It is commonly known that the urea formation reaction from ammonia and carbon dioxide via ammonium carbamate is an equilibrium reaction and that the urea conversion in any urea plant is limited. That is why downstream of the urea synthesis section the urea is separated from the ammonium carbamate in a recirculation section. Ammonium carbamate is dissociated into ammonia and carbon dioxide gases by means of low pressure and the addition of heat. The ammonia and carbon dioxide gases are dissolved in water and recycled back to the urea synthesis section. The urea content should be minimal as urea in the ammonium carbamate recycle leads to lower efficiencies. What are the causes and remedies for a high urea concentration in the ammonium carbamate recycle?

Leandro Blum of Petrobras in Brazil starts this round table discussion: What could cause a higher urea concentration in the low-pressure carbamate condenser level tank and thus in the ammonium carbamate recycle?

Muhammad Farooq of SABIC Agri-Nutrients in Saudi Arabia asks for more information: Can you provide details of the inputs to the carbamate tank at your plant?

Leandro replies: In our recirculation section we have a rectifying column and two low-pressure carbamate condensers where vapours from the column are condensed and go to the carbamate tank. According to our mass balance we should expect a urea content of some 0.2 wt-% in the tank, but we normally see 1-1.5 wt-%. We think that the vapours from the column are carrying over urea solution that enters the top of the column.

RD Patel of Notore Fertilisers in Nigeria shares his experiences: The following are causes of high urea concentration in the ammonium carbamate recycle:

- carryover to the rectifying column off gases;
- from the urea recovery system;
- recovery from the desorption/hydrolyser section.

Mark Brouwer of UreaKnowHow.com in the Netherlands joins the discussion: A higher urea concentration in the low-pressure carbamate condenser level tank has sometimes been seen due to entrainment from the rectifying column.

The following factors can play a role:

- high load on the rectifier (actual plant capacity related to design);
- low pressure (increases vapour flows);
- fouling in rectifier causing build-up of liquid;
- too low disengagement height in top of rectifier;
- type of sprayer which causes small droplets;
- a combination of the above.

When did the urea concentration increase? Has it ever been low? Check the urea content in the rectifying column outlet vapour line. In case it shows high urea content it means that your bed system is blocked and needs cleaning or in case there are trays then clean the holes.

Malik Muhammad Sohail of SABIC Agri-Nutrients in Saudi Arabia shares his experiences: In my opinion, the following should be checked:

- heat load to rectifier (relates to entrainment);
- mass flow of solution inlet;
- rectifier outlet urea concentration;
- high liquid level at top of rectifier;
- inspection of top part (plates/packing).

Masood Yousaf of Fatima Fertilizer in Pakistan joins the discussion: Other possible causes of urea carryover in the rectifier are:

- high level;
- blockage of the packing bed.

Akbar Ali of SABIC Agri-Nutrients in Saudi Arabia asks for clarification: What can we expect as a negative impact if the urea concentration increases to 4 wt-% or more due to carryover from the rectifier column top?

Mark replies: If in the past the urea percentage in the carbamate tank was normal but now you are faced with this problem it might be due to displacement of the chimney tray (Chinese hat) in the outlet of the recirculation heater to the rectifier separator.

Norozipour of Khorasan Petrochemical in Iran shares his experiences: The following can cause urea carryover from the rectifying column:

- overload of rectifying column;
- high level;
- fouling in the packing and tubes due to corrosion product and some oil in the process and even partial blockage of packing bed (our case);
- malfunctioning of distribution sprayer in the top;
- low pressure.

We were faced with this problem, and we changed the packing and exchanger. As we know, if urea carries over with the gas phase, it means we lose capacity of the plant and will consume more energy to decompose this product to NH_3 and CO_2 in the hydrolyser section and send it back to the synthesis section.

Amirzadeh of Pardis Petrochemical Co. in Iran contributes to the discussion: We had the same problem in our unit. Please check these items before taking any actions:

- check your synthesis conditions, if everything is ok, this problem is caused by something else;
- check for any plugging/fouling in the rectifying column, such as plugging in the packing bed, overflow line from top part to the condenser;
- In case you have same the temperature in the top of the column and the loop line your inert valve at exit of the column may have a problem such as choking or bad design in sizing.

Naseem of SABIC Agri-Nutrients in Saudi Arabia shares his experience: Carryover happens if the L/G ratio is on the higher side. Liquid accumulates at the top and gases push it out. In the rectifying column it can happen due to:

- choking of orifice plugs at bottom of rectifying column if available;
- choking of the recirculation heater tubes;
- compression of the packing bed due to pressure;
- decrease in superficial area in bed or voids due to corrosion products;
- partial choking of LV which will appear with level sensor.

Observation: urea content is high in the low-pressure carbamate condenser level tank. Analyse the ammonium carbamate solution in the level tank. In case the urea content is higher than design, it is clear that there is solution carryover.

Short term remedy: Increase the operating pressure gradually up to the design pressure to shift the liquid. Increase to 0.5 bar higher than normal and observe the condition. Repeat it until the desired result and 1 barg below PSV set pressure. If the situation remains the same, shut down the plant.

Permanent solution: Shut down the unit and clean the heater.

Long Term: Shut down the plant clean the packing bed as well as the heater tubes. If the orifice plugs are installed at the bottom, replace them with an orifice plate.

Muhammad Bilal Shabeer of Fauji Fertilizer Bin Qasim in Pakistan asks a question: How does choking of the tubes increase the L/G ratio? Are the tubes blocked?

Naseem replies: L/G means liquid to vapour ratio in the column. When there is less decomposition and liquid is continuously coming then the L/G ratio will be affected. When the heater is choked, and decomposition of carbamate decreases, it reduces the gas flow through bed while the liquid is still coming.

Mark adds another option to the list of possible causes: Another cause could be the liquid distributor plate holes. These holes get smaller over time due to iron-oxide precipitation. Once the diameters become too small, the liquid level rises to over the chimneys resulting in urea carryover. They are easily reamed back to full size, or larger.

Mohamed Tarek Sadek of Helwan Fertilizer in Egypt shares his experiences: We have also experienced the carryover of urea solution in the rectifying column to the LPCC in our Stamicarbon urea plant.
The reasons were:

- plugging of the Rasching rings in the packing bed in the upper part of the rectifying column;
- plugging in the tubes of heater and that's why the opening of the steam valve on the heater recirculation became higher than normal in order to reach the right set point for the urea solution out of rectifying column.

The consequences were:

- level in LPCC level tank increases sharply;
- level in urea tank decreases (due to urea solution carryover in the rectifying column). Therefore, take care, you must act before the urea solution pump and urea melt pump start to cavitate. You could also isolate a header to avoid decrease of the main header pressure to the granulator.
- concentration of solution flow from LPPC to HP scrubber via HP carbamate pump changes, which leads to change in the synthesis loop conditions (so take care).

The solutions are to decrease the possibility of the carryover phenomenon in the rectifying column.
From the process side:

- decrease the synthesis load to decrease load on the rectifying column;
- increase the recycle pressure (more than 4 bar) to damp the liquid solution either in the rectifying column or LPCC.

From the mechanical side during shutdown and after complete drainage of the plant:

- mechanical cleaning must be done using a high-pressure condensate (jet pump);
- chemical cleaning to remove any deposits in the recirculation heater tubes or the Rashing rings in the packing bed. Broken rings in the packing bed should be replaced.

Bob Edmondson, Expert of UreaKnowHow.com shares his experience: We suffered from this problem and corrected it by drilling the holes in the liquid distributor to increase their size. After that carryover was no longer a problem.

Hassan Abdul Raheem of Fauji Fertilizer Bin Qasim in Pakistan contributes to the discussion: Urea carryover from the rectifier may be due to the following reasons:

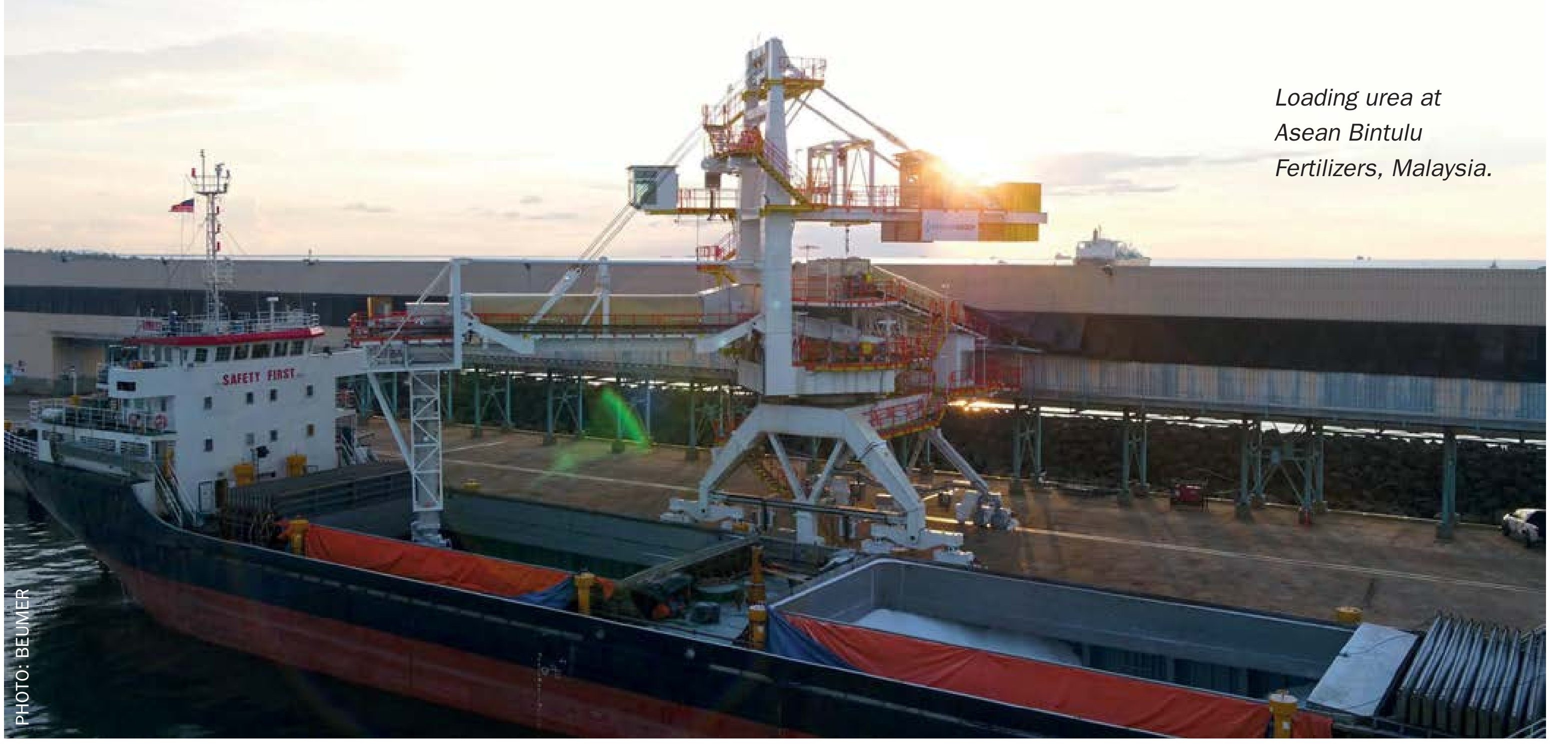
- low stripping efficiency in stripper e.g., improper distribution of reactor effluent on ferrules, loose ferrule gasket looseness, CO_2 flow disturbance etc.;
- high load on rectifier;
- high heat load on recirculation heater;
- mechanical damage of gas risers or partially blocked holes in tray;
- partially blocked recirculation heater tubes;
- high vapour velocity;
- low bottom level in stripper;
- high liquid level in rectifier.

Carryover Indications are:

- rectifier feed inlet temperature matches rectifier vapour temperature;
- visibly check from vapor sample point;
- sudden level increase in LPCC;
- decreasing level of rectifying column;
- 75 % urea solution tank level drops from normal condition;
- rectifier liquid outlet temperature.

Shoaib of Fauji Fertilizer Bin Qasim in Pakistan confirms Hassan's observations: We have suffered from the carryover problem in the rectifying column a number of times, specially at particular loads.

China and the urea market



Loading urea at Asean Bintulu Fertilizers, Malaysia.

PHOTO: BEUMER

Covid, demographics and a shift from an industrial to a consumer-led economy have stalled China's previously breakneck growth, with a potential impact upon all commodity markets, including fertilizer. At the same time, Chinese export restrictions have overheated the urea market.

China remains the largest producer and consumer of urea in the world. In 2021 it consumed 33% of all of the 150 million tonnes of urea produced globally. Historically China has tried to ensure self-sufficiency in fertilizer production, particularly nitrogenous fertilizers. Initially this was based on ammonium bicarbonate production, but beginning in the 1980s China switched wholesale towards coal-based urea production. Urea now accounts for half of all nitrogen fertilizer application in China. This concentration on urea also left China with a large overhang of unproductive or marginally productive capacity, which has turned the country into a swing producer in spite of large-scale capacity closures over the past few years. At the same time it also became the largest exporter of urea in the world. But while urea sustained China through the boom years of the 1990s and 2000s, its exports have fallen significantly since 2015, and last year faced major government export restrictions for half the year.

China's economy

After China began to open up and reform its economy in the 1980s, GDP growth averaged over 9% per year for a sustained period. The country grew rapidly, with hundreds of millions lifted out of poverty. China also became the workshop of the world, its industry coming to dominate many sectors. But since the beginning of the 2010s, the period of high growth based on investment, low-cost manufacturing and exports seems to have run its course. One of the key constraints has been demographic; in 1980 China began its 'one child' per couple policy, which has rapidly slowed the growth of the country's population, but has meant since the start of the 21st century that fewer people are entering the labour force at the same time that the number of retirees increases. Industrial and commodity markets have also become saturated, with no further room for growth, and the government has begun to shift policy from investment towards consumption, and made efforts to tackle issues such as pollution and carbon emissions.

The impact of covid has been another major factor. China's GDP officially grew by 6.0% in 2019, but this dropped to 2.2% in 2020 as the country became ground zero for the covid epidemic and instituted draconian lockdowns that seemed to control the disease within China. As a result the economy bounced back to 8.1% growth in 2021, but last year saw the return of new, more virulent strains that led to prolonged lockdowns in many major cities which were only lifted late in the year due to increasing public protest. China's GDP is estimated to have grown by just 3.0%.

It is expected that, following the relaxation of covid lockdowns, China's economy will return to stronger growth this year – 4.6% according to the OECD. But the country also faces significant structural issues, including a large overhang of debt, especially private debt, and a moribund housing market that has been swamped by over-building, regulatory tightening that led to a liquidity squeeze for developers, and mortgage boycotts by owners of homes still under construction.

Agriculture

China feeds 20% of the world's population with just 7% of the world's arable land. However, this has created its own issues in terms of overapplication of fertilizer, degradation of soil and nitrate pollution. Belatedly the government has begun to tackle this by encouraging farmers to be more sophisticated in their application of fertilizer to balance nutrient requirements and increase efficiency of nutrient use. Fertilizer consumption was officially capped in 2020 and it is intended that it will fall, although in fact consumption had been falling before that. Chinese farming has faced increasing costs over the past decade, in terms of both land, labour and, more recently, fertilizer and other inputs and this has helped crimp consumption. There is also a move towards more enhanced efficiency nitrogen products as well as organic fertilizer and soil amendments. In 2022, the impact of the war in Ukraine drove up fertilizer prices and this is believed to have had an impact on urea consumption.

But while agricultural consumption of urea continues to slowly decline, this is balanced by rising industrial consumption of urea for diesel exhaust treatment, urea-formaldehyde and urea-melamine resins etc. Urea consumption peaked in 2013 at 59.3 million t/a, and dropped to around 50 million t/a by 2017, where it has roughly remained since then. In 2021 consumption was 49.7 million t/a.

Coal prices

Feedstock pricing and availability is also an issue for Chinese producers. Around 20-25% of Chinese urea capacity uses natural gas as a feedstock, which is virtually unavailable during winter because it is required for power generation. Coal prices have also been rising, eroding margins, and coal has occasionally not been available at any price. Government targets for Chinese states to reduce CO2 emissions means that some state governments such as Inner Mongolia and Shanxi are also forcing local urea plants to run at lower rates or not at all.

The impact of the Ukraine war has been to disrupt supplies of coal from Russia because of inability to access the SWIFT global payments system, which has also contributed to high coal prices in China in 2022.

Urea production

In addition to falling domestic consumption and high feedstock prices, Chinese domestic urea producers have also faced the government's attempt to crack down on polluting industries. In some ways this has been beneficial for the urea industry as a while, with older and less efficient plants closing down to be replaced by larger, more efficient plants, often based on bituminous coal rather than more expensive anthracite. Stricter regulations on emissions have also resulted in accelerated closure of older capacity. Chinese urea production fell from just over 70 million t/a to 55 million t/a in 2021.

Covid, conversely has had little effect on urea production. Indeed, urea operating rates actually increased in 2022, from an average of around 56% to 66% by the end of December. IFA assessed Chinese urea production for Q1-Q3 2022 to be up 15% on 2021 figures.

New plant construction continues in China. Stamicarbon recently announced that it would license the largest plant that it had ever constructed in China, at 3,790 t/d (1.25 million t/a). The plant will produce a mixture of prilled urea (1,560 t/d), granular urea (1,100 t/d) and diesel exhaust fluid (DEF), as well as having a large melamine side stream which will take 1,130 t/d of urea.

Exports

China's surplus of urea meant that during the 2000s and into the 2010s it was the largest exporter in the world, with exports reaching 13.7 million t/a in 2015. However, although consumption has declined, production has declined faster, leading to exports dropping rapidly, to just 2.4 million t/a in 2018, before settling back at around 5 million t/a in 2019 and 2020. But fears over high domestic pricing have meant periodic restrictions on exports by the Chinese authority. During the 2010s this was achieved by a quota system which restricted exports to certain months of the year when domestic demand was low in order to try and keep domestic production at home at times of high international prices, when it can be more profitable for Chinese producers to export than serve the domestic market.

In July 2021, China began asking major urea and ammonium phosphate producers to stop selling abroad. Three urea producers in Shanxi, Hebei and Shandong were asked by the government to suspend applications for China Inspection and Quarantine Certificates. This was followed up in October 2021 by announcement that China would be carrying out "inspections on import and export chemical fertilizers strictly under the latest regulations," according to a notice from the National Development and Reform Commission (NDRC). The effect was to limit or even suspend exports of some fertilizers, especially phosphates, to ensure domestic supply. Even so, Chinese urea exports were around 5.3 million tonnes in 2021, comparable with figures for 2019 and 2020.

The export restrictions have continued into 2022 and have had a marked effect on urea exports. Q1 urea exports were 303,000 tonnes and Q2 exports were 421,000 tonnes. There was a pick up in Q3 as China relaxed some of the restrictions on a temporary basis in order to serve some large Indian urea tenders, and Q3 export figures shot up to 849,000 tonnes, but even so, this represents a 65-70% decline on 2021 figures overall. Exports from January-September totaled 1.57 million tonnes, as compared to 4.0 million tonnes for the same period of 2021. South Korea and Pakistan have also been major recipients of Chinese urea according to customs data.

In spite of last year's higher production, it is anticipated that export restrictions will continue into 2023. On December 29th 2022, China's Customs Tariff Commission of the State Council said that tariffs on some commodities would be "adjusted" in 2023. It is expected that this means that restrictions will continue for 1H 2023 out to July.

Urea pricing

Chinese policy continues to have a major impact on fertilizer pricing. The export restrictions in July and October 2021 caused urea prices to almost double, and in spite of some rises caused by the Ukraine war and interruptions to Russian exports, urea prices have not reacted as badly to the war as they did to the interruption in Chinese supply. Fortunately some factors have mitigated against this during 2022, including new capacity which has helped ease tightness in the market. Around 3.8 million t/a of new capacity came onstream outside China during 2022, and another 3.2 million t/a is expected in 2023, and 2.2 million t/a in 2023.

Likewise, fertilizer consultancy Profercy notes that where it is available, Chinese urea has often been offered at some of the most competitive levels, for example in Indian purchasing tenders. In the most recent IPL India purchasing inquiry (for shipments to 5th December), up to 320,000 tonnes is due to be shipped via 5-6 trading companies, with netback prices in the mid-$620s/t f.o.b. China. ■

Global gas markets after Ukraine

With Europe facing a long-term shortage of natural gas, and Russia looking east for new customers, how will changing global gas markets affect production of key syngas-based chemicals?

PHOTO: HOEGH LNG

A liquefied natural gas floating storage and regasification unit, left, and an LNG tanker.

The war in Ukraine and associated cutbacks on Russian supplies of natural gas to Europe have had a devastating impact on ammonia and downstream nitrogen markets. Natural gas is Europe's key source of energy; in 2021, the EU-27 consumed 412 bcm of gas, mainly for power generation, but also household heating and industrial processes. Over 30% of households in the EU use gas to heat their homes. But of that 412 bcm, 83% was imported from outside the EU in 2021, and half of those imports came from Russia.

After the imposition of sanctions on Russia, supplies of natural gas began to be curtailed, sending prices to record levels and forcing the shutdown of two thirds of EU ammonia capacity. By August, the Dutch TTF gas price had risen to €320/MWh (approximately $100/MMBtu). The Nordstream 2 pipeline had already not received certification by the German authorities, and in September sabotage destroyed the Nordstream 1 pipeline across the Baltic Sea. With gas transit via Ukraine very limited, only the Yamal-Europe line via Belarus and TurkStream across the Black Sea were still delivering gas from Russia to Europe, and even here the volumes were dwindling. In November only 1.86 bcm of gas was delivered from Russia to Europe, compared to a figure of 10.1 bcm for the same month in 2021 and closer to a usual figure of 14-15 bcm in 2018-19.

Europe's response

The response by European authorities has been a duel pronged approach of managing demand and looking for alternate sources of supply. To an extent Europe can rely upon higher imports of liquefied natural gas (LNG), with LNG imports rising by 65% in the first six months of war. The US has been a key supplier, with around 9 million t/a of new long term supply contracts signed in 2022, as well as Qatar and Nigeria. Volumes of pipeline gas from Norway and Algeria have also increased substantially. However, in the absence of Russian supply, there is not enough physical infrastructure to fully meet European gas demand at peak, and there were serious concerns about the impact of a cold winter on European gas use.

To this end, there was a concerted attempt to fill gas storage capacity during the summer, with storage capacity reaching 88% going into winter, compared to a figure of 45% for the previous year. EU gas storage looks to be on course to exit winter at around 50% capacity, reducing the call on LNG. Shutdowns by industrial consumers, including the ammonia industry, also helped ease the demand situation. It is estimated that European gas consumption will be 10% lower in 2022 compared to 2021, with industrial consumption falling by 15%, contributing to a global decline in gas demand of 0.8% for the year.

The situation was also eased by a mild winter weather in December, leading gas prices to fall significantly. By December TTF prices were down to €135/MWh ($40/MMBtu), and by January gas prices of $17/MMBtu were available – still high by historical standards, but back to more normal levels than the extremes seen in mid-2022.

The EU has now agreed a cap on wholesale gas prices from Russia, beginning on February 15th. After that date, if prices rise above €180/MWh for more than three days running, gas prices will be capped at a level equivalent to or below the global price of LNG, plus €35, for 20 working days (5 weeks). The cap will include a suspension mechanism that would kick in if energy supplies came under threat or demand began to surge. Russia has condemned the mechanism as anti-market, and Intercontinental Exchange (ICE), which operates trading at the TTF gas trading hub, says that it may relocate activities from the Netherlands to outside EU jurisdiction as a result. There are wider concerns that Europe's gas market could face a breakdown of buyers and sellers, risking security of supply and higher energy costs.

Meanwhile, there is also an attempt to rush new gas infrastructure into service. Floating storage and regasification units (FSRUs) could be one such solution. Germany is rapidly commissioning its first floating LNG import terminal, and there are another five such projects under development – Germany is one of the countries in Europe most affected by the loss of Russian supply. Sky high gas prices have also been a major impetus to increased supply of renewable electricity.

LNG

The impact on the LNG market has been a significant one. The IEA forecasts that Europe's LNG imports will increase by over

60 bcm in 2022, or more than double the amount of global LNG export capacity additions, keeping international LNG trade under strong pressure for the short- to medium-term. LNG prices peaked at record levels of $54/MMBtu in August 2022, though they have fallen back since then as the gas supply situation eased in Europe. Still, both Japan and Korea have instituted policies to reduce reliance on imported LNG for power generation and have developed contingency plans for possible LNG supply disruptions. Asian gas demand growth was flat in 2022, after rising by 7% in 2021. The International Energy Agency forecasts that 2023 could see a rise of 3% in Asian gas demand, but this may affect European LNG purchases. One of the issues going forward is that as China eases its draconian covid lockdown regime, ad its economy picks up, so it is likely to return to the LNG market in a more significant way. Morgan Stanley has predicted that Chinese LNG demand could increase by 16% (10 million t/a) during 2023. The global LNG market expanded by 5% in 2022, driven primarily by European demand.

Table 1: **Natural gas demand and production by key region/country (bcm)**

	Demand			Production		
	2021	**2022**	**2023**	**2021**	**2022**	**2023**
Africa	169	166	171	262	270	278
Asia Pacific	895	895	923	650	669	681
of which China	364	370	390	205	220	230
Central/S America	153	147	147	147	149	151
Eurasia	634	619	614	955	841	817
of which Russia	501	484	479	762	651	623
Europe	604	548	531	223	232	235
Middle East	564	582	596	694	715	732
North America	1,084	1,114	1,102	1,178	1,212	1,235
of which USA	867	890	876	973	1,010	1,041
World	4,103	4,071	4,085	4,109	4,089	4,129

Source: IEA

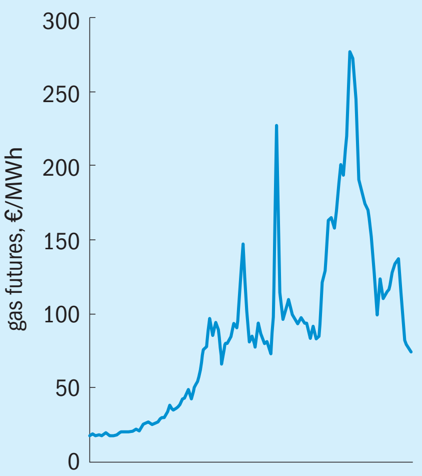
North America

US natural gas prices spiked counter-seasonally in 2022 due to the tightness in global gas and power markets. NYMEX front month contracts reached a high of $9.68/MMBtu in August 2022, though they have fallen back since then in line with falling gas prices around the world, reaching $4/MMBtu by the end of the year. The shutdown of the Freeport LNG export facility has helped gas volumes that might otherwise have been sucked out into the international market stay within the US, providing something of a cushion to US prices. US gas demand is still rising, however, as coal-fired power stations continue to be replaced with gas-fired ones. US LNG exports are also high and rising, and with Europe still desperate for US gas, this is likely to continue. US dry gas production has been at record levels and still rising since June 2022. However, there are concerns that shale gas well completions are not keeping pace with rising demand, and the forecast is for generally higher US gas prices over 2023 and 2024.

Ammonia production

Europe's ammonia production has been badly affected by the record gas prices over the past year. By August it was estimated that around 70% of production capacity across the continent had been idled. This coincided with ammonia prices of over $1200/tonne in Europe. High European ammonia prices drew in imports from all over the world, especially the US. Argus calculates that US Gulf coast-based ammonia producers exported more than 620,000 tonnes of ammonia in 2H 2022, the total in more than 10 years. Even with relatively high US gas prices, delivered prices into Europe gave US producers record margins. Even with European gas costs falling and some producers re-starting, Argus assesses, European producers' feedstock costs at more than $1,270/t, still well above the delivered c.fr price for northwest Europe.

Fig. 1: **Dutch TTF natural gas prices Jan 2021-present**



Source: ICE

The outlook for 2023

There is no sign of the war in Ukraine stopping or of any serious negotiations that might bring fighting to a halt. It seems that both Russia and Ukraine (and its western backers) are in things for the long haul. That being the case, there is no prospect of any let-up in the current difficult market for natural gas. Indeed, things may worsen.

Table 1 shows IEA estimates for 2022 and predictions for 2023 in terms of demand and production. European gas demand is forecast to continue to slip this year as gas prices remain high and volatile. While Europe will probably exit this winter with historically high levels of gas storage, and banking giant ING has said that the present gas supply situation in Europe "could not have been better", it is likely that Russian supplies will fall still further, possibly to zero this year, meaning that European supply will remain tight. "The ability of the EU to completely turn to other sources is just not possible. Therefore, Europe is likely to go into the 2023/24 winter with tight storage, which could leave the region vulnerable," said ING. While some FSRUs will be deployed during 2023, Europe still faces a hard cap on how much gas it can import, and making it through the winter of 2023-24 will likely require further cuts in consumption.

On the supply side, supply chain issues, labour shortages and rising costs will all play a role in the more modest supply growth expected over the coming year. ■

The crisis in global gas markets, issue 375, Jan/Feb 2022, p16.

A complete listing of all articles and news items that appeared in *Nitrogen+Syngas* magazine during 2022.

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Nutrien's site at Redwater, Alberta, one of the places it is currently producing blue ammonia.

PHOTO: NUTRIEN

Low carbon ammonia projects

A review of the current slate of plans for green and blue ammonia production.

The ammonia industry is in the early stages of a process of profound change. The move from gas- and coal-based production to low carbon feedstocks, either hydrogen from water electrolysis using renewable power – green ammonia – or conventional sources with carbon capture and storage – blue ammonia – will be one of the defining changes in the industry over the next few decades. However, the scale and pace of adoption will depend upon a number of factors, from technological solutions to capital and operating expenses, and government inducements.

Technology

The technology is available, as discussed in our major article in the previous issue (Decarbonisation of ammonia and methanol, *Nitrogen+Syngas* 380, Nov/Dec 2022). However, it has not been used before at such scale, and many producers and licensors have chosen to proceed cautiously, via pilot and demonstration plants, or small-scale side feeds into existing facilities.

It is expected that blue ammonia, using carbon capture and storage, will be the major source of low carbon ammonia over the remainder of this decade, but CCS comes with its own set of issues, relating to the acidic behaviour of CO_2 under pressure, if it comes into contact with water. While there are now a number of large scale CCS sites around the world gathering acid gas for reinjection into gas or oil wells (enhanced oil recovery or EOR), long term storage remains a topic of research and development, so most of the blue ammonia will be associated with existing oil and gas infrastructure. As Table 1 shows, blue ammonia projects currently cluster in the Middle East and the oil and gas producing states of the US, with some others in places such as Indonesia and Canada. They are also associated with current large scale nitrogen production sites with large producers who are familiar to the ammonia industry and hence a safer bet for investors and finance companies than novel green ammonia projects. Nutrien, for example, has been a pioneer in this regard and says that it already sequesters CO_2 to make an equivalent of 1.0 million t/a of blue ammonia at its sites in North America. The company says that it expects to make a final investment decision this year on a plan to add carbon capture and storage at its Geismar, Louisiana site to sequester 90% of CO_2 emissions, producing approximately 1.2 million t/a of blue ammonia. Germany's thyssenkrupp Uhde has been selected as technology partner. Because of the involvement of existing producers and plants these projects are generally likely to go ahead, though some of the capacity figures (e.g. for the Ascension Clean Energy – ACE – project in Louisiana) are for notional future expansions rather than the initial phase of the project.

Green ammonia

The progress of green ammonia projects has been a different story. While there are some existing fertilizer producers involved, including Fertiberia, Yara and CF Industries, these are mainly in smaller-scale add-ons to existing production at present, though Yara has the goal of completely converting its Porsgrunn ammonia plant in Norway to renewable feeds by the end of the decade. However, the larger scale green projects are often much more speculative and dependent upon grants and other incentives to cover the initial investment cost. There are a number of projects in the few hundred thousand tonne per year size range now, as well as some very ambitious government-driven projects in the Middle East, such as the ACWA Power development at the new Neom technology city in Saudi Arabia. How fast these projects can come to market remains uncertain. Renewable feeds are notoriously fickle, and even in the sun-baked deserts of Arabia the sun does not shine half the time. Green production can be mixed with existing gas-based production relatively easily provided it only represents a smaller percentage of the feed, but at large percentages turn-down capacity for ammonia reactors becomes very relevant, and some kind of hydrogen storage, possibly quite expensive, must be considered.

Some green projects are also predicated on demand emerging in, e.g. the maritime sector for clean shipping fuels. While this demand is likely to emerge, how far and how fast remain open to question. Perhaps more certain is demand for ammonia as a co-firing power plant fuel in various Asian countries, but particularly Japan, which is likely to need several million t/a of ammonia by 2030 to meet carbon reduction targets.

Other technologies

Other routes are under study. In the US, Terrestrial Energy is partnering KBR to examine the feasibility of using nuclear power to electrolyse water for ammonia production using Terrestrial's Integral Molten Salt Reactor (IMSR) technology.

As we discuss elsewhere in this issue (pages 30-31), reduction of methane to hydrogen and carbon – sometimes described as 'turquoise' hydrogen – is also under study, though the technology remains unproven at scale and the size of the market for carbon black could limit its applicability.

Finally there is also the prospect of biomass-based or similar feeds. Yara is using biomethane as a feed to its ammonia plant at Cubatao in Brazil, and expects to have converted 3% of the feed by the end of this year, with the eventual aim of running the entire facility on biomethane by 2030.

Speed of development

If all of the projects, including speculative ones, were taken into account, then there could be tens of millions of tonnes of low carbon ammonia operational by 2030. More realistically, there are likely to be several large blue ammonia projects and a larger number of smaller green projects. World-scale green projects may need government backing to de-risk the investment cost. Argus has estimated that total installed capacity for green and blue ammonia could reach 10-15 million t/a by 2030, rising to several times that by 2040 as a price premium for low carbon ammonia develops as a result of government policies on low carbon taxation, helping to drive new investment, and assuming that as larger scale installations are made, the cost of electrolysers and of renewable power are also likely to fall. By 2040, Argus estimates, green ammonia could achieve cost parity with conventional 'grey' ammonia f.o.b. Middle East even without government incentives, at which point the pace of development is likely to pick up markedly.

Table 1: **Major blue ammonia projects**

Company	Site	Capacity, t/a	On-stream
ACE	Louisiana, USA	7.2 million	from 2027
ADNOC	Ruwais, UAE	1.0 million	2025
CF Industries	Donaldsonville, USA	1.7 million	Ongoing
CF Industries	Yazoo City, USA	500,000	Ongoing
Horisont Energi	Barents Blue, Norway	1.0 million	2025
Nutrien	Geismar, Redwater, Joffre, USA/Canada	1.0 million	2021
Nutrien	Geismar, USA	1.2 million	2027
PAU	Sulawesi, Indonesia	660,000	2026
SAFCO	Al Jubail, Saudi Arabia	40,000	2020
SAFCO	Al Jubail, Saudi Arabia	1.0 million	2026
QAFCO	Mesaieed, Qatar	1.1 million	2026
OCI	Beaumont, USA	1.1 million	from 2025
Yara	Gulf Coast, USA	1.0 million	n.a.

Source: BCInsight

Table 2: **Green ammonia projects**

Company	Site	Capacity, t/a	On-stream
ACWA Power	Neom, Saudi Arabia	1.3 million	from 2026
ACME Cleantech	Mangalore, India	120,000	Feasibility study
AmmPower	South Louisiana, USA	1.3 million	Feasibility study
CF Industries	Donaldsonville, USA	20,000	2023
Danis Power to X	Ramme, Denmark	5,000	2023
Fertiberia	Puertellano, Spain	20,000	2022
H2Perth	Kwinana, Australia	600,000	2026
H2-Hub	Gladstone, Australia	1.7 million	2025-30
Hy2Gen	Sauda, Norway	200,000	2027
Incitec Pivot	Gibson Island, Australia	50,000	Feasibility study
Korean JV	KIZAD, UAE	200,000	n.a.
Linde JV	Coega Ngqura, South Africa	780,000	2026
MadoquaPower	Sines, Portugal	500,000	Feasibility study
Mintal HET	Mongolia, China	390,000	2025
OQ	Salalah, Oman	330,000	by 2030
OQ	Duqm, Oman	100,000	2025
SCEZ	Ain Sokhna, Egypt	140,000	2026
Strike Energy	Project Haber, Australia	800,000	2026
TGS	Vietnam	180,000	Feasibility study
Total Eren	Magallanes, Chile	660,000	Feasibility study
Unigel	Camacari, Brazil	60,000	2022-26
Yara	Porsgrunn, Norway	20,500	2023
Yara	Porsgrunn, Norway	800,000	2027
Yara	Pilbara, Australia	4,000	2024
Yara	Sluiskil, Netherlands	75,000	2025

Source: BCInsight

Nitrogen + Syngas 2023

Sagrada Familia, Barcelona at night.

MR_PIBOON/ISTOCKPHOTO.COM

CRU Events will host the 2023 Nitrogen + Syngas conference and exhibition at the Hyatt Regency Barcelona Tower in Barcelona, 6-8 March.

CRU has recently announced the agenda for CRU's 36th Nitrogen + Syngas conference and exhibition which will be held as a live, in-person event in Barcelona on 6-8 March 2023. This highly respected annual technical event for the global nitrogen and syngas community provides an important platform for technical professionals from across the nitrogen and syngas industries to connect, do business and learn about the latest developments in operations, technology, process and equipment. The meeting attracts a truly global audience of producers, licensors and materials and equipment providers from around the world, facilitating business networking and peer-to-peer knowledge sharing.

The extensive technical agenda showcases the latest technology, process, materials and equipment developments that are driving operational efficiency, sustainability and reliability for nitrogen and syngas producers. The 2023 agenda will feature three content tracks with a record 63 technical papers and will have a significant focus on energy efficiency, low-emission technologies and sustainability, in particular the role nitrogen and syngas will play in the energy transition.

For the first time, the event will include a dedicated content track on innovations in sustainability and decarbonisation. Additional tracks will continue the conference's long tradition of sharing operational experience and lessons learned from operators working in ammonia, urea and nitrates facilities.

The conference will open with a series of technical showcase presentations, which give short, informative product updates, before moving into the opening keynote session which provides crucial "big-picture" insights into the major market forces shaping the nitrogen and syngas industries. Opening the session is the global nitrogen market outlook from CRU's Principal Nitrogen Analyst, Shruti Kashyap, which will provide essential context on supply, demand and pricing.

Attention will then turn to accelerating role of ammonia in the energy transition, starting with an overview of costs associated with the production of low emission ammonia, from CRU's Alex Amin; which will be followed by OCI's views as a producer on investing on low-emission ammonia capacity. Financing green projects will also be covered, as well as a presentation from Lloyd's Register Decarbonisation Hub on the opportunities and considerations for the use of ammonia as a marine fuel.

On the following two days the technical programme is split into three tracks. For more information about the event visit www.nitrogensyngas.com

TRACK 1

TUESDAY 7 MARCH

- Electrified steam methane reforming by eREACT™: Emissions-free syngas manufacturing *Topsoe A/S*
- Reducing CO_2 footprint and increasing ammonia production via injection of green hydrogen into existing ammonia plants *thyssenkrupp Industrial Solutions AG*
- Recuperative reforming – A key element for blue syngas production *Technip Energies, Clariant and Casale*
- Blue hydrogen production: Achieving minimum carbon footprint and minimum operating cost, comparing SMR and ATR *KT – Kinetics Technology SpA*
- Low carbon hydrogen: A climate silver bullet *BASF*
- How optimal integration of SOEC electrolysis and Topsoe ammonia technology can significantly impact plant economics *Topsoe A/S*
- The best of low carbon hydrogen technologies for ammonia *Air Liquide Engineering & Construction*
- Barents blue ammonia project: A landmark towards sustainability *Saipem*
- Blue ammonia for lower CO_2 emissions *thyssenkrupp Industrial Solutions AG*
- Blue NH_3 with HISORP CC: An adsorptive CO_2 removal process *Linde*
- KBR's blue ammonia technology: Mega-scale with proven technology *KBR Technology*
- Tangible solutions to face the challenge and implement a sustainable transition: Casale technologies for emission reduction in existing plants and newbuilds *Casale SA*

WEDNESDAY 8 MARCH

- TrueBlue Methanol™ – A low carbon emission methanol production process *BD Energy Systems LLC*
- KBR ammonia cracking technology: A roadmap from renewable energy source to green hydrogen supply where it is needed the most *KBR*
- Contribution to materialize economical clean fuel ammonia value chain *Toyo Engineering Corporation and JGC Holdings Corporation*
- Turbomachinery technologies for decarbonisation: Ammonia/hydrogen burning gas turbines *Baker Hughes*
- Duplex stainless steel for use in alkaline electrolysers with demand on extreme service life – green hydrogen *Alleima*
- Improving sustainability of steam reformers *Schmidt + Clemens Group*
- Syngas processing in waste-to-renewable energy technology with reduction of CO_2 footprint *Siemens Process Systems Engineering Ltd.*
- *Euromel®* G5 new generation: The green and energy saving melamine technology *Eurotecnica Contractors and Engineers*
- Innovative technology to recover nitrogen and produce a climate friendly fertilizer *EasyMining Services Sweden*

TRACK 2

TUESDAY 7 MARCH

- Toyo's new urea process "ACES21-LP" provides great benefits to urea plant owners in cost and energy savings *Toyo Engineering Corporation*
- Application of technology features in a large-scale urea granulation plant *thyssenkrupp Fertilizer Technology GmbH*
- Latest developments and projects in fluidized bed granulation *Green Granulation Ltd/Casale*
- Upgrading salty by-product of acidic scrubber *Stamicarbon*
- Superior mechanical reliability of urea plants through post-EPC assistance *Toyo Engineering Corp.*
- A blocked leak detection system: What to do? *UreaKnowHow.com*
- Use of Safurex® thin foils for pressure, level and flow transmitters *Stamicarbon*
- Improving the performance of the HP synthesis and wastewater treatment sections of IFFCO Kalol *IFFCO Kalol*
- Optimizing explosive mixture in a vintage urea plant to enhance production capacity and energy efficiency for sustainable operation *Engro Fertilizers Limited*
- Lessons learned from replacing a HP stripper and HP scrubber during turnaround *Abu Qir*
- Carbamate solution carryover during urea plant start-up *Petrokimia Gresik*
- Sustainable urea plant operation during stripper ferrules (liquid dividers) unavailability and & in-house repair of stripper ferrules *Fatima Fertilizer Company Limited*

WEDNESDAY 8 MARCH

- Optimized FTC flex gauze packs for catalysis of ammonia oxidation *Heraeus Deutschland GmbH & Co. KG*
- Optimization of ammonia oxidation by CFD modelling and experiments. Role of mass transfer on product selectivity *Umicore*
- Start me up – improved activation can improve gauze performance *Johnson Matthey*
- Latest Improvements in the Uhde EnviNOx® Process for N_2O abatement *thyssenkrupp Industrial Solutions*
- Emission monitoring & reporting from nitric acid production – A moving target *SICK AG*
- Effective reduction of nitrogen oxide and ammonia emissions by utilizing environmentally compliant technologies *Mitsubishi Heavy Industries Engineering, Ltd and Navoiyazot JSC*
- Stami nitric acid *Stamicarbon*
- Safety of nitric acid and ammonium nitrate plants *KBR*
- Predicting precious metal recoveries from nitric acid plant cleaning *PGM Technologies*

TRACK 3

TUESDAY 7 MARCH

- First commercial references of the new award-winning ammonia synthesis catalyst AmoMax-Casale® *Casale and Clariant*
- Case study: Decreasing energy consumption during turn-around *PT Pupuk Kalimantan Timur*
- Syngas plant feedstock conversion – Utilising alternatives to natural gas *Johnson Matthey*
- LTS catalyst ShiftMax217® has generated significant monetary benefits through increased energy efficiency *Clariant*
- Process integration & optimization of HyCO plant with H_2 purification & CO_2 reforming *Sahara International Petrochemical Company (Sipchem)*
- Seeing inside the box: REFORM CMS innovation in reforming monitoring and optimisation *Johnson Matthey and OnPoint Digital Solutions, LLC*
- MegaZonE™ – First commercial reference of novel methanol synthesis technology *Clariant*
- Creep life assessment of non-standard materials: Reformer tubes and outlet manifolds *Quest Integrity*
- Pressure equipment failures on ammonia and nitric acid plants from stress relaxation cracking *Becht*
- Understanding amine activated hot-pot systems *Optimized Gas Treating*
- Fatima Fertilizer's Plant Site – A Guinness world record holder site in safety *Fatima Fertilizer Company Limited*
- How Enhanced Reality technology speeds up the onboarding of operators and reduces plant downtime related to operational errors *Voovio Technologies SL*

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- Benfield system revamp experience at Yara plant *Kinetics Process Improvements Inc (KPI) and Yara Belle Plaines Inc*
- Lessons learned from restarting a mothballed ammonia plant *Matix Fertilizers*
- Process and efficiency improvement through ammonia front end pressure drop reduction *Engro*
- Experience with repair and replacement of the second ammonia converter (R-0502) in the ammonia plant-1A of Pupuk Kaltim Fertilizer *Pupuk Kaltim*
- Case study: Ammonia converter troubleshooting *Misr fertilizers production Co. (MOPCO)*
- The subsequent effect of leakage found in ammonia converter effluent on ammonia, urea, and utility plant *Petrokimia Gresik and Pupuk Indonesia Holding Company*
- Boosting reliability of ammonia plants by switching outdated 101CA/B and 102C boilers with a proven and reliable design *SCHMIDTSCHE SCHACK | ARVOS and Casale*
- Application of CFD for optimization of waste heat boilers *Steinmüller Engineering GmbH*
- Reducing fired heater CO_2 emissions and fuel consumption *Tube Tech*

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Methane pyrolysis – hope or hype?

Cansu Doganay of Lux Research takes a look at the current technology landscape for methane pyrolysis for producing low-carbon hydrogen from natural gas.


PHOTO: M.M.PHOTO/SHUTTERSTCOCK.COM

The solid carbon byproduct of methane pyrolysis can be sold as carbon black.

Methane pyrolysis – also known as methane cracking or turquoise hydrogen – is the high-temperature breakdown of methane into hydrogen gas and carbon. It competes directly with blue hydrogen – hydrogen from steam methane reforming and carbon capture and sequestration (CCS) – for producing low-carbon hydrogen from natural gas. In methane pyrolysis, all the carbon content in the methane is captured in solid form rather than emitted as CO_2. Methane pyrolysis also requires approximately half the amount of energy required by steam reforming to produce the same amount of hydrogen. Finally, the solid carbon byproduct can be sold as carbon black, offsetting the cost of hydrogen produced. Together, these factors make methane pyrolysis a

Table 1: **Methane pyrolysis technology landscape**

	Plasma	Thermal	Catalytic
Corporates	● Gazprom	● BASF ● Sumitomo Chemical	-
SMEs	● Monolith Materials, ● HiiROC, ● Plenesys, ● SEID AS, ● Graforce GmbH, ● Levidian, ● H-Quest Vanguard	● Ekona Power, ● Aurora Hydrogen, ● Modern Electron, ● Standing Wave Reformers	● Hazer group, ● C Zero, ● Eden Innovations, ● Hycamite
Research institutes	● Centre National de la Recherche Scientifique (CNRS), ● Dalian University of Technology, ● Russian Academy of Sciences, ● Tsinghua University, ● Beijing Jiaotong University, ● Chinese Academy of Sciences, ● National Research Centre Kurchatov Institute, ● Shahid Beheshti University, ● University of Warsaw, ● Zhejiang University.	● Karlsruhe Institute of Technology (KIT), ● Netherlands Organisation for Applied Scientific Research (TNO), ● Academia Sinica Taiwan, ● Aligarh Muslim University, ● Beijing Institute of Technology, ● Chiba Institute of Technology, ● Fritz Haber Institute of the Max Planck Society, ● Pacific Northwest National Laboratory, ● University of Alberta ● United States Department of Energy (DOE)	● Netherlands Organisation for Applied Scientific Research (TNO), ● Russian Academy of Sciences, ● Chinese Academy of Sciences, ● University of California Santa Barbara, ● United States Department of Energy (DOE), ● University of Seoul, ● Ajou University, ● Indian Institute of Technology System (IIT), ● University of Calgary, ● University of Milan.

Source: Lux Research

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promising technology option to produce low-carbon hydrogen.

Methane pyrolysis takes different forms, and they can be categorised as thermal, plasma, and catalytic pyrolysis. Despite the variations, they all share common technical challenges: high process temperatures required for high conversion rates, hydrogen gas purity, and separation of solid carbon from the gas phase to avoid catalyst poisoning (if any) and reactor system blockings.

Plasma: The most mature form of methane pyrolysis utilises a plasma torch to pyrolyze methane gas at temperatures between 1,000°C (cold plasma) and 2,000°C (hot plasma). Cold plasma typically leads to methane conversion of less than 50% with no catalysts, while hot plasma typically results in conversion above 90%. Given the highest technology readiness level among all routes of methane pyrolysis, plasma pyrolysis is the strongest technology route today. The Norwegian company Kværner (now Aker Solutions) deployed the first and only commercial-scale methane pyrolysis facility utilising hot plasma technology in 1997, where the hydrogen produced was recirculated in the plasma torch. The facility was decommissioned in 2003 for underproducing carbon black. Nowadays, Monolith Materials is the leading startup closest to commercialisation. It utilises thermal plasma technology based on Kværner's process and launched its first demonstration facility in the US in 2020, outputting carbon black as the primary product. Other plasma pyrolysis companies include HiiROC (hot plasma) and SEID AS (cold plasma). Gazprom is the only corporation now active in plasma technology for methane pyrolysis – its cold plasma technology is supported by a nickel catalyst to reach methane conversion efficiencies of 80%, but the technology is still at the laboratory scale with no disclosed timelines for commercialisation.

> The misalignment of carbon black and hydrogen market size is still impeding commercialisation.

Thermal: In thermal, or hot, pyrolysis, methane dissociates into hydrogen and carbon at temperatures above 1,200°C with no catalysts. The main downside of this noncatalytic process is the long cracking times below 1,000°C. This technique favours low pressures and high temperatures to achieve the highest conversion rates. At low pressures, however, there is a tendency to produce intermediates, such as olefins and aromatics, which decompose to carbon and hydrogen with increasing residence time. Differentiation revolves around the type of reactor used in the process. BASF utilises an electrically heated moving bed reactor where carbon granules flow counter to the gas phases and methane pyrolyses directly on the granules at 1,400°C. KIT passes methane through a liquid tin bubble column reactor at 1,200°C, where the solid carbon formed floats on the liquid and can be separated through undisclosed means. TNO also uses a molten metal reactor operating above 1,000°C and separates out the carbon black from the liquid metal using a molten salt. Microwave-assisted methane pyrolysis, has recently emerged, bringing a new approach to conventional thermal pyrolysis. Sumitomo Chemical is the only corporate developing a methane pyrolysis technology using microwave energy – currently at lab scale, with commercialisation plans by the early 2030s. Alberta, Canada–based startup Aurora Hydrogen also develops microwave-assisted pyrolysis and raised $10 million to take its technology to pilot scale, targeting 200 kg of hydrogen production per day. Right now, all thermal pyrolysis platforms are at lab scale and aren't likely to reach commercial scale before 2030.

Catalytic: In catalytic pyrolysis, methane breaks down into hydrogen and carbon over a metal catalyst at temperatures between 600°C and 900°C. Packed bed and fluidised bed reactors are typically considered for catalytic pyrolysis, and iron, nickel, and cobalt, which are relatively abundant and cheaper than noble metal catalysts, are the most intensively studied catalysts for this process. While nickel shows the best catalytic activity, it deactivates above 600°C. Cobalt-based catalysts also show decent catalytic performance, but cobalt is more expensive and toxic than a nickel-based catalyst and requires an extra step to purify the carbon black. Iron-based catalysts are cheap, nontoxic metals with a more stable catalytic activity. Even though catalysts lower the activation energy to initiate the process, regeneration and quick deactivation of catalysts at operating temperature are the biggest obstacles to commercialisation of catalytic methane pyrolysis. While the necessity to regenerate could be avoided by using carbonaceous catalysts, their activity significantly drops over time. Catalytic pyrolysis is still at an early stage of development without a clear leader. Hazer Group uses a fluidised bed reactor with an iron ore catalyst, operating at 850°C. It's at pilot scale, with no clear targets for commercialisation. C-Zero is the newest entrant to the methane pyrolysis sector; the company uses a bubble column reactor, operating over 1,000°C, filled with undisclosed molten liquid that acts as both a catalyst and a heat transfer medium to crack methane. The company has recently raised funds to build its first pilot plant with a daily capacity of 400 kg of hydrogen.

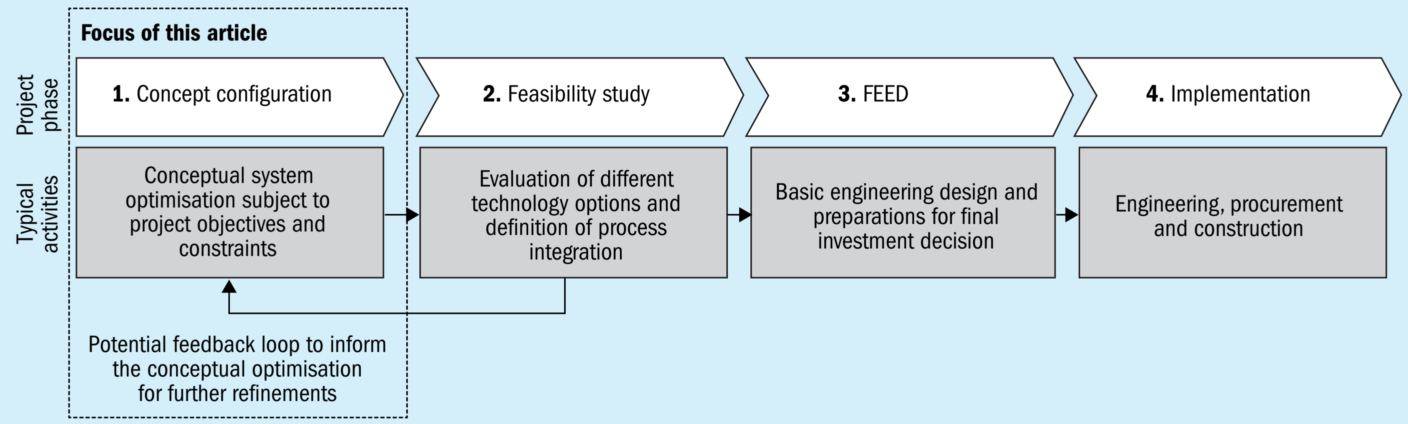
Since Kværner's first commercial facility in 1997, the methane pyrolysis landscape has evolved to include novel approaches by startups with differentiated technologies. These new directions differ by the energy source, heat transfer medium, and/or catalysts. Most recently, Aurora Hydrogen and Sumitomo Chemical have been developing microwave-assisted methane pyrolysis as another means of energy supply and taking this technology to pilot scale. Similarly, C-Zero uses an undisclosed molten liquid as a combination of heat transfer medium and catalyst. It's likely that new startups developing unconventional approaches to methane pyrolysis will emerge as academic projects spin out into companies.

Despite all the companies endeavouring to commercialise their technologies, however, the misalignment of carbon black and hydrogen market size is still impeding commercialisation. The global carbon black market today is estimated at 15 million tonnes/annum – if all of this carbon black were to be supplied by methane pyrolysis, it would correspond to a hydrogen production of 6 million t/a, which is just 8% of the global hydrogen market. Therefore, deploying methane pyrolysis at the global scale will crash the carbon black market and essentially make it worthless. With the new entrants and increasing competition in the methane pyrolysis space, a handful of companies now claim they can compete on cost with blue hydrogen without selling the carbon black. These claims, though, have yet to be proven. ■

Sizing hydrogen storage for green ammonia

Due to the inherent nature of the renewable power, sizing eSyngas plants powered with renewable energy brings complexity normally not faced by natural gas-based facilities. In this article, **Dr Raimon Marin** and **Dr Solomos Georgiou** of AFRY discuss the application of AFRY's state-of-the-art modelling tool to optimise the size and production of a green hydrogen system and a green ammonia plant based on given renewable power profiles and their associated variability (e.g., hourly, daily, seasonally, and annually).

Fig. 1: **Schematic representation of the area of applications of AFRY's model during the project life**



Source: AFRY

Dimensioning power-to-X syngas plants (eSyngas) utilised in the production of e-methanol or green ammonia (i.e., ammonia synthesised from green hydrogen), and powered with renewables (RES) comes with a level of complexity not seen in natural gas fed syngas plants. For example, an off-grid eSyngas plant cannot run at a fixed rate around the clock in the same way as natural gas-fed facilities do. Instead, they are subject to the variations (e.g., hourly, daily, seasonal and annual) imposed by RES. This variability needs to be considered during the sizing of main plant components including RES (considering both solar and wind where appropriate), access to grid (considering any relevant constraints), electrolysers, hydrogen storage, battery storage and the syngas production unit. This creates an optimisation problem that needs to be addressed during the early phases of the project, namely during the conceptual and/or feasibility study. This may need some refinement during later phases of the process, as shown in Fig. 1. Utilising its wide expertise, AFRY offers a project lifecycle solution as a one-stop-shop for clients developing power-to-X projects, from early-phase concept configuration all the way to project implementation.

Electrolytic hydrogen produced with RES (green hydrogen) follows the fluctuations of wind and solar energy, which is a relatively easy match for most electrolysers in the market today (PEM and high-pressure alkaline electrolysis). However, syngas plants traditionally have less flexibility, and this poses a challenge when coupling them with electrolysers. To overcome this challenge balancing solutions will likely be needed. These solutions can include the following:

- electricity storage with batteries
- improved dynamics of syngas plants
- use of hydrogen storage and/or
- access to green electricity via power purchase agreements (PPA).

Typically, utilising batteries as electricity storage is a capital-intensive solution which is mostly viable for short duration storage back up. World leading syngas licensors are currently developing ammonia and methanol technologies, which are able to adapt to the variability of renewables[1]. However, even in situations where large facilities can be operated at very low turndown ratios, (e.g., low turndown ratio 10%), with production rate variations in the range of %/min, some hydrogen storage solution may still be desirable to smooth out the operations of the facility.

Bulk hydrogen storage can be done either in liquid or gaseous state. Liquid hydrogen storage has been realised at large scale[2]. However, it is an energy intensive approach which uses up to 30% of the hydrogen stored as energy input, therefore coming with a very high cost. Gaseous state storage has been engineered and deployed for some significant sizes[3, 4]. While storing hydrogen in its gaseous state is less costly than storing it in liquid state, sizing and optimising the gaseous state storage to secure smooth and steady plant operation is paramount for the techno-economic soundness of any project.

AFRY has developed a proprietary model that can be used to optimise the size of the storage, the other key components in a hydrogen production system (e.g., solar and/or wind capacity, electrolyser capacity, access to grid where relevant) and subsequently the syngas plant capacity. But how can this model be used in practice to successfully size and optimise a hydrogen production system relying on a renewable energy profile and the capacity of an e-syngas facility?

Model description

AFRY's proprietary model helps to achieve an optimised system setup and performs various assessments at a plant/project level. The model is based on a cost optimisation challenge with the ability to optimally size and dispatch electrolytic hydrogen production systems. It is able to optimise the lowest levelised cost of production of hydrogen (LCOH) or the lowest "missing money" which can represent the gap to financial viability. It is also able to utilise high resolution data (e.g., hourly), spanning the lifetime of the system and takes advantage of AFRY's state-of-the art power market projections for reliable power cost/revenue stream potential when there is access to the power market.

The model incorporates both technical and financial characteristics of the project in its optimisation. It ensures that demand is not only met but also that it is carried out in the most financially efficient way.

As renewable resource availability can vary within a year as well as across years, AFRY's model has been developed to capture the weather variability/risk and optimise based on different weather patterns; both in terms of ensuring security of hydrogen supply and sizing the system cost-optimally.

The versatility of the model allows the impact of numerous aspects such as location, demand constraints, access to grid, costs, available revenue streams, policies such as temporal correlation, power purchase agreements (PPAs) and more to be assessed. Different project configurations can be modelled including, for example, off-grid systems with co-located RES, grid connected systems with renewable power through PPAs, grid connected systems with access to the power market as well as systems predominantly utilising otherwise curtailed renewable power.

Additionally, as the model is targeted at optimising the system at plant level, some of the system components can be defined when they are known or fixed. Constraints that serve to limit the capacity of some components can also be enforced when needed. In this way, the system can be optimised in terms of both sizing and dispatch subject to any project specific parameters and/or constraints.

In terms of outputs yielded by the model, both physical and financial outputs can be obtained. Both of these output categories can then be obtained at different temporal resolutions, spanning from a system's lifetime down to even hourly variations depending on the output and/or the user's preference. Typical physical outputs include, for example, optimal capacities of components, hydrogen offtake demand (or green ammonia demand), hydrogen production, hydrogen storage level, injections and withdrawals from hydrogen storage, battery level, battery flows, power exports to the grid, power imports from the grid, and more. Common financial outputs include LCOH and its breakdown into the different cost elements, annual cash flows, missing money, revenues from power sales to grid, and more.

AFRY analysed three case studies to illustrate the capabilities of AFRY's model. These case studies utilise different approaches to meet the same annual ammonia production target whilst also overcoming the same challenge: sizing an off-grid hydrogen production plant and ammonia plant for the given RES profile. For simplification, the LCOH has been taken as a proxy for the ammonia production cost, as it is highly likely for LCOH to be the main contributor to the green ammonia production cost. Note that for simplicity, any power required by the ammonia plant is not considered as part of these case studies and is assumed to be sourced independently. For these case studies, RES representing the Netherlands are used to show the relative differences between all the results; therefore all results presents have been normalised.

Case study 1: Flat profile demand

This case study assessed the hydrogen storage size for the selected renewable profile, with no power curtailment for an assumed 50/50 split between solar and wind, and with ammonia plant operation at a flat 100% throughput, similar to how traditional syngas facilities would operate around the year.

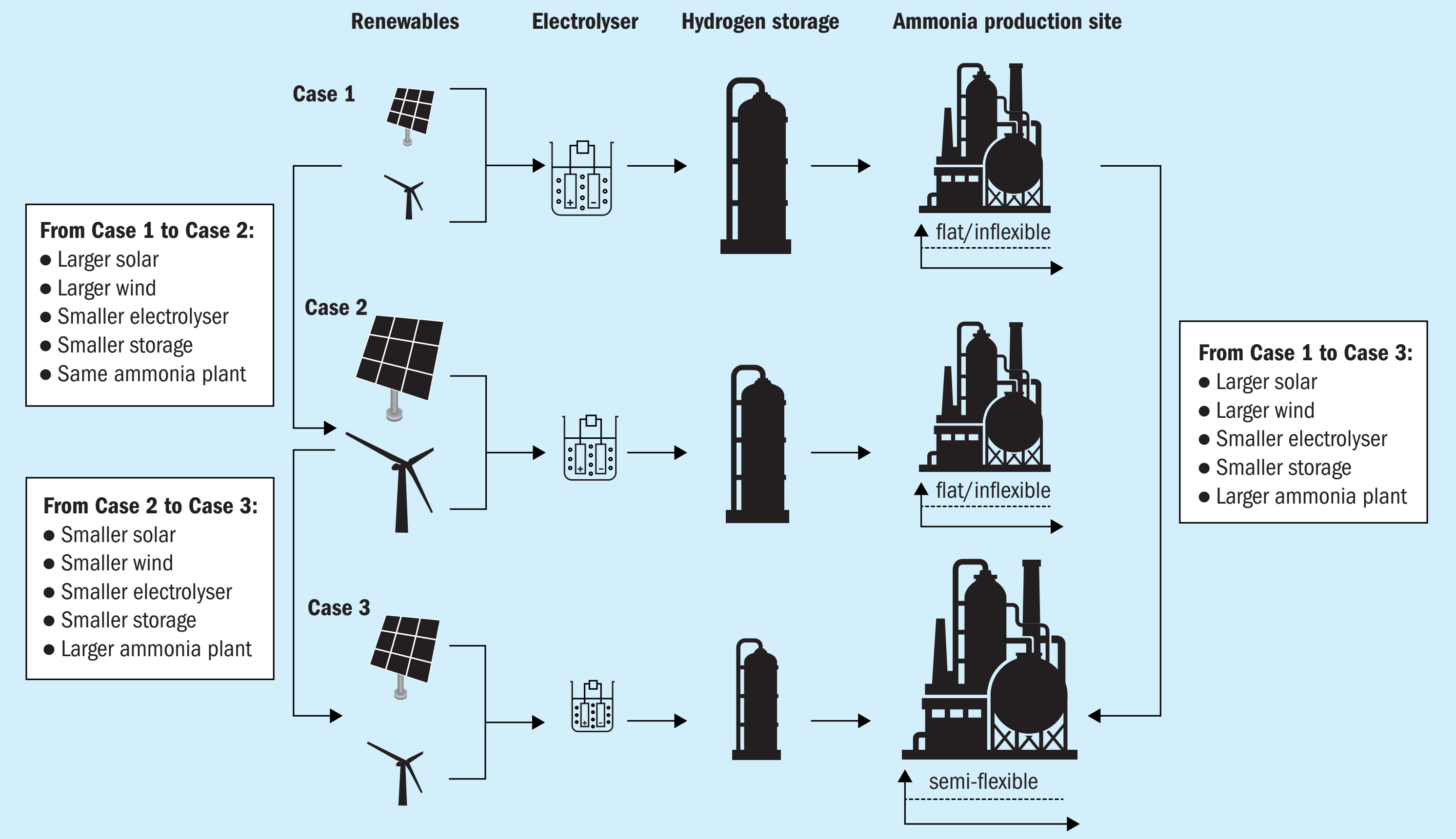
Case study 2: Asset optimisation for a flat profile demand

In this case study, the renewable capacity (wind and solar) is optimised along with the electrolyser capacity and hydrogen storage for a set annual ammonia production with a non-flexible hydrogen demand. In other words, the hydrogen production plant is optimised to ensure a steady supply of hydrogen, which the ammonia plant needs to operate rigidly at its desired capacity.

Case study 3: System optimisation – assets and hydrogen demand

In this case study, a holistic approach was taken to optimise the plant's overall operations, including renewable capacity (wind and solar), electrolyser capacity, hydrogen storage and green ammonia's annual production with semi-flexible hydrogen demand; thus, assuming that ammonia can be produced semi-flexibly. In this case, the renewable energy supply, electrolyser capacity and hydrogen storage must adapt to the turndown ratio set for the ammonia facility, which is set at 40%. The frequency at which the plant rate is changed to adapt to the RES available was also set to three days. This means that when the operators change the plant throughput it will remain at the same level over the course of three days before a throughput modification is allowed again even in situations where the hydrogen production goes below 40% of its nominal capacity due to the lack of RES. Should this happen, hydrogen from storage is withdrawn to sustain ammonia production. The three-day constraint is arbitrary and can be modified. The operator of the facility must define the operational philosophy for each particular project.

Fig. 2: **Summary of case studies and their optimised component capacities***



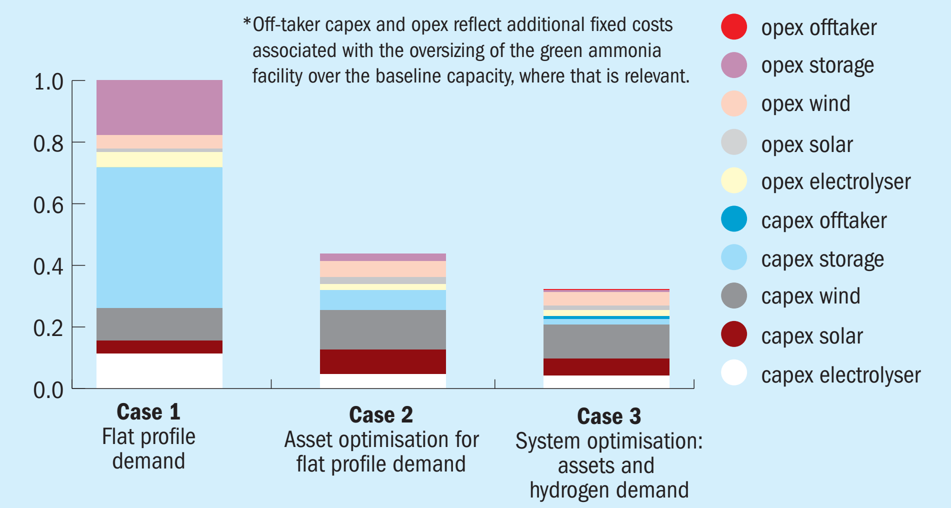
** Size of the icons is indicative of their relative capacity between the cases (relative differences in size of icons not to scale).*

Source: AFRY

Comments and discussion

Fig. 2 summarises the three case studies considered and their corresponding optimal configurations. The icons in Fig. 2, from left to right, represent renewables, electrolysers, hydrogen storage and ammonia production site, while the size of the icons are indicative of the relative capacity between the cases. As can be seen, optimising both capacities and ammonia production can result in a significantly different project setup. The most significant benefits can be observed when comparing the non-optimised case 1 to any of the other two cases. Nevertheless, all hydrogen supply system components can potentially be downsized by adding some flexibility to hydrogen offtake and optimising the ammonia capacity and production profile.

Fig. 3: **Normalised breakdown contribution to the ammonia factored LCOH***



Source: AFRY

The next step is to observe the contribution that capex and opex have on the ammonia factored LCOH, including key components of a renewable hydrogen production plant and any additional fixed costs associated with the oversizing of the green ammonia facility over the baseline capacity, where that is relevant. Fig. 3 shows that in case 1 (non-optimised scenario), storage costs largely overtake any other cost. By optimising the facility, like in cases 2 and 3, the storage contribution is reduced to a marginal contribution to the overall ammonia factored LCOH. For cases 2 and 3 renewables serve as the main contributors to the LCOH. In case 3, optimising the ammonia production reduces the LCOH by more than 25% compared to case 2, with all the common components between the two cases showing a decrease. It is worth noting that the overall LCOH drop in case 3 is achieved despite the additional fixed costs associated with the larger ammonia plant. This shows how having the appropriate conceptual design for a plant at the early stages of a project delivers a competitive and

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Table 1: **Key indicators for the three case studies considered**

	Case 1	Case 2	Case 3
Electrolyser capacity	1.00	0.40	0.37
Hydrogen storage capacity	1.00	0.14	0.04
LCOH (NH_3 factored)	1.00	0.44	0.32
Ammonia production capacity	1.00	1.00	1.32
Ammonia production	1.00	1.00	1.00

Note: Indicators are normalised to the maximum corresponding value of the three case studies.
Source: AFRY

sound techno-economical approach to deploying a green ammonia facility.

Table 1 compares the electrolyser, storage capacities and ammonia production between the different case studies. The electrolyser capacity, a key capex syngas plant driver, is largely reduced in cases 2 and 3. However, small differences between the last two cases are seen in the form of optimised electrolyser capacity. The significant difference, however, is in the storage size. The holistic approach of optimising the ammonia production capacity yields a much smaller storage capacity compared to both cases 1 and 2. Not only does this improve the cost of production of the ammonia factored LCOH, but it can also facilitate the deployment of the storage, considering that scaling up these facilities can prove difficult.

The deployment of the hydrogen storage facilitates the smooth operation of the green ammonia plant within the operational constraints. In case 3, the plant is oversized by about 30% to meet the annual production of ammonia. This means that for a targeted annual production of 100 ktpa, the nameplate capacity of the ammonia plant would be 130 ktpa. Note that currently, and probably for the foreseeable future, the capex of green hydrogen production systems will remain relatively higher than those for ammonia synthesis plants. Hence, oversizing the later with respect to the former could make sense, depending of course on other factors such as the cost of hydrogen storage and RES generation profiles. Furthermore, oversizing the ammonia capacity allows the operator to take advantage of favourable weather conditions to produce surplus ammonia, providing the supply chain is able to cope with temporal ammonia overproduction. To illustrate this, Fig. 4 shows a sample snapshot of the hydrogen resource-based production profile and the ammonia production profile for case study 3.

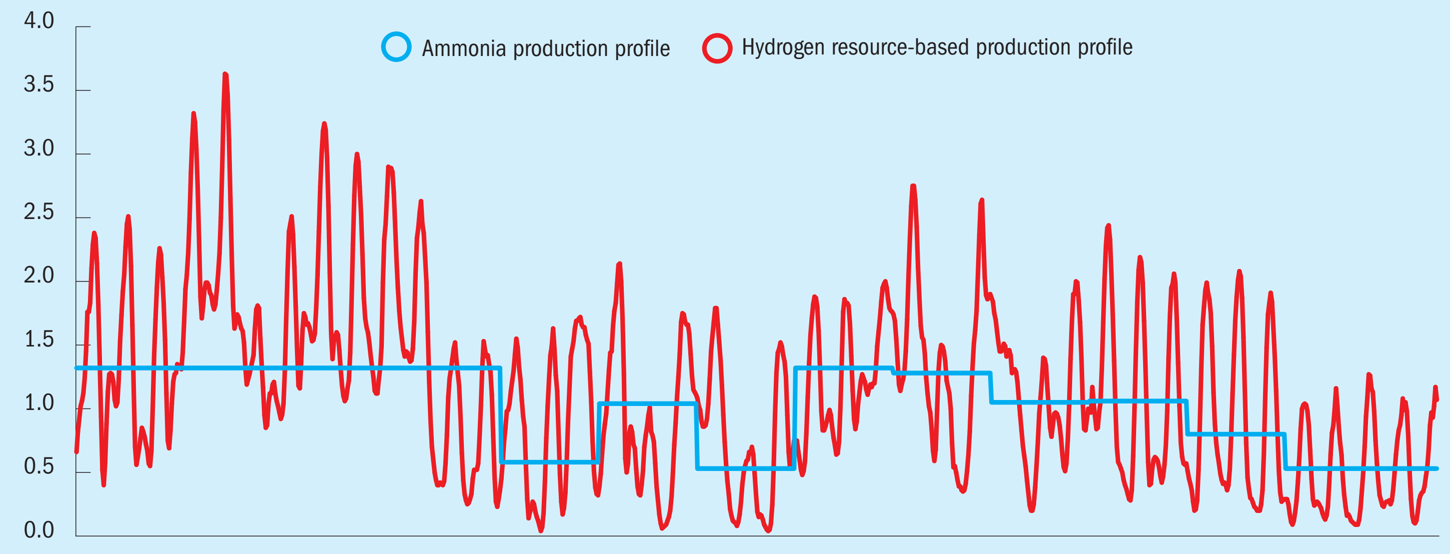
Grid-connected hydrogen production plants

Grid-connected hydrogen production plants can be built in areas where the infrastructure allows it. In such cases, green PPAs could be used to secure renewable energy to produce green hydrogen and thereafter ammonia. In case of grid-connected plants, bulk hydrogen storage is likely to be needed depending on the PPA energy volumes and temporal correlations requirements, such as the green ammonia plant's capacity to operate in hot idling mode. AFRY's model also incorporates features to consider PPAs to size the overall complex in a similar way described in the previous case studies. In such cases, PPA prices can be varied on a yearly basis as well as within the year if a profile is applied.

Temporal correlation requirements

Temporal correlation, in this case the correlation between renewable energy production and consumption, is a legal imperative for labelling hydrogen as green in some regions such the EU. At the time of writing, it is still unclear what the temporal correlation requirements will be for green hydrogen. This represents a possible source of uncertainty for stakeholders interested

Fig. 4: **Normalised hydrogen resource-based production profile and normalised ammonia production profile for a generic RES profile from The Netherlands over a period of 42 days**



Source: AFRY

in the deployment of green hydrogen production. Although initial EU policies have indicated the possibility for an hourly temporal correlation requirement (i.e., every hour of green hydrogen production should match the hour of renewable generation), it is possible that this requirement could be mitigated (e.g., to a monthly, quarterly or any other time interval). AFRY's model incorporates this temporal correlation feature, hence allowing the scrutinization of its implications in terms of ammonia factored LCOH. Table 2 illustrates some representative results of the impact of the temporal correlation, which apply to case study 3 outlined previously. As expected, the hourly correlation imposes a very strict scenario that could have a detrimental impact on the cost competitiveness of green ammonia, whereas a more relaxed correlation (e.g., monthly, or quarterly) could significantly improve its cost competitiveness. It is worth mentioning that the values tabulated in Table 2 are highly dependent on the conditions and parameters selected.

Table 2: **Normalised ammonia factored LCOH and hydrogen storage contribution to LCOH at different temporal correlations scenarios**

Temporal correlation	Normalised ammonia factored LCOH	Hydrogen storage contribution to LCOH
Hourly	1.00	7.7%
Monthly	0.83	0.8%
Quarterly	0.79	0.6%

Source: AFRY

Conclusions

Having a holistic approach to the definition of the plant size is critical for the financial success of any Power-to-X project.

For any given location, the ideal scenario for sizing the production capacity (i.e., plant capacity) should be taken into consideration for all assets involved, from renewable assets and/or grid connection options, to the process operating units (e.g., electrolysers, storage, syngas facility…).

Besides the renewable asset (i.e., wind/solar assets), hydrogen storage can play a large role in the capex of the project, hence careful sizing shall be considered. ■

References

1. www.stateofgreen.com/en/solutions/reddap-the-worlds-first-dynamic-green-ammonia-plant/
2. www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/022322-worlds-largest-liquid-hydrogen-storage-sphere-nears-completion-for-nasa
3. www.iberdrola.com/press-room/news/detail/storage-tanks-green-hydrogen-puertollano
4. www.hybritdevelopment.se/en/a-fossil-free-development/hydrogen-storage/

Advanced Methanol Amsterdam

Advanced Methanol Amsterdam (AMA) is a production facility, that will be realised in the Port of Amsterdam's Biopark, which is destined to produce advanced methanol that meets the European renewable energy directive (RED) requirements. Once completed, AMA will be the flagship production site for GIDynamics and GIDARA Energy and for its High Temperature Winkler (HTW®) gasification technology. AMA will also be the first of its kind green methanol unit designed by Casale.

Isabella Muscionico, Pietro Moreo (Casale SA) and Dennis Chafiâ, Nivya Uday Kodimaniyanda, Niek De Nooijer (GIDynamics).

Casale has been active for several years in the development and optimisation of sustainable technologies to be applied in the production of both ammonia and methanol, which are two of the most energy intensive chemical products, responsible for the emission of large quantities of CO_2.

There are essentially two routes to reduce the carbon footprint: the first is to capture and sequestrate the CO_2 after its generation, resulting in so-called "blue" products; the second is to totally avoid the CO_2 generation and emissions by the use of renewable energy and feedstocks which results in "green" products.

These routes have led to the development of Casale Flexiblue and Flexigreen baskets which include schemes for the eco-friendly production of ammonia, hydrogen and methanol.

Although the biomass gasification route leads to a plant which is similar to a coal gasification plant, of which Casale has almost 20 references in China, the Flexigreen methanol scheme has been developed to meet to the challenges of the renewable methanol market.

"Green" methanol can be produced using renewable energy and renewable feedstocks via two routes:

- Bio-methanol is produced from sustainable biomass which includes forestry and agricultural waste and byproducts, biogas from landfill, sewage, municipal solid waste (MSW) and black liquor from the pulp and paper industry.
- E-methanol is obtained by using CO_2 captured from flue gases or direct air capture and green hydrogen, i.e., hydrogen produced with renewable electricity.

Methanol is a key product in chemical industry: it is one of the four bulk chemicals (alongside ethylene, propylene and ammonia) used for producing all other chemical products and it is used as fuel (either by itself or as a blend with gasoline, or for the production of biodiesel, or in the form of MTBE as well as DME).

Nowadays, more than 99% of methanol is produced from fossil fuels and its production is responsible for 10% of the CO_2 emissions from the whole of the chemical and petrochemical industries.

Based on current forecasts, the production of methanol will increase by 20% by 2025/2030. It is in this scenario, with these environmental constraints, that the green methanol market will become increasingly popular.

The production of renewable methanol is being boosted by the recent COP26 inputs to mitigate climate change by substantially reducing or eliminating CO_2 emissions: green methanol could be a key item in decarbonisation strategy, particularly as a feedstock in the chemical industry or as a fuel in road or marine transport.

The main obstacle to green methanol uptake is its higher cost compared to fossil fuel-based production, and that cost differential will persist in the recent future. The implementation of several policy interventions could reduce costs mainly addressing process differences and facilitating the scale-up of production and use. With the right support mechanisms, and with the best production conditions, renewable methanol could approach the current cost and price of methanol from fossil fuels.

Currently, in the Netherlands, around 20% of the waste is not recycled. The HTW gasification technology has been modified and employed to utilise this waste to produce syngas and thereafter biomethanol with the use of Casale's Flexigreen methanol scheme.

GIDARA Energy B.V. is focused on converting non-recyclable waste into advanced biofuels by using the patented High Temperature Winkler (HTW®) technology, acquired by GIDARA Energy B.V in 2019. The technology can be utilised to produce valuable products such as advanced biofuels for use in the road transport, marine and aviation sectors, helping these sectors to reduce their carbon emissions and become more sustainable.

The flagship Advanced Methanol Amsterdam facility will produce approximately 90,000 tonnes of advanced methanol per year by converting local non-recyclable waste equivalent to that of 290,000 households annually, which would otherwise be landfilled or incinerated. The advanced methanol meets governmental objectives to achieve CO_2 emission reductions as defined in the European and national frameworks. The produced renewable fuel will replace fossil fuels, creating significant carbon savings. The objective is to meet the demand for cleaner fuels, reduce global carbon emissions and create a more

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circular economy, with more advanced biofuel and biochemical facilities to come.

Gasification and gas treatment

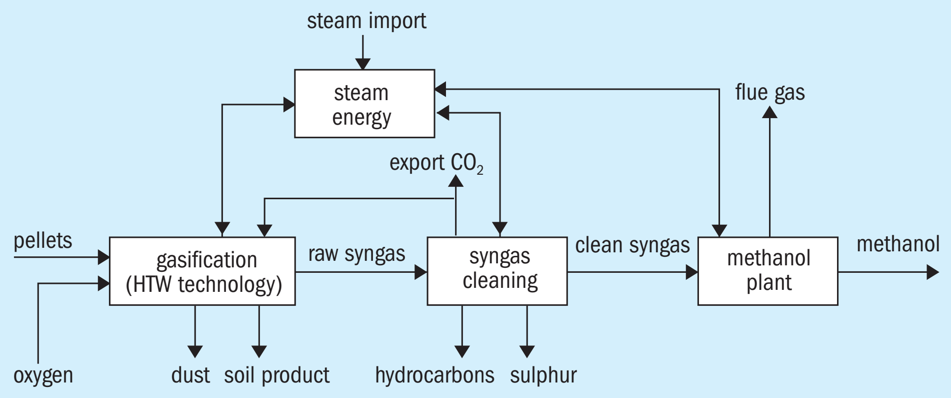
The methanol produced in the Advanced Methanol Amsterdam facility is based on the thermochemical conversion of carbonaceous feedstock, more specifically RDF and biomass waste material. The whole process can divided into three main process blocks. The first step is thermochemical biomass conversion using the High Temperature Winkler (HTW®) gasification technology to produce raw synthesis gas. In the second step the raw syngas is subjected to gas treatment, whereby the raw syngas is adjusted and cleaned, and the capture of CO_2 takes place. The clean syngas is then introduced to the methanol production unit where it is converted to methanol (Fig. 1).

State-of-the-art HTW® gasification technology

The HTW technology was originally developed for lignite feedstock in the 1920s by Rheinbraun AG in Germany. It was further developed in the 1970s by thyssenKrupp Industrial Solutions, together with Rheinbraun AG (now RWE AG) into a pressurised version of the Winkler gasifier which resulted in improvements that led to an increase in the carbon conversion efficiency thereby enhancing the quality of the produced syngas. In the 1990s the application of this technology towards bio-application began to be investigated. In 2010, the technology was acquired by thyssenKrupp Uhde and thereafter, by GIDARA Energy B.V., in 2019. Technology developments continued resulting in today's state-of-the-art HTW® gasification technology employed in the Advanced Methanol project which has the following key improved features:

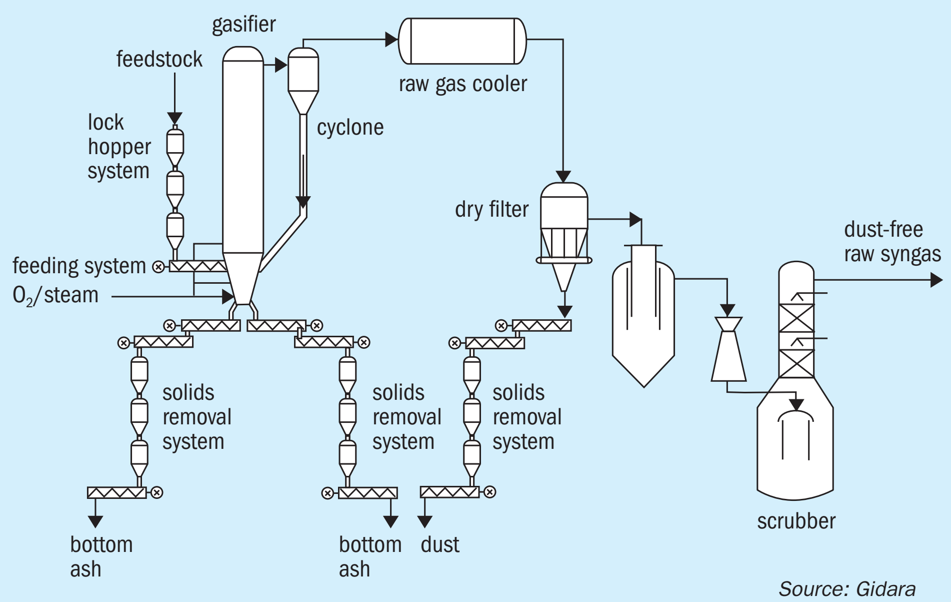
- multi-media injecting nozzles along the height of the gasifier to provide subzonal-reaction spaces, targeting different reaction mechanisms;
- spiral flow pattern in the freeboard zone which results in achieving optimum reforming and tar-cracking reaction rates, thereby producing a tar-free brand of raw syngas;
- handling a wide variety of feedstocks comprising lignite, coal, peat, biomass, MSW, RDF, SRF, high plastic content waste, sewage sludge, etc.;
- provision of a quench system at the top of the gasifier which allows the exploration of higher temperature in the freeboard zone, assisting the production of the tar-free brand of raw syngas;
- smoothens the thermal stress effect on different location of gasifier pressure vessels while operating at different temperature ranges in the fluidised bed and free board zones.

Fig. 1: **AMA facility – block flow diagram**



Source: Gidara

Fig. 2: **AMA gasification unit**



Source: Gidara

AMA gasification unit

The gasification unit (Fig. 2) converts pelletised feed material (PFM) by means of thermochemical conversion (gasification) under pressurised conditions with the aid of oxygen, steam and CO_2 into raw syngas. The raw syngas is dedusted and chlorine components removed.

Pellet storage

The feed material (PFM) enters the facility at the pellet storage/handling area. The area provides a storage buffer for the PFM. From here, the PFM is distributed and transported to the feeding system at the top of the gasification unit where it is fed into two feeding trains of the gasifier.

Feeding system

The feeding system includes two identical feeding trains, each able to handle 60% of the gasifier capacity. In the feeding system the pressure of the PFM fed to the gasifier is increased from ambient pressure to gasification pressure. This pressurisation is achieved using CO_2 in a lock hopper system, leading to a charge bin again at pressurised conditions. This ensures leak-tight feeding of the PFM at the required pressure, to the gasifier. The feedstock is fed to the gasifier by means of cooled feeding screws.

HTW gasifier and raw gas cooling

In the gasifier, gasification takes place in a fluidised bed at a pressure of 15 bara, converting the feedstock material into syngas, bottom product, and dust. The conversion takes place by non-catalytic gasification reactions.

Overall, this set of reactions is endothermic and receives its heat from the partial oxidation of the feedstock and syngas by pure oxygen which is fed to the gasifier. Steam and CO_2 are added to control the equilibrium and produce the required syngas composition.

The gasifier comprises two main zones, the gasification and post gasification zones. Oxygen, steam, and CO_2 are supplied as gasification agents to the gasifier at a controlled flowrate through single or specialised multilayered nozzles. The gasification zone of the gasifier is a fluidised bed located in the conical part of the reactor. The fluidised bed is made up of solid remnants of the gasified PFM, also referred to as the bed material. This zone is operated under controlled conditions wherein temperature and the concentration of gasification agents are adjusted to enhance the conversion of the feedstock material towards gas components and fly-char. The converted material from the gasification zone enters the post-gasification zone, where the temperature is adjusted through a controlled supply of oxygen and steam. Here, the carbon content in the fly-char (entrained dust) is further converted in the presence of steam to produce carbon monoxide and hydrogen. In parallel, the intermediate hydrocarbon content of the raw gas undergoes steam cracking, thereby achieving a high carbon conversion efficiency. The high temperature condition in the post-gasification zone provides even further decomposition of intermediate hydrocarbons and tars.

The individual conversion reactions between the reagents are very complex. In simplified form, the reactions taking place in the gasifier can be summarised by the following basic equations:

$$C + O_2 \rightarrow CO_2 \quad \Delta HR = -393.6 \text{ kJ/mol}$$

$$C + \tfrac{1}{2}O_2 \rightarrow CO \quad \Delta HR = -123.1 \text{ kJ/mol}$$

$$C + H_2O \rightarrow CO + H_2 \quad \Delta HR = +118.5 \text{ kJ/mol}$$

$$C + CO_2 \rightarrow 2CO \quad \Delta HR = +159.9 \text{ kJ/mol}$$

$$C + 2H_2 \rightarrow CH_4 \quad \Delta HR = -79.4 \text{ kJ/mol}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad \Delta HR = -41.1 \text{ kJ/mol}$$

The raw syngas which leaves the gasifier at the top contains a considerable amount of entrained particles. The major portion of these particles is separated from raw syngas in the raw gas cyclone and returned into the fluidised bed zone of the gasifier through recirculation line.

The raw syngas leaving the HTW gasifier has at a high temperature and thus needs to be cooled to a temperature that it is more suitable for the subsequent process steps. This is done in a raw gas cooler, generating saturated high-pressure steam and cooled raw syngas.

Bottom product removal

Most of the carbon present in the feedstock material is converted together with oxygen and steam into raw syngas during the gasification in the fluidised bed, leaving the gasifier at the top to be further processed. The remaining nonconverted carbon material along with other inorganic solid components accumulate as ash at the bottom of the gasifier as the bottom product. This is withdrawn using cooled screw conveyors and guarantees the stable state of the fluidised bed. The screw conveyors cool and transport the bottom product to lock hoppers wherein the bottom product is depressurised with the help of CO_2 to ensure no syngas can escape with the bottom product. The bottom product is then pneumatically conveyed to storage silos where it is stored under inert gas conditions until it can be collected for transport.

Dry dust removal

The fine dust particles passing with the raw syngas through the gasifier cyclone must be removed in the dry dust filter to avoid plugging of the downstream processing equipment. To remove the dust a ceramic filter is used that gives a very high removal efficiency of the dust from the raw syngas. The dust is removed from the filters by pulses of CO_2 and collected at the bottom of the filter, from where it is removed in the same way as the bottom product, using cooled screw conveyors and a lock hopper system to depressurise the dust. After depressurisation dust is pneumatically conveyed to storage silos where it is stored under inert gas conditions until it can be collected for transport.

Quench and scrubbing

The purpose of the syngas quench and scrubbing is to remove the corrosive component hydrogen chloride, and partly wash out ammonia, HCN and any residual dust by wet scrubbing and to saturate the raw syngas with water. To achieve this, the raw syngas is washed with water. The raw syngas, already de-dusted in the upstream hot gas filter unit is quenched with water and thus saturated in the immersion cooler. Subsequently, the quenched gas enters the raw gas scrubber. Surplus water is separated in the lower part of the scrubber. Packing elements and clean water on the top of the scrubber support the removal of the above-mentioned substances. The acidity of the process water system is adjusted by feeding caustic soda. The raw syngas leaves the raw gas scrubber at the top of the scrubber and is passed to the downstream gas treatment unit. Surplus water from the system is released as wastewater by level control from the immersion cooler to the wastewater treatment area.

AMA gas treatment

In the gas treatment section, the raw syngas is adjusted to the required compositions and cleaned to remove impurities producing clean syngas, before it is introduced to the methanol production unit. It is critical for the methanol production to receive the syngas at the right composition. Also, the removal of the impurities is important as they can poison the catalyst used in the methanol synthesis The gas treatment unit consists of four process areas, namely, raw syngas adjustment, acid gas removal, sulphur removal and CO_2 polishing.

Raw syngas adjustment

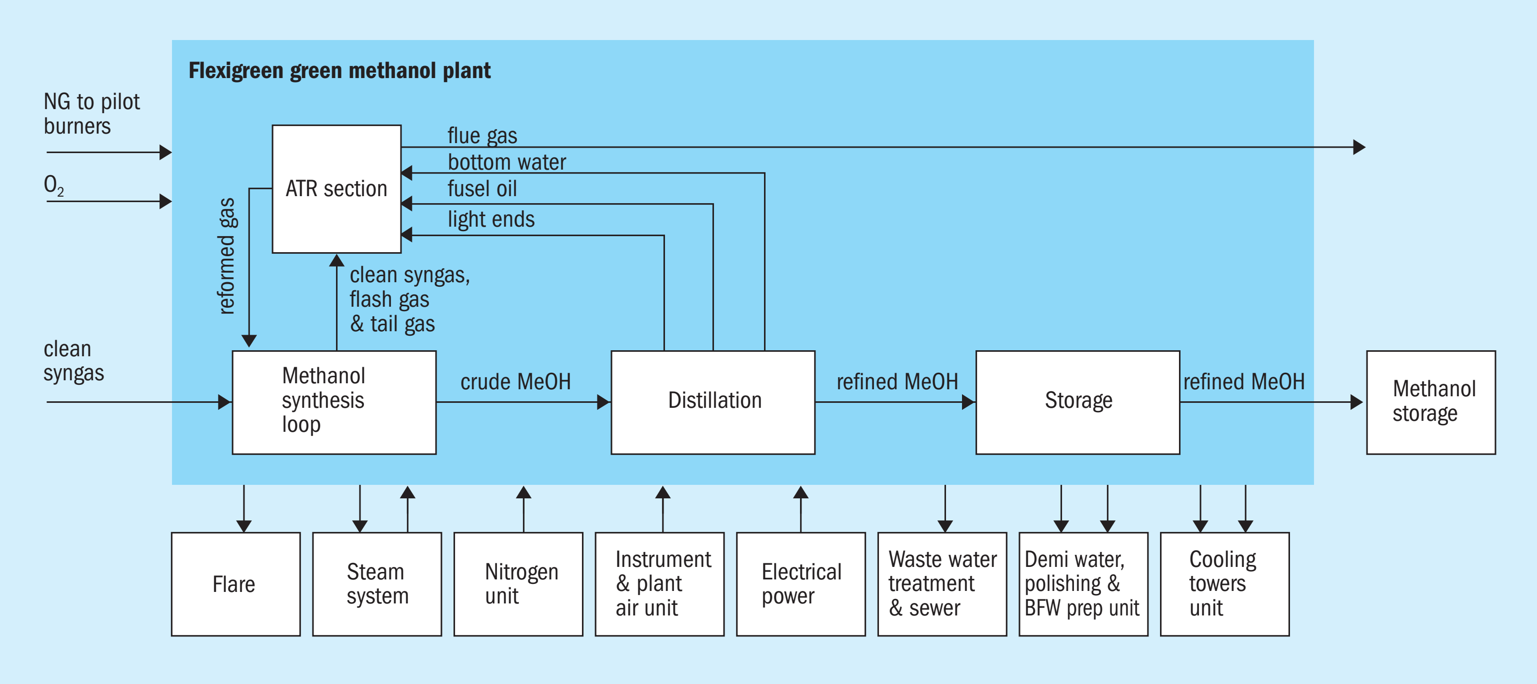
The objective here is to process the raw syngas from the gasification unit and to produce adjusted syngas. The raw syngas adjustment area consists of the following process sections:

- CO shift conversion over a catalyst to adjust the CO and H_2 ratio achieving one required for the downstream methanol unit;
- HCN and COS hydrolysis to convert the HCN and COS to NH_3 and H_2S, respectively, over a catalyst bed;
- heat recovery;
- compression.

Raw syngas adjustment produces:

- adjusted syngas, the outlet stream from the compressor, which will be further processed in the downstream acid gas removal;
- process condensate by-product is sent to wastewater treatment.

Fig. 3: **Block flow diagram of green methanol plant**



Source: Casale

Acid gas removal

The technology used for acid gas removal is Linde's Rectisol wash unit (RWU) for treatment of a partly shifted gas. Here, a physical wash agent is utilised to remove contaminants such as H_2S, COS, HCN, and higher hydrocarbons as well as bulk CO_2 removal from the adjusted syngas feed down to the required specifications for methanol unit. The lean wash agent facilitates simultaneous "washing out" and absorption of the abovementioned impurities. Loaded wash agent is then regenerated and recycled back with any losses being compensated via make-up.

Acid gas removal produces:

- purified syngas, free of H_2S/COS and with a minimal concentration of CO_2, suitable for methanol synthesis;
- acid gas by-product, consisting mainly of CO_2 and H_2S, which will be further treated to produce clean CO_2 product.
- hydrocarbon by-product, consisting of benzene and naphthalene.

Casale methanol process

Casale has implemented the most appropriate customisation of the Flexigreen methanol standard scheme to design the methanol generation sections for AMA project.

Units involved in Casale scope are: the synthesis loop, the autothermal reformer (ATR) section, the distillation section and the crude and refined methanol daily storage section.

Fig. 3 shows a block flow diagram of the green methanol plant.

Casale methanol process main sections

Methanol synthesis loop

The aim of the methanol synthesis loop section is to convert synthesis gas into methanol.

Overall, the synthesis loop (Fig. 4) is very simple notwithstanding it is very efficient and the heat integration with the distillation section plays a key role: there are only eight main items of equipment.

The make-up gas from upstream units mixed with the hydrogen-rich streams from the hydrogen recovery unit (HRU) and the ATR section, after compression in a dedicated compressor, is sent to a catalyst guard bed where sulphur compounds, still present in the make-up gas from upstream units, are removed. The aim of the guard bed is to reduce the total sulphur concentration in the gas after desulphurisation catalyst adsorption below 0.02 ppm vol.

The compressed stream is mixed with the recycle gases at the discharge of the circulator and routed to the gas-gas heat exchanger where it is heated up to converter inlet temperature using the heat of synthesis converter effluent product.

The feed gas enters the converter (an Isothermal Methanol Converter, IMC) and directly flows to the catalyst isothermal zone, where the methanol synthesis reaction takes place. As the gas crosses the isothermal zone, the reaction proceeds while the temperature is kept almost constant by releasing the reaction heat to the plates, wherein medium pressure steam is raised. The plates inside the converter act as a boiler with forced circulation.

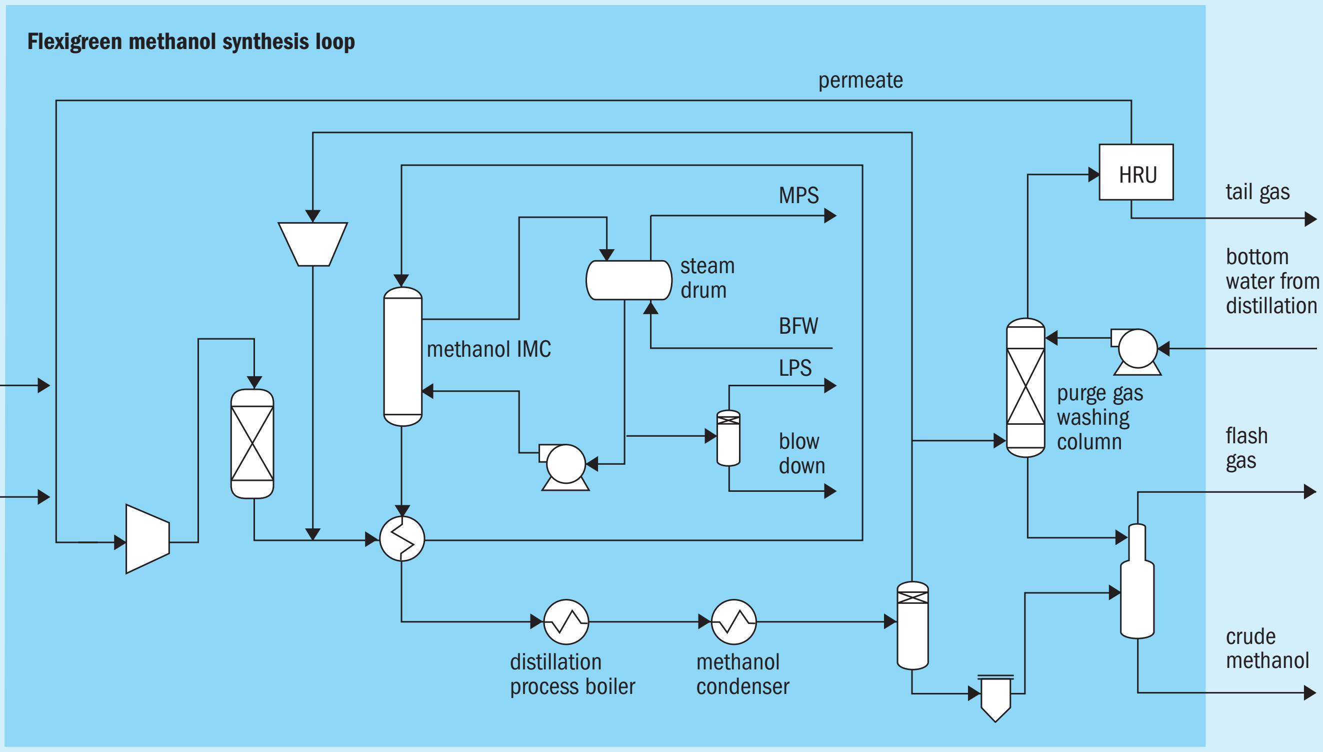
The converter outlet gas is first routed to the gas/gas heat exchanger, then to the topping column gas heated reboiler and finally to the trim condensers where the final condensing temperature is reached.

Crude methanol is separated in the high-pressure separator, then let down to low pressure in the low-pressure separator where dissolved vapours are washed counter currently by a mixture of water and methanol from the purge gas washing column. Gases from the low-pressure separator (flash gas) are sent, as fuel, to the ATR section, while the crude methanol is sent directly to the distillation section.

From the top of high-pressure separator, the vapours containing non-converted reactants are mainly recycled back to the synthesis loop through the syngas compressor circulator. A stream of purge gas is removed from the recycle gas in order to control syn-loop inerts level and is routed to the purge gas washing column, where it is washed by a portion of bottom water from the distillation section to recover the produced methanol. Washed purge gas from the top of the column is sent to the HRU unit to recover as much hydrogen as possible. Recovered hydrogen is recycled back to the synthesis gas compressor suction while the tail gas from HRU unit is sent, as feed, to the ATR section.

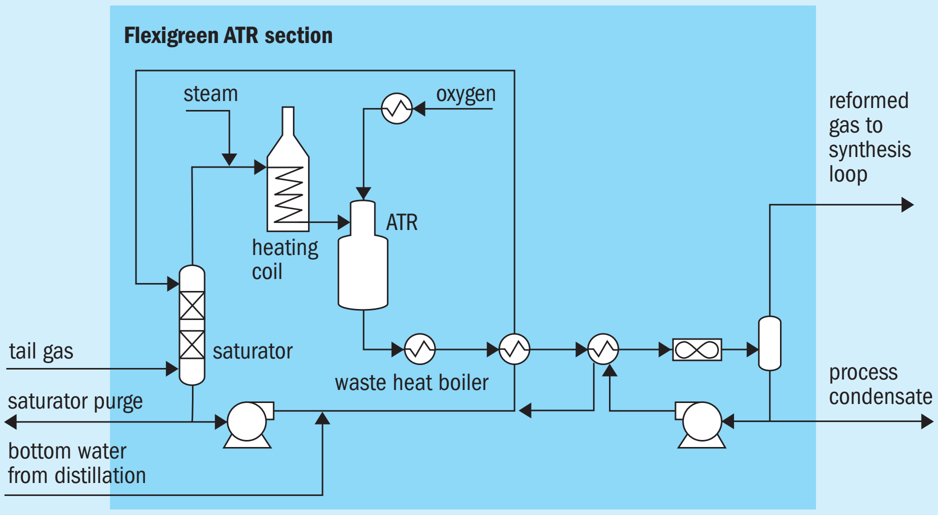
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56

Fig. 4: **Methanol synthesis loop**



Source: Casale

Fig. 5: **ATR section**



Source: Casale

ATR section

The purpose of the ATR section (Fig. 5) is to convert the methane present in the tail gas from the HRU into synthesis gas via steam reforming.

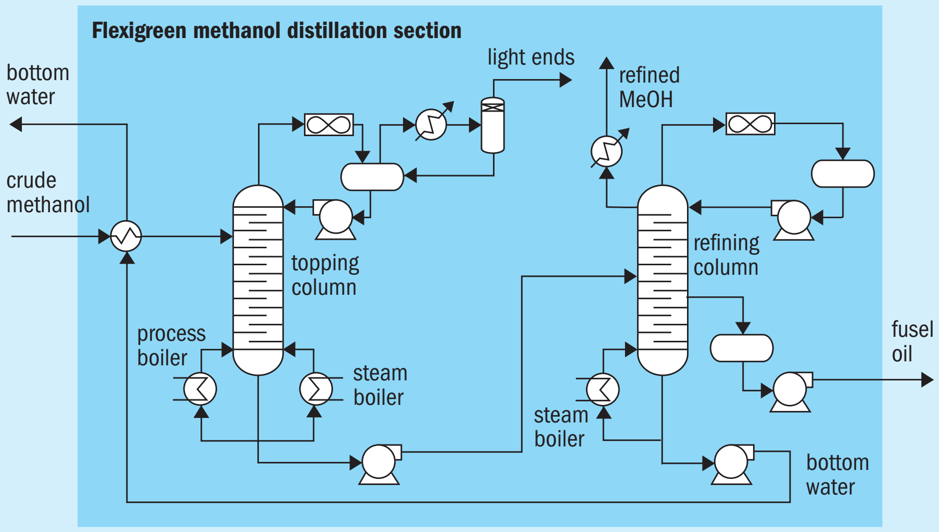
The major portion of the tail gas is sent to the ATR feed gas saturator. Make-up water to this column is the complementary part of the bottom water from the distillation section and a portion of the process condensates from the condensate separator installed at the end of ATR train. The saturated gas is mixed with a suitable steam flowrate and heated up to a suitable ATR inlet temperature in a furnace in the dedicated ATR feed preheater coil. This stream is routed to the Casale patented ATR burner where it is properly mixed with a preheated pure oxygen stream. The burned mixture reacts on a catalytic bed where syngas is generated via steam reforming. The reformed gas is cooled down in a waste heat boiler (generating high-pressure steam), then in the saturator circulation heaters and finally in an air cooler. The gaseous stream, rich in hydrogen and carbon oxides, can be recycled back to the suction of the synthesis compressor as additional make-up gas to the methanol synthesis loop. The process condensates from the condensate separator are partially pumped and recycled back as make-up water to the saturator tower while the other portion is diverted from the methanol unit to other complex sections.

Continuous cooling of the ATR burner is assured by circulating boiling feed water flowing in the burner itself.

Installation of a fired heater is necessary for two main reasons:

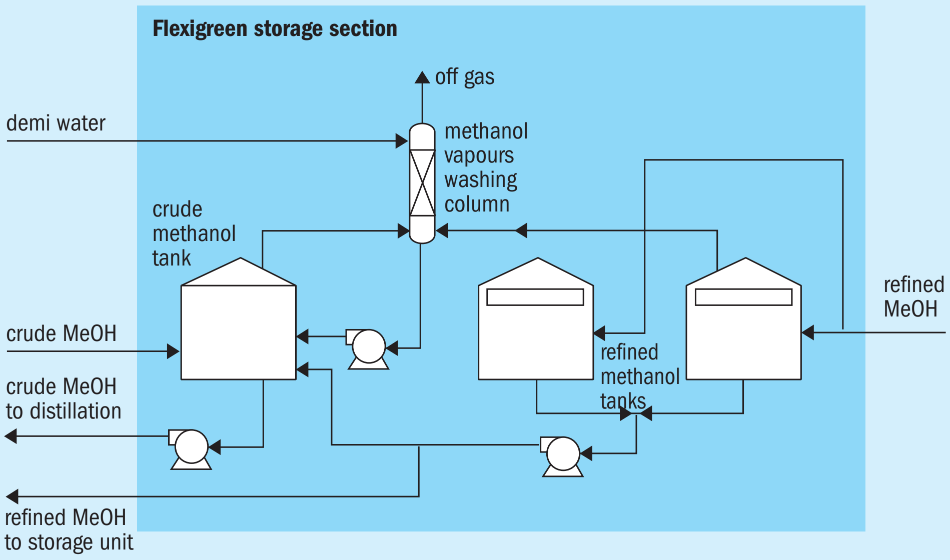
- reaching the suitable ATR inlet temperature;
- burning all the waste streams produced in the methanol plant. Waste streams are produced in the methanol purification process (i.e.: flash gas, light ends and fusel oil). Additionally, it is necessary to divert from the system a quote of purge gas (more specifically a quote of tail gas from HRU) to keep at an optimised level the inert gases concentration such as nitrogen and argon in the methanol synthesis section.

Fig. 6: **Methanol distillation section**



Source: Casale

Fig. 7: **Storage section**



Source: Casale

In addition to the main process service (ATR feed pre-heating), the fired heater has been designed in order to maximise the heat recovery through BFW preheating and high-pressure steam superheating.

The fired heater is equipped with a selective catalytic reduction (SCR) system to minimise flue gas composition environmental impact.

Distillation section

Purification of the crude methanol generated in the synthesis section occurs in the distillation section (Fig. 6). Only two distillation columns are typically foreseen in the Casale Flexigreen methanol distillation section: one topping column and one refining column.

The components which are more volatile than methanol (namely the light ends) are separated in the topping column fed with the crude methanol directly from synthesis loop.

The conventional distillation tower top operating pressure is 0.6 barg.

The light ends components leave the column from the condensing section at the top of it while the reboiling duty is supplied thanks to a process reboiler installed in the synthesis loop and a LP steam reboiler.

The topped crude is pumped to the refining column where the components, which are less volatile than methanol, are removed.

The conventional distillation tower operates at a pressure slightly above atmospheric. It is provided with a full condenser and an LP steam reboiler. In this column, water and heavier impurities are removed from methanol product.

Refined methanol is extracted from the top portion of the column while the bottom water is taken off at the base of the column and pumped to methanol synthesis and ATR sections.

A few trays from the bottom of the tower there is a sufficient concentration of heavier components (namely fusel oils) to allow them to be purged from the system and routed, as fuel, to the ATR section.

Storage section

The storage section consists of a crude methanol tank and two refined methanol tanks and their pumps (Fig. 7).

The crude methanol tank is a conical fixed roof while the refined methanol tanks are floating roof tanks. All tanks are sealed with nitrogen to avoid air contamination which can cause product deterioration and inflammable mixture. To minimise methanol emissions to the atmosphere a washing column washes all vapours from all the tanks with water.

Advantages of Casale process scheme

Table 1 shows the advantages of the Casale process scheme.

SN, carbon efficiency and methanol production

A peculiarity of methanol generation from biomass used as the carbon source is the composition of the feedstock of the methanol synthesis loop, namely the composition of the synthesis or make-up gas, which is rich in carbon oxides and methane, but poor in hydrogen.

For optimised generation conditions (optimum stoichiometric number) and a high yield in methanol production (high carbon efficiency and production), the Casale approach foresees:

- optimisation of the methanol plant make-up gas composition through the upstream shift and acid gas removal sections;
- recovery of the hydrogen present in the synthesis loop purge gas via the HRU unit;
- the highest exploitation of the carbon content of the make-up stream through a dedicated tail gas from synthesis loop conversion section: the so-called

ATR section. In the ATR section the tail gas from HRU unit, rich in methane, is converted via steam reforming reaction in synthesis gas.

Methanol plant water/heat balance

The total water balance of the methanol section generation is closed to zero. The plant imports boiling feed water, demiwater and LP steam, and exports a corresponding flow of boiling feed water, MP steam, superheated HP steam, LP steam condensate and process condensates, thanks to process and bottom distillation water reuse in methanol plant battery limit as well as deep heat integration. The ATR section is characterised by HPS generation in the waste heat boiler and saturator circulation heaters downstream of the ATR reactor, while boiling feed water pre-heating and HP steam superheating occur in the fired heater. This heat recovery, together with the medium-pressure steam generation in the IMC reactor and with the exploitation of the condensing synthesis loop gas downstream of the IMC which is able to supply heat to the distillation section (via process gas heated topping column reboiler), provide an almost self-sustaining unit in terms of heat/water demand: only low-pressure steam import for methanol distillation is expected while the overall steam export (medium-pressure steam export + high-pressure steam export) during normal run is slightly higher than the low-pressure steam import.

Saturator

In the ATR section, the tail gas is saturated in the saturator tower. The steam gained in the tower depends on the quantity of heat recovered downstream of the ATR reactor by the saturator circulating water. In this way, a decrease of import of valuable HP steam is achieved.

Since a portion of the process condensate and bottom water from the distillation section are used as make-up streams for saturator circulating water, two additional advantages are achieved:

- pollutants contained in these two make-up streams (such as traces of methanol synthesis by-products and syngas) are stripped out and recovered as reactants for the reforming reaction;
- a lower liquid effluent flowrate with a lower quantity of pollutants to be disposed of.

The methanol plant waste stream balance from the Flexigreen methanol solution envisages the minimum export of waste streams.

Common waste stream such as tail gas from the HRU, flash gas, light ends stream, fusel oil and bottom water from the distillation section are all recycled in the methanol plant BL. The actual continuous waste emissions which are exported from the methanol unit are: the saturator purge stream, the steam drums blowdown stream and the flue gas from the fired heater stack.

Table 1: **Advantages of the Casale process scheme**

Focus	Advantage
Stoichiometric number (SN)	Increased from 1.99 to 2.2 From make-up to make-up + H_2 from HRU + reformed gas
Carbon efficiency	Increased from 70% to 90-95% From no ATR section to with ATR section
Methanol production	Increased from 200 t/d to 260 t/d From no ATR section to with ATR section
Methanol plant flexibility	Range 50-100%
Methanol plant water/ heat balance	Water balance close to 0 Heat balance: heat integration with process streams.
Saturator	● Recovery of valuable reactant for reforming reaction ● Low liquid effluent flowrate with low pollutants content
Methanol plant waste stream balance	Minimised List of continuous effluent export: ● saturator purge stream ● steam drums blowdown streams ● flue gas

Source: Casale

Key Casale proprietary items for green methanol

Isothermal methanol converter

The methanol converter (Fig. 8) The methanol synthesis converter is the key piece of equipment for the methanol synthesis: its design influences the stability of the total system as well as the maximum obtainable synthesis make-up gas conversion into valuable product.

Over the last decades, Casale has developed and optimised its methanol converter to address all possible constraints including new eco-friendly requirements, resulting it in the isothermal methanol converter.

The distinguishing feature of this layout is that the heat released by the methanol generation reactions in the catalytic bed is absorbed by a cooling medium flowing in plates. The cooling medium can be either synthesis gas or boiling water whose selection is based on the quantity of generated heat and heat and material balance of the complex.

Plates give the flexibility needed by a fruitful technology to cover different demands. They can be designed in radial configuration and, therefore, they can overcome the common tube layout design constraint: the tubesheet. With this design, the distribution of both water and gas in the plates is guaranteed by dedicated collectors installed in the pressure vessel.

The most significant features of the Casale IMC design are:

- presence of only one continuous layer of catalyst;
- no catalyst by-pass: the reacting gas flows through the entirety of the catalyst volume;
- better performance, resulting from the advanced design, ensuring the best catalyst temperature profile with
- the highest uniformity;
- suitable design of the heat exchange elements for this particular service and the critical environment in which they have to operate (catalyst loading and unloading, thermal expansion, mechanical stress, corrosion stress);
- easier mechanical construction;
- highest reliability thanks to the industrialised and automated production process of the reactor's internal components;
- easier catalyst replacement and maintenance of the internals;
- flexibility to use any first-class commercially available catalyst;
- Casale experience in designing synthesis converters.

At present, 26 Casale isothermal plate cooled methanol converters are on stream and others are under construction/engineering, with capacities ranging from 260 t/d to 8,000 t/d, the latter in a single vessel. The total worldwide installed capacity using Casale Converters (of several different types: adiabatic quench cooled, adiabatic interchanger cooled, isothermal plate cooled) is about 30% of the current total world capacity.

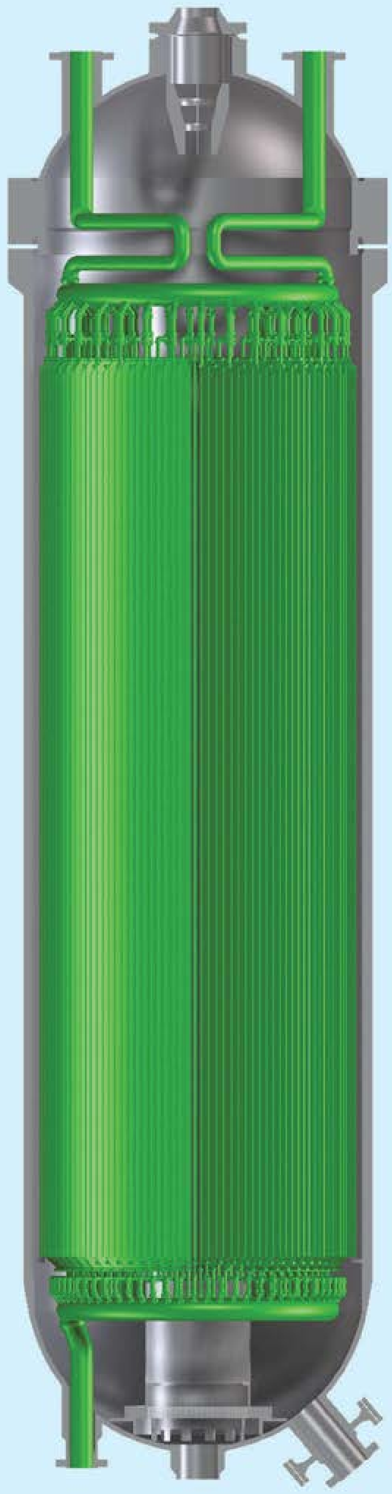
ATR reformer design and ATR burner

The ATR is a bottle-shaped reactor in which the methane steam reforming reaction to generate synthesis gas occurs. It is characterised by a catalytic bed installed in a refractory-lined pressure vessel. The Casale ATR design is conceptually very simple. The bottle-shaped reactor can be divided into two parts: the top cylindrical part and the bottom cylindrical part. The burner is installed in the top, and the catalyst bed is in the bottom.

The methane-rich gas is introduced from one side at the top of the low-diameter cylindrical chamber (top cylindrical part), before the burner tip, perpendicular to the burner. The oxygen stream is introduced at high velocity axially at the top of the bottle-shaped reactor inside the burner. The high velocity of the oxygen causes mixing between the two streams and the combustion reaction takes place instantaneously after mixing. A circular distributor with a small pressure drop is provided upstream of the burner tip to obtain a uniform flow of methane-rich gas before it is mixed with the oxygen. The combustion chamber length is chosen in order to avoid impingement of the burner flame over the reforming catalyst while achieving an almost uniform distribution of temperature and gas composition at the chamber outlet before the catalyst bed. The impingement of the flame on the catalytic bed would damage its superficial layer resulting in performance losses (higher methane slip) and increased pressure drop.

The fluid-dynamic flow field inside the combustion chamber is designed to protect the refractory lining from the high temperature core of the flame, preventing hot spots on the lining surface. The burner tip is provided with a forced convection cooling water system to protect the burner from the high combustion temperature. The water path inside the burner tip ensures uniform cooling of all

Fig. 8: **Isothermal methanol converter**



Source: Casale

the burner walls. In particular, the heat transfer coefficient of the water flow has been enhanced according to the tip that is near the flame.

Besides the solutions implemented by Casale in the design of the reactor itself, the ATR burner is also a proprietary item, designed and supplied by Casale. The design of the Casale ATR burner relies on CFD tools used to simulate the flow and temperature fields inside the combustion chamber and within the burner body, taking into account the strong correlation between turbulence and chemical kinetics. The CFD results are also coupled with thermal and FEM analysis of the burner's solid surfaces, which are essential to understand and optimise the burner design. These calculations are confirmed by industrial experience. The approach followed by Casale addresses most of the common problems relating to reformer burners such as poor mixing, soot formation and overheating of the surfaces exposed to the flame.

The main features of the Casale pure oxygen autothermal reformer burner are:

- Good mixing between oxygen and natural gas, with an almost uniform field of temperature, velocities and composition at catalytic bed entrance:
  - Achieve a better equilibrium approach due to almost uniform temperature and composition at the catalytic bed inlet.
  - A shorter flame; avoiding the impingement of the flame on the catalytic bed thus resulting in longer life of the catalyst, better performances and no pressure drop increases due to sintering/milling.
- Soot-free operation.
- High flexibility in operation, allowing running the burner with good performances in a wide range of flow rates.
- Low temperature of the reformer refractory lining.
- Water-cooled burner tip in order to ensure several years of safe operating life with low temperature of the burner surfaces exposed to the flame:
  - No plant shutdown related to burner failure.
  - Proven trouble-free operation.
  - Up to eight years of proven operation with a single Casale burner.
- Flame stability.

Casale has acquired sound experience in the design of ATR reactors for both ammonia and methanol production and for both two-step reforming and pure ATR (with coke oven gas) configurations. Casale has several referenced ATR reactors for methanol production in operation or scheduled for start-up, with capacities ranging from 350 to 7,000 t/d. At present there are 9 units in operation, including a 5,000 and a 7,000 t/d methanol plants. ■

Fig. 1 *Large methanol plant in North America (5,000 t/d)*

PHOTO: AIR LIQUIDE

Decentralised small scale methanol plants

Air Liquide presents the results of an internal study to identify preferred natural gas-based plant configurations at a methanol capacity of 250 t/d. Delivering small capacity plants requires a focus on the total cost of ownership (TCO) for the economics to be successful, in addition to the CO_2 footprint of the operation. As found by this study, SMR concepts are naturally power balanced for standalone greenfield operations and show no particular advantage for power import in a brownfield setting. POX and ATR cases are greatly improved and even advantaged in a brownfield setting compared to SMR when shifting from power balance to power import cases.

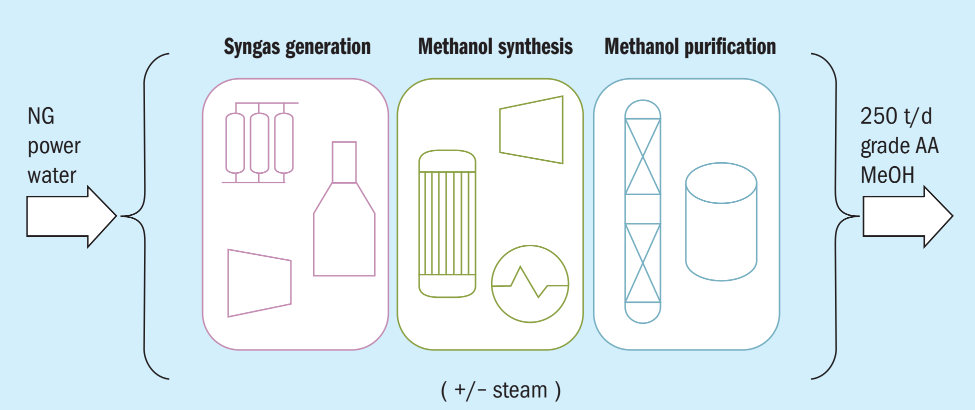
Stéphane Haag, **Bryce Williams**, **Karsten Covella**, (Air Liquide Forschung & Entwicklung GmbH) and **Hans Kopetsch**, **Alexander Roesch** and **Veronika Gronemann** (Air Liquide Engineering & Construction).

Methanol is an important building block for producing high value chemicals and is a perfect fit for energy storage and for producing clean fuels. Methanol is a molecule fully mastered by Air Liquide[1-7]. Air Liquide Engineering & Construction is a leading technology provider and licensor for methanol production plants with a methanol technology market share of more than 45% (2000-2017 based on plant capacities). Methanol plant designs are available for all capacities up to 10,000 metric tonnes per day (single train), based on a variety of different hydrocarbon-containing feedstocks. Since 1969, more than 68 licenses have been sold globally for a capacity of more than 55.5 million tonnes per year of methanol production. The predominant route to produce methanol uses natural gas as feedstock. Fig. 1 shows a large methanol plant in North America using the Lurgi MegaMethanol™ process to produce 5,000 t/d of methanol, based on natural gas feedstock. Air Liquide's scope of work for this plant included the license, basic engineering, detailed engineering and proprietary equipment.

In addition to its R&D and various commercial products in its portfolio, including the Lurgi™ Methanol and Lurgi MegaMethanol™ technologies[8-10], Air Liquide is also well-known for its syngas generation and synthesis units, for the production of oxygen such as air separation units (ASU) as well as for hydrogen recovery such as pressure swing adsorption units (PSA), making it a one-stop shop for customers wanting to build small-scale methanol plants.

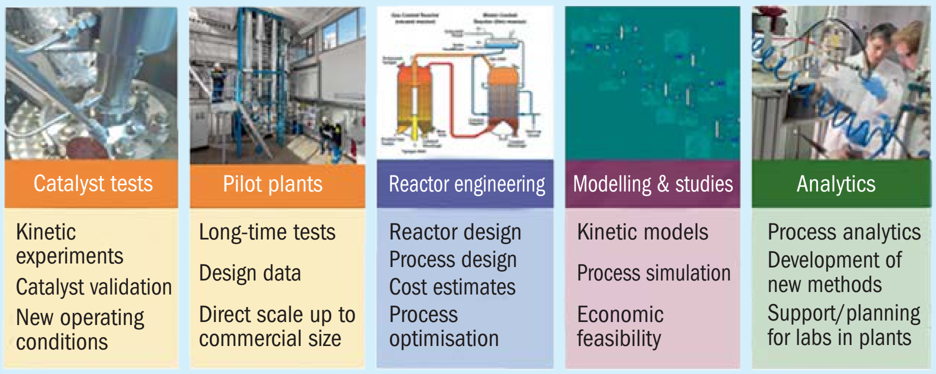
Despite the trend for designing large-scale methanol plants, smaller capacities in specific geographies are also of interest for customers that have a source of natural gas available. Therefore, small-scale plants at a capacity of about 250

Fig. 2: **Block flow diagram of a small-scale methanol concept at Air Liquide**



Source: Air Liquide

Fig. 3: **Capabilities and expertise of Air Liquide R&D**



Source: Air Liquide

t/d can be useful in specific situations and locations. Small-scale methanol based upon natural gas makes particular sense for distributed production to monetise remote gas supplies (e.g. flare gas). In this case, the avoided emissions are significant, irrespective of the plant efficiency, because the gas would have otherwise been directly flared. Alternatively, small plants can be used to locally produce methanol and avoid difficult (costly) logistical supply - thus avoiding the emissions of transport. A large margin exists between local gas prices and the cost remote customers are required to pay for methanol.

The study

Delivering small capacity plants requires a focus on the total cost of ownership (TCO) for the economics to be successful, in addition to the CO_2 footprint of the operation. In this article, Air Liquide presents the results of a study to identify preferred natural gas-based plant configurations at a capacity of 250 t/d of methanol (Fig. 2).

Without economies of scale, smaller plant capital costs (e.g. capex) for equipment, engineering and construction contribute the majority of the TCO in comparison to operating costs, which includes the feedstock and utilities. Thus, a particular focus was placed on the syngas generation section of the plant where the majority of the capex is located. Another focus was to ensure that the carbon footprint of these small-scale units can be minimised.

Use of remote/stranded gas is seen as a major field of application in connection with the geographically dispersed and oversupplied US market, but also in other regions where gas associated with crude production is routinely flared. In these locations, production of a liquid methanol product represents monetisation of an otherwise wasted resource and the avoidance of greenhouse gas emissions (either as methane or CO_2). In some locations, such as North America, government regulations and public pressure are driving the reduction of flare usage. US Methanol has seen some success based upon the relocation of older, small-scale assets to new locations, but these opportunities are limited.

Another potential market is underutilised syngas-producing assets. Converting syngas assets partly (or fully) to methanol synthesis units can be successful because the capital-intensive syngas asset already exists and therefore, the incremental investment costs for methanol are low. In addition, integration at an existing site for a small methanol unit for captive use will offer benefits on utility investment. Furthermore, recent changes in the tax credits in the US amplify the potential value of these opportunities for hydrogen producing assets. Avoidance of CO_2 emissions of existing steam methane reforming (SMR) plants can have a significant financial impact in these geographies.

Thirdly, integration with methanol consumers is also foreseen to be an interesting market. Of these, the largest downstream market for methanol is formaldehyde. Potential customers could be methanol consumers at locations where transport of methanol is costly due to distances from major ports and at the same time, local supplies of natural gas are available.

Air Liquide leverages competencies in engineering and construction as well as pilot studies which are able to generate results that can be scaled up for design and optimisation of commercial offers. Fig. 3 provides an overview of the capabilities and expertise of Air Liquide R&D. Linking to the small-scale methanol topic from natural gas, these pilots are used to de-risk more aggressive operating conditions, to fine tune existing kinetics and to estimate the amount of by-products produced within the methanol synthesis. These aspects are key elements in order to make small-scale setups more attractive.

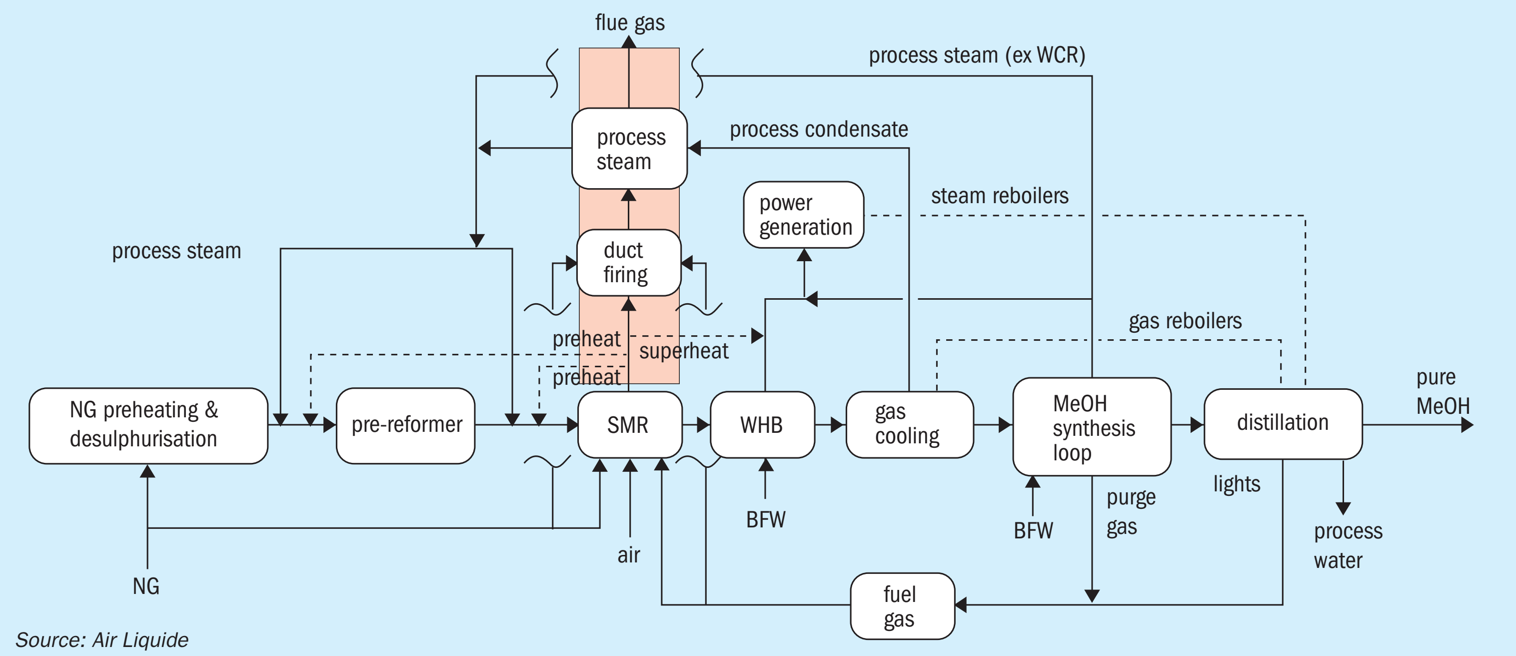
Results

Screening of different syngas generation processes

After the syngas generation section, the process flowsheet of the methanol synthesis and distillation sections were held more or less constant for the screening of the syngas generation process. The synthesis section is composed of a syngas compressor, an interchanger, a water-cooled reactor, a final cooler, a crude methanol separator and a recycle compressor – the same assumption is taken for all cases. The design of the underlying equipment and operating conditions were optimised for the respective syngas of each case studied. In the distillation section, an optimised system was consistently used to produce Grade AA methanol product. In some cases, specific heat integrations were modified for better operating costs.

1 47 | 2 48 | 3 49 | 4 50 | 5 51 | 6 52 | 7 53 | 8 54 | 9 55 | 10 56 | 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

Fig. 4: **SMR power balanced case used as a reference or study base case**



Source: Air Liquide

POX and ATR-based process set-ups always require a PSA unit to recover hydrogen from the methanol synthesis purge gas. This hydrogen is added to the reformed gas to manage the stoichiometric number (SN) of the make-up gas mixture composition. Oxygen production for the POX and ATR cases were included within the plant scope – either by modular, standardised cryogenic air separation units, vacuum swing adsorption units or other air separation technologies developed by Air Liquide.

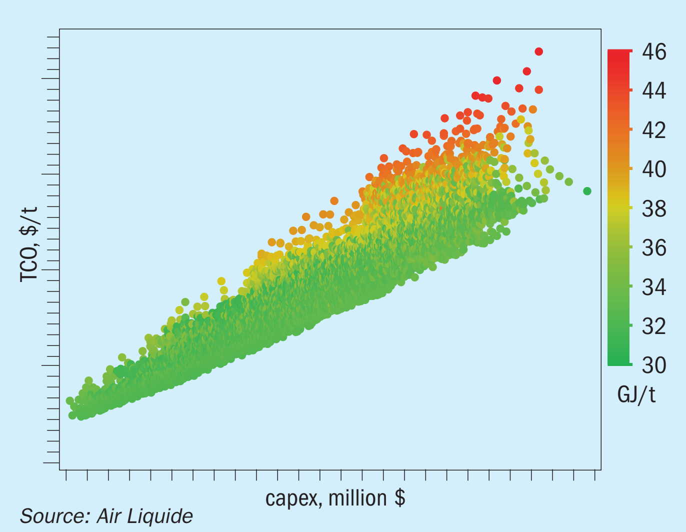
The various process setups have been compared as stand-alone units that were independent of imported utilities, except for gas and water. Thus, power demand was balanced by on-site production within the scope of the plant. The equipment and operating costs for this are included in the total cost of ownership (TCO). The TCO includes both depreciation and operating costs per tonne of methanol product. When import power was used, the indirect emissions were estimated assuming a carbon loading of 500 kg CO_2 per MWh, a mid-range carbon loading considered typical for the US power grid.

Basic equipment designs were made and the capital costs were estimated from reference projects executed by Air Liquide Engineering & Construction and internal cost databases. Operating costs were estimated by validated simulation tools – the same used to design world-scale plants. Taken together, the TCO was calculated, including the capital portion as a depreciation charge, to represent the gate cost of methanol using a consistent set of assumptions.

Definition of a base case

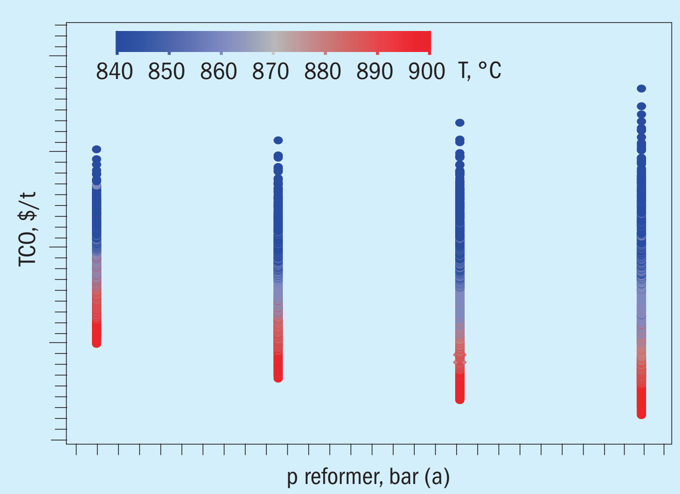
The SMR case depicted in Fig. 4 was used as the base for this study. Syngas by POX and ATR can also be considered for methanol production, however, more than one reforming step was not considered to be economically feasible for small-scale methanol plants. Each case considered different configurations or operating conditions for syngas production by SMR, ATR or POX.

Fig. 5: **TCO vs. capex and specific NG demand for SMR cases**



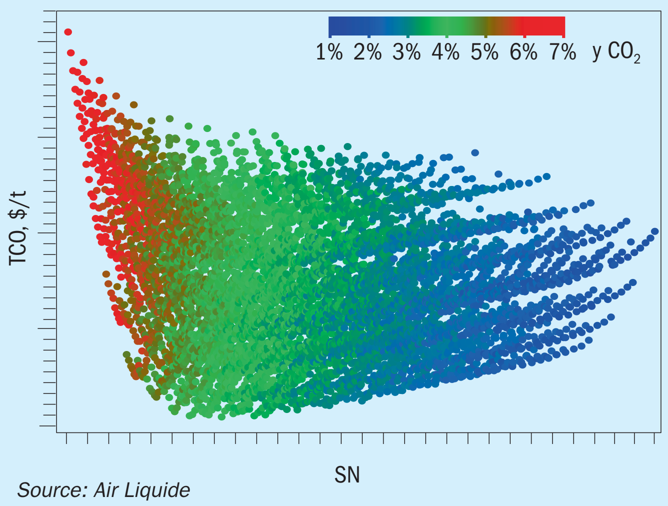
Source: Air Liquide

Fig. 6: **TCO vs. operating temperatures and pressures of the SMR**



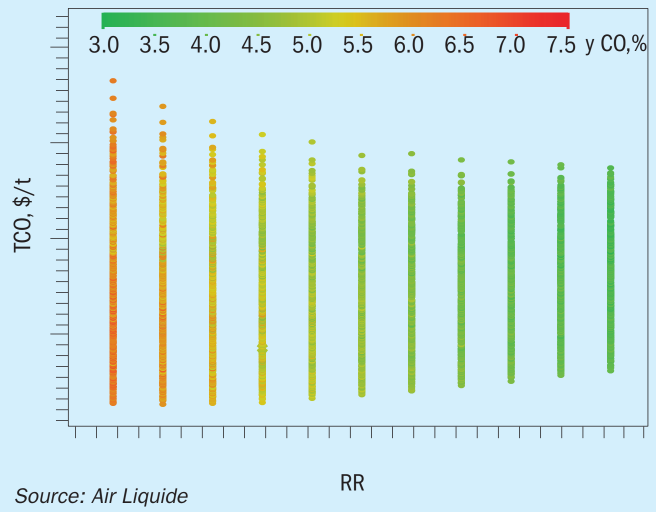
Source: Air Liquide

Fig. 7: **TCO vs. SN at methanol reactor inlet for SMR cases**



Source: Air Liquide

Fig. 8: **TCO vs. recycle ratio in the methanol synthesis for SMR cases**



Source: Air Liquide

Grade AA methanol product makes sense for a standard product offer, as it provides maximum flexibility for downstream applications. A lower grade could be offered by eliminating or adjusting the final purification column. Some formaldehyde producers accept up to 15% water content, for example – a capital and energy savings versus production of Grade AA. Nevertheless, in this work, only Grade AA methanol has been considered.

A sensitivity analysis for the SMR base case has been performed. Parameters such as steam to carbon ratio (S/C), SMR temperature and pressure and synthesis loop pressure and recycle ratio were all investigated:

- steam/carbon ratio (S/C)= 2-2.7;
- SMR temperature = 840-900 °C;
- SMR pressure = 16-25 bar;
- recycle ratio (RR) for the methanol synthesis = 2-4;
- methanol loop pressure = 60-80 bar;
- stoichiometric number at methanol reactor inlet: $SN = (H_2 - CO_2)/(CO + CO_2)$ in vol-%.

Many parameters can affect the TCO and can be optimised regarding the specific location and environment of such a small-scale methanol unit. For example, the main factors that affect the TCO for the SMR cases are:

- The reformer temperature – higher temperatures lead to lower TCO.
- Higher reformer pressures are beneficial for optimum TCO for intermediate S/C, CO, CO_2 and RR.
- Higher loop pressures are preferred for methanol synthesis.
- In general, more aggressive (lower SN) conditions help to lower TCO but shouldn't be too extreme both for TCO and also feasibility reasons.

The results for the SMR cases regarding TCO are illustrated in Figs 5-8. This extensive study allows optimised process parameters versus TCO for each situation inside a given flowsheet. In these figures, a wide parameter space was studied to determine the limiting Pareto front for capex (and TCO), in relation to operating conditions for the SMR and synthesis.

Any of the three technologies SMR, ATR and POX could be used upstream of the methanol synthesis. Besides the TCO, particular attention has been given to the estimation of the CO_2 emissions in comparison to the reference case presented in this section.

Power balance cases

The three main options for syngas generation from natural gas (POX, ATR and SMR) were evaluated by constructing process simulations and estimating the TCO of the produced methanol as seen in the upper portion of Table 1.

The power balanced cases show that both POX and ATR solutions have a higher TCO than SMR. This is because the waste heat in the SMR case is sufficient for the required power production. The oxygen-based solutions require additional gas (beyond tail gas) for dedicated power, impacting the relative efficiency and CO_2 emissions.

Table 1: **Comparison of different syngas generation technologies relative to a SMR reference case**

Technologies upstream of methanol synthesis (250 t/d)	Power	Total relative* capex	Total relative* TCO	Relative* efficiency**	Relative* CO_2 emission (t/t MeOH)
SMR base case	balance	1.000	1.000	1.000	1.000
Optimised POX	balance	1.052	1.046	1.063	1.240
Optimised ATR	balance	1.091	1.077	1.091	1.340
SMR	import	1.026	1.014	0.972	0.920
Optimised POX	import	1.000	1.004	0.947	1.000
Optimised ATR	import	0.987	1.010	0.906	0.980

** Relative to the SMR base case, ** Based on million BTU/t MeOH*

Source: Air Liquide

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 53 54 55 56

Power import cases

With power import possible, both POX and ATR designs could be competitive with the SMR on the basis of both TCO and CO_2 emissions as can be observed in the lower portion of Table 1. This is at least partly attributed to the more aggressive reactor and catalyst conditions. Developments on a brownfield site would strongly benefit from existing utilities that can be easily expanded, such as cooling water, oxygen supply, low carbon hydrogen supply or demand for co-product CO, all of which would tip the balance in favour of POX and ATR solutions.

The best options to produce 250 t/d methanol at low TCO were generally quite similar in cost, process efficiency and CO_2 emissions. However, they rely on different methanol reactor inlet gas compositions; many of which were quite aggressive and below what has been commercially proven. This is why an extensive test campaign of more than 2000 hours on stream in the pilot plant at Air Liquide R&D – Innovation Campus Frankfurt (ICF) was performed under different conditions, sometimes far from conventional operation, to better understand the limitations of some of the possible solutions proposed during the study.

Fig. 9: **Air Liquide R&D pilot plant - Innovation Campus Frankfurt (ICF)**

PHOTO: AIR LIQUIDE

Results of experimental test campaign

Like all methanol synthesis units for syngas from conventional feedstocks, the pilot plant at Innovation Campus Frankfurt is equipped with a tubular water-cooled reactor and a recycle for unconverted syngas (see Fig. 9). The reactor tube of the pilot unit has dimensions comparable to commercial plants. Scale-up from the pilot unit to any commercial size unit is performed by multiplying the number of reactor tubes with the ratio of the respective production capacities.

Some results of the test campaign are given in Table 2. Experiments with several different operating conditions and gas compositions were performed. Therefore, the amount of by-products produced with more aggressive conditions has been carefully analysed and quantified, especially for lower SNs at the methanol reactor inlet. Hence, this test campaign was completed in order to define the boundaries of possible operations for conditions that are not usual for methanol synthesis.

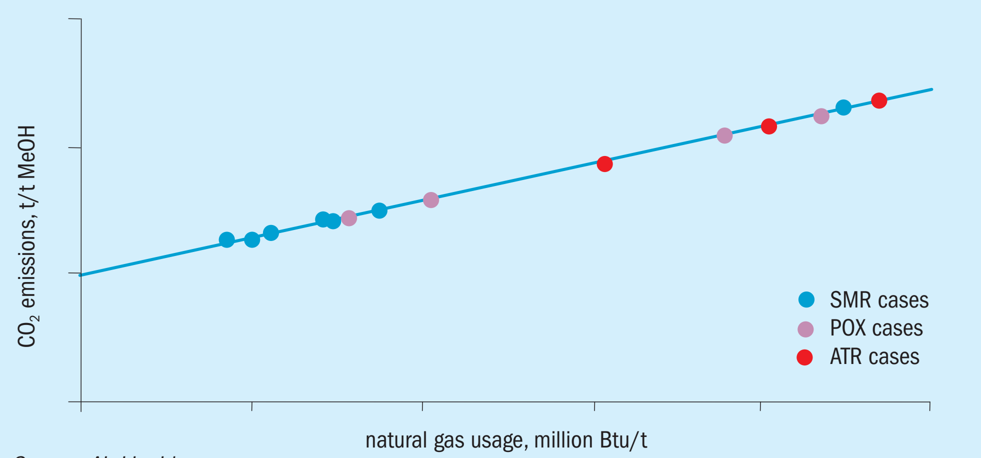
A critical variable is the SN = $(H_2 - CO_2)/(CO + CO_2)$ in vol-% at the inlet of the reactor. An SN of 2 represents enough hydrogen for all carbon-containing molecules to react to methanol. Typically, the SN focus is on the make-up syngas to the synthesis loop. While the SN of the make-up and reactor inlet are not completely unrelated, these studies have shown that it is more important to focus on the SN at the reactor inlet[11]:

Table 2: **Experimental results in pilot plant with unusual operation and low SN at methanol reactor inlet**

Test campaign in pilot plant	SN MUG	SN reactor inlet	T** (°C)	P (bar)	RR	Relative* GHSV (h^{-1})	Relative* XCOx Plant (%)	Relative* by-products (wt ppm)
SMR case	3.6	12.4	240	80	2.2	1.000	1.000	1.000
Classic POX	2.1	5.1	220	73	2.0	0.849	1.015	1.646
POX low SN	2.0	3.1	211	75	2.5	0.775	0.990	1.936
POX low SN	1.9	2.2	232	60	1.2	0.828	0.945	10.721
ATR low SN	1.9	2.6	214	70	2.3	1.201	0.937	1.509
ATR low SN	2.1	2.6	225	65	2.0	1.642	0.884	2.089
ATR very low SN	1.8	1.6	230	60	1.9	1.610	0.854	2.138
ATR very low SN	1.8	1.4	248	80	3.1	0.549	0.962	3.839

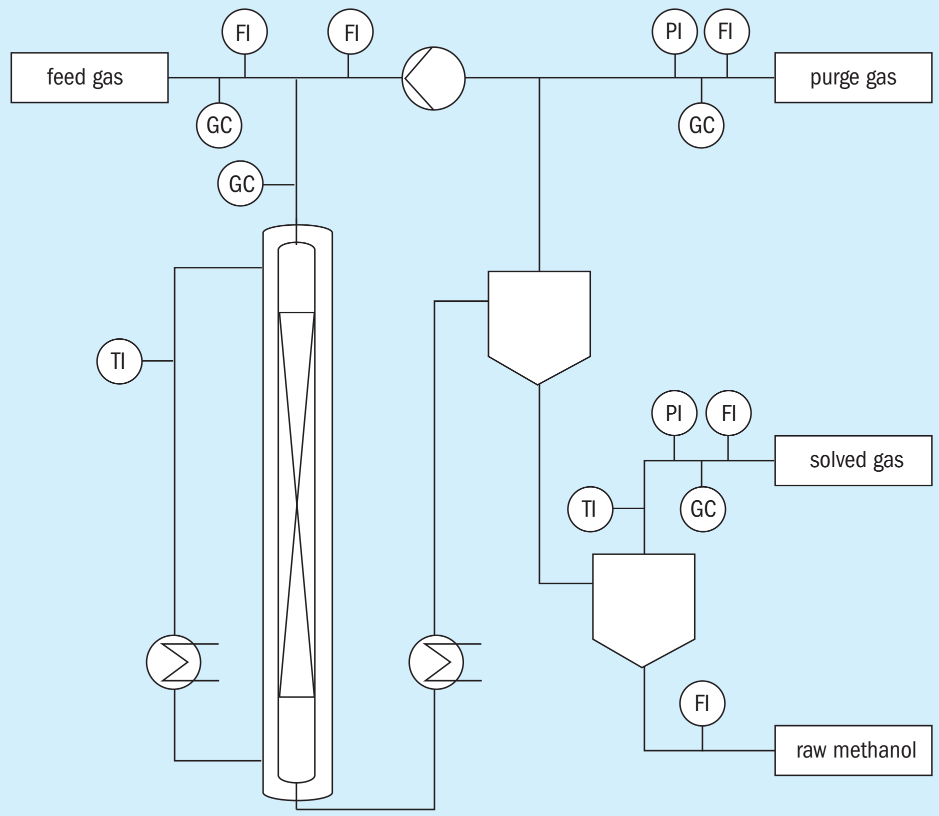
** Relative to the SMR base case, ** Temperature of the water jacket of the WCR* — *Source: Air Liquide*

Fig. 10: **Overall process efficiency vs. CO_2 emissions for selected power balanced cases**



Source: Air Liquide

Fig. 11: **Flowsheet of pilot plant configuration**



Source: Air Liquide

- SN is not an issue for SMR as there is excess H_2;
- commercially) proven conditions when SN > 3.
- low SN conditions when SN < 3.
- very low SN conditions when SN = 1.6 - 1.8.

As can be observed in Table 2, the amount of by-products produced during the methanol synthesis is very sensitive to operating conditions and gas compositions. It is crucial to manage the amount of the different by-products present in the crude methanol with adequate and feasible conditions in order to allow a proper distillation to obtain a Grade AA methanol product at the end of the process.

Discussion

Firstly, any of the three technologies can be the basis for technically viable options. The most important distinction for the technical options is the power balance. The SMR as studied is naturally power balanced and shows no particular advantage for power import. Steam produced in the waste heat boiler and burning of off gas streams provides enough steam for power production to run the plant. As will be described, the POX and ATR cases are greatly improved when shifting from power balance to power import cases.

A long-established and intuitive result was that CO_2 emissions are linearly related to overall natural gas usage (feed + fuel) for all power balanced cases, independent of the technology. It can be seen in Fig. 10 that a range of SMR, ATR and POX cases were checked, all landing on the same trend line. Power balance is best suited for the remote gas case. Among these the SMR gave the lowest specific usage and emissions. The most economic case (lowest TCO) did not correspond to the lowest emissions. Thus, the trade-off between capex and opex at small capacities favours capex reduction over feedstock minimisation. The opposite is typically true at 5,000 t/d scale.

The favourable SMR results under power balanced conditions can be understood as the power requirements of the air separation unit in POX and ATR cases drive on-site utility demand and require additional investment and gas usage for on-site power production.

The SMR case not only shows better TCO figures than ATR and POX, but the CO_2 emissions are also significantly lower than for the oxidative processes. This can be observed for several SMR cases with different options as shown in Fig. 10 in comparison to ATR and POX for power balanced scenarios.

All three syngas technologies can be made to work in a competitive fashion - economically and environmentally. The SMR is likely best suited to remote, standalone operation. The oxygen-based POX and ATR solutions compete better on a developed site with local methanol demand and import power[12-13]. As is usually the case, the optimal solution depends on specific local conditions. If the complete avoidance of CO_2 emissions is the main target for a small-scale methanol plant, access to a low carbon hydrogen and energy supply enables utilisation of CO_2 captured from other processes for direct conversion into methanol.

Dedicated CO_2 capture was excluded from this analysis. However, based upon the higher portion of CO_2 that is produced at pressure within the syngas process for POX and ATR, these processes would also be favoured versus SMR which has a higher portion of the CO_2 in low pressure flue gas.

Materials and methods

Experimental setup

The test points were performed in the pilot plant at Innovation Campus Frankfurt. This pilot plant incorporates gas recycling and online analytics to follow conversion and selectivity over time. A scheme of the methanol synthesis pilot plant setup is shown in Fig. 11. For the syngas fed to the pilot plant, the term feed gas and/or make-up gas (MUG) is also used. The syngas is mixed from cylinder gases in technical quality in a mixing station. Therefore, the syngas is free of sulphur and ammonia.

The essential data for a complete process characterisation are the temperature profiles, pressure profiles, mass flows, gas compositions (feed gas or make-up-gas, reactor inlet, reactor outlet, purge gas and solved gas) as well as the composition of raw methanol after the water-cooled reactor (WCR).

The tube dimension of the WCR is comparable to the commercial scale WCR. In the tube centre, an additional tube is placed for measurement of the temperature profile. A catalytic bed of five metres has been filled into the WCR with a commercial methanol catalyst delivered by Clariant.

Using the composition and flow data, complete material balances are established for all C, H, O and N components, thereby establishing catalyst parameters such as conversion and selectivity.

Gas composition used in the test campaign

Table 3 provides the gas compositions of the different feedstock used to generate the data available in Table 2.

Conclusions

Air Liquide is able to perform such an in-depth analysis since it owns all the syngas technology.

The SMR front end provides commercially referenced conditions and is conveniently in power balance. Moreover, SMR generally allows the lowest CO_2 emissions of all cases. The amount of by-products present in the crude methanol is also very low with a feedstock for the methanol synthesis coming from a SMR unit.

Nevertheless, ATR as an alternative offer can be suitable for specific cases especially if oxygen is available. Therefore, some ATR cases show lowest capex (also lowest TCO) of commercially referenced synthesis conditions. For the reason, the trade-off between lower capex and higher opex has to be studied carefully for each location.

Some POX cases under high-CO/low SN conditions for the methanol synthesis allow the cheapest TCO. Nevertheless, these synthesis conditions are too extreme for conventional operating parameters but could be the focus for future lab tests and catalyst developments.

On request, this study can also be performed with additional boundaries including abatement of CO_2, considering individual geographical constraints. ■

References

1. Pontzen F.; Liebner W. et al.; Catalysis Today, 2011, Volume 171, pp. 242-250.
2. Haag S.; Drosdzol C.; Williams B.; Pena V.; Palauschek N.; Wilken M.; Günther A.; Gronemann V.; Roesch A., Chem. Ing. Tech. 2022, Volume 94, No. 11, pp. 1–13
3. Oelmann T.; Schuhmann T.; Gorny M.; Strozyk M.; Drosdzol C.; Haag S.; Castillo-Welter F.; Oil & Gas European Magazine, 2021, Volume 4, pp. 28-32
4. Do N.T.Q.; Haag S.; Gronemann V.; Schuhmann T.; Oelmann T.; Gorny M., Schwarz H.; Werner S.; Reitmeier S.J.; Gebert S.; Reitzmann A., Oil & Gas European Magazine, 2020, Volume 2, pp. 17-21
5. Haag S.; Drosdzol C.; Williams B.; Pena V.; Palauschek N.; Wilken M.; Günther A.; Gronemann V.; Roesch A.; Chem. Ing. Tech. 2022, Volume 94, No. 11, pp. 1–13
6. Haag S.; Castillo-Welter F.; Schuhmann T.; Williams B.; Oelmann T.; Günther A.; Gorny M.; Oil & Gas European Magazine, 2019, Volume2, pp. 67-70
7. Hauser A. et al.; Metals, 2022, Volume 12(6), pp. 1023-1054; https://doi.org/10.3390/met12061023
8. Air Liquide Engineering & Construction. Available online: https://www.engineering-airliquide.com/technology-handbook
9. Gronemann V.; Liebner W.; di Zanno P.; Nitrogen+Syngas, 2010, Volume 308, pp. 36
10. Ott J.; Gronemann V. et al.; Ullmann's Encylopedia Ind. Chem., Weinheim, 2012, Volume 23, pp. 25-48
11. Schuhmann T.; Wurzel T.; Williams B.; Gronemann V.; Oelmann T.; Haag S.; Do N.T.Q.; Process for preparing methanol, WO 2021213700 A1
12. Covella K.; Kopetsch H.; Williams B.; Aoun J.; Apparatus and method for producing methanol, US20220289651 A1
13. Kopetsch H.; Williams B.; Covella K.; Aoun J.; Method and apparatus for reforming hydrocarbon gas for methanol production, EP4056532 A1

Acknowledgments

The authors want to acknowledge Clariant as a catalyst supplier and a long-time partner for providing the commercial catalyst used in the test campaigns at Air Liquide R&D.

Table 3: **Composition of MUG for tests described in Table 2**

Feed composition/ make-up gas	H_2 (vol-%)	CO (vol-%)	CO_2 (vol-%)	Inerts (CH_4 + N_2) (vol-%)	SN (MUG)
SMR case	76.0	16.6	3.7	3.7	3.6
Classic POX	68.2	27.4	3.7	0.7	2.1
POX low SN	65.4	27.7	2.9	4.0	2.0
POX low SN	64.9	31.8	1.1	2.2	1.9
ATR low SN	67.8	22.3	8.3	1.8	1.9
ATR low SN	68.1	22.8	7.0	2.1	2.1
ATR very Low SN	66.3	23.1	8.8	1.8	1.8
ATR very Low SN	66.1	23.6	8.5	1.8	1.8

Source: Air Liquide

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ISSN: 1750-6891

Design and production:
JOHN CREEK, DANI HART

Mixed Sources FSC

Printed in England by:
Buxton Press Ltd
Palace Road, Buxton, Derbyshire,
SK17 6AE

BCInsight

Published by: BCInsight Ltd
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