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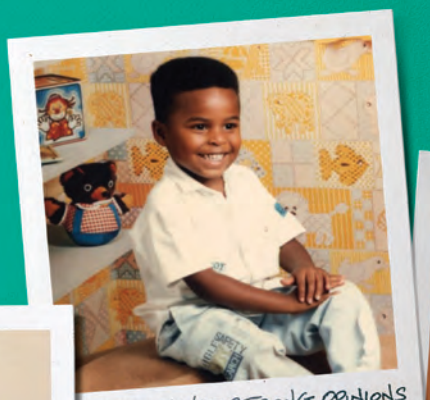
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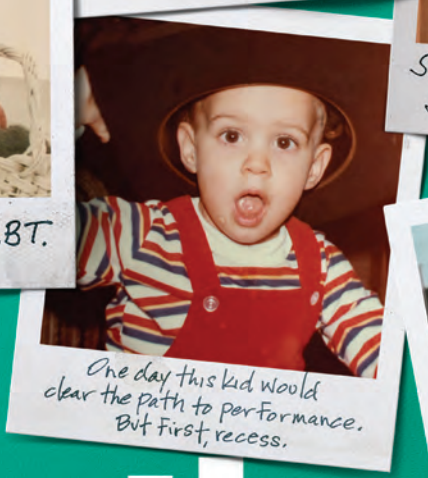
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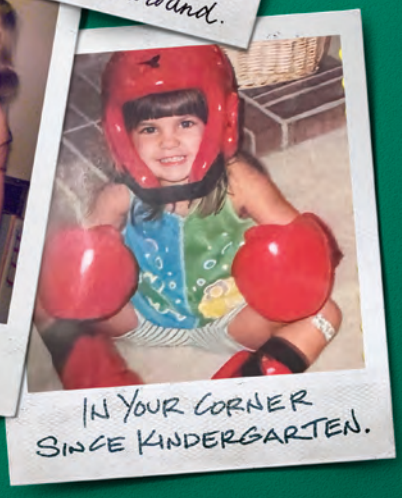
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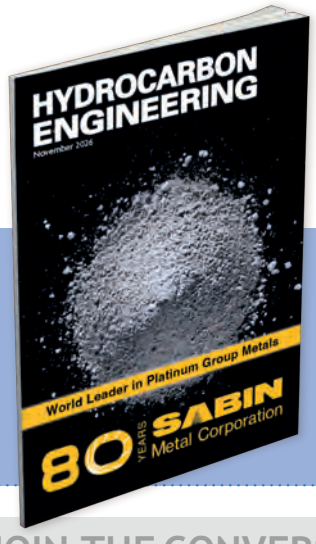
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THIS MONTH'S FRONT COVER

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COMMENT

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HYDROCARBON ENGINEERING



CALLUM O'REILLY
SENIOR EDITOR

Let me take you back in time to 1996. A memorable year for a number of reasons. Dolly the Sheep. Bill Clinton re-elected. Comet Hyakutake. The Atlanta Olympic Games (and Michael Johnson). Euro '96 (when football nearly came home. And I may have cried). The Spice Girls. Oasis. Charles and Diana's divorce. Trainspotting. Independence Day. Mission: Impossible. Tamagotchi. The Nintendo 64. The Macarena. A Game of Thrones (one for our Assistant Editor, Ellie Brosnan). A computer defeats a chess champion (a landmark moment in AI). The list goes on.

1996 was also the year *Hydrocarbon Engineering* published its first issue, and we're proud to have spent three decades covering the technologies, challenges, and innovations shaping the downstream sector.

A lot has changed since then – in the world, in technology, in the downstream sector, and in this magazine. For a start, we no longer publish sections in black and white. QR codes and URLs have replaced reader enquiry forms. And you don't see as many adverts featuring CD-ROMs or floppy disks. But some things never change (and I'm not just referring to our Sales Manager, Chris Atkin). The need to share knowledge, explore new ideas, and keep pace with an evolving industry remains as important as ever. As our Editorial Director, James Little (another whose name has remained ever-present in the pages of this magazine) outlined in the inaugural version of this column back in September/October 1996: "Our role as publishers is to supply up-to-date, high quality and essential technical information, providing a link between the hydrocarbon processing industry worldwide and the individual plant." Thirty years on, this remains our commitment to the sector we serve.

Over that time, *Hydrocarbon Engineering* has evolved alongside the industry, reflecting its changing priorities and the technologies shaping its future. The magazine has also helped build a wider portfolio of industry-leading energy titles, spawning *World Pipelines*, *LNG Industry*, and *Tanks & Terminals*, while its content has helped inspire the creation of sister titles including *World Fertilizer* and *Global Hydrogen Review*. Our latest supplement, *EnviroTech* (the third edition of which is out now and can be accessed by logging into your account, or signing up for a subscription, over at www.hydrocarbonengineering.com), speaks to one of the biggest challenges that our industry has faced in the past 30 years: how the downstream sector can remain competitive and drive decarbonisation in the era of the energy transition.

We'll continue to provide a platform for the industry to tell its story, shining a light on the processes, equipment, and technology that are shaping the future of the downstream sector. As we said in our opening note to you 30 years ago: "this journal is published for you, the reader. If you have any comments on this or future issues, or wish to make an editorial contribution yourself, please do not hesitate to contact us." (You can use the email addresses on the left of this page. We no longer use fax or carrier pigeon.)

And to all of our readers, contributors, and partners who have been part of our story over the past 30 years: thank you. Here's to the next chapter.

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WORLD NEWS

Brunei | Honeywell Technologies partners with Hengyi Industries for efficiency improvements

Honeywell Technologies has announced that the company will provide process technologies, licensing, engineering, proprietary equipment, catalysts, and technical support services to help Hengyi Industries improve efficiency and reliability with higher-value petrochemicals production. Honeywell Technologies UOP solutions will be used to support Phase II of Hengyi's Pulau Muara Besar (PMB) petrochemical project in Brunei.

The PMB planned hydrocracking, aromatics complex, and dehydrogenation units are expected to be among the world's largest facilities of its kind. PMB will reach approximately 20 million tpy crude-processing capacity in Phase II.

"With more than 100 years in the energy sector and technologies deployed in hundreds of aromatics complexes and process units, we help refining customers get more from their existing assets, feedstocks, and resources," said Rajesh Gattupalli, President of Honeywell Technologies UOP. "Our solutions are designed to continue in helping PMB improve efficiency and reliability while positioning them to diversify into higher-value petrochemicals to meet evolving market demands."

Qatar | Cheniere signs long-term SPA to supply QatarEnergy with LNG through 2054

Cheniere Energy Inc. has announced that its subsidiaries, Sabine Pass Liquefaction, LLC (SPL) and Corpus Christi Liquefaction, LLC (CCL), have each entered into long-term LNG sale and purchase agreements (SPA) with QatarEnergy to supply a total of 4 million tpy of LNG through 2054.

Under the SPAs, QatarEnergy has agreed to purchase 2 million tpy of LNG from each of SPL and CCL on a free-on-board (FOB) basis for a purchase price indexed to the Henry Hub price plus a fixed fee. Deliveries under the SPAs will begin in the early 2030s, with 1 million tpy of the SPL SPA subject to a positive final investment decision with respect to the first phase of the SPL Expansion Project.

India | Topsoe secures technology contract for SAF project

Topsoe has signed a licensing agreement with Bharat Petroleum Corp. Ltd (BPCL) to provide its kerosene hydrotreating technology for co-processing for SAF production at the Mumbai Refinery.

Under the agreement, BPCL will revamp its existing 4000 tpd Kerosene Hydrotreater Unit to co-process 5% renewable feedstock, in the form of used cooking oil, alongside conventional feedstock. Using Topsoe's kerosene hydrotreating technology, BPCL will produce SAF within its existing refinery infrastructure, without the need for a new dedicated SAF production unit. The project builds on the two-decade-long relationship between Topsoe and BPCL.

Having achieved final investment decision, the facility revamp is already underway, with commissioning expected by the end of 2026.

The SAF produced will be supplied to airlines refuelling international passenger flights at Indian airports, as the nation builds its domestic SAF ecosystem ahead of mandatory compliance with the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2027.

China | COMY launches waste plastic-to-propylene chemical recycling pilot

Zhejiang COMY Environmental Technology has officially launched its waste plastic-to-propylene chemical recycling pilot project at the Yanzhao Green Chemical Laboratory in Cangzhou, Hebei, China. The pilot advances COMY's proprietary Plastic-to-Propylene (PTP) technology toward industrial commercialisation, offering a scalable route to convert mixed, low-value waste plastics into virgin-equivalent propylene.

Built on nearly two decades of R&D focus on plastic chemical recycling, COMY's PTP process employs a highly selective catalytic cracking and olefin recombination route. Unlike mechanical recycling, which requires carefully sorted, clean feedstock, PTP is engineered to handle mixed, contaminated waste polyolefins without intensive pre-washing – aligning with the actual composition of global plastic waste streams. The process achieves meaningful energy-efficiency gains over conventional naphtha-based propylene production, while yielding high-purity propylene alongside valuable co-products, including aromatics and light hydrocarbons.



WORLD NEWS

DIARY DATES

18 November 2026
Global Hydrogen Conference
Virtual
www.globalhydrogenreview.com/events/global-hydrogen-conference-2026

30 November - 3 December 2026
ERTC
Madrid, Spain
www.worldrefiningassociation.com/event-events/ertc

1 - 3 February 2027
NARTC
Houston, Texas, USA
worldrefiningassociation.com/event-events/nartc

16 - 19 February 2027
Laurance Reid Gas Conditioning Conference
Norman, Oklahoma, USA
www.ou.edu/pacs/lrgcc

28 February - 2 March 2027
AFPM Annual Meeting
San Antonio, Texas, USA
www.afpm.org/events/AnnualMeeting2027

9 - 10 March 2027
StocExpo
Rotterdam, the Netherlands
www.stocexpo.com

21 - 23 March 2027
AFPM International Petrochemical Conference
San Antonio, Texas, USA
www.afpm.org/events/IPC27

11 - 15 April 2027
AMPP Annual Conference & Expo
Columbus, Ohio, USA
ace.ampp.org

20 - 22 April 2027
Sulphur World Symposium
Vienna, Austria
www.sulphurinstitute.org/symposium-2027

14 - 18 June 2027
ACHEMA
Frankfurt, Germany
www.achema.de

USA | EIA: US refineries have been running at very high rates in 2026

The US refinery fleet has run at higher-than-normal rates this year, with refinery utilisation averaging more than 95% of capacity between May and September 2026, the highest for those months since 1998, reports the US Energy Information Administration (EIA).

Tight global product supplies this year have boosted margins for petroleum products, particularly for diesel, incentivising the increased run rates.

Since 1991, US refinery utilisation has averaged 92% from May to September, compared with 88% across the other seven months.

While refinery utilisation was the highest since 1998, total US refinery output was only the highest since 2019 because refining capacity has decreased by 4% since then.

In the first three weeks of October, US refinery utilisation decreased but remained above the five-year seasonal average.

India | Technip Energies secures EPC contract for refinery modernisation project

Technip Energies has been awarded a large engineering, procurement, and construction (EPC) contract by Hindustan Petroleum Corp. Ltd (HPCL) for its lube modernisation and bottom upgradation (LMBU) project at the Mumbai Refinery in Maharashtra, India.

The contract covers the delivery of a 550 000 tpy integrated hydrocracker and catalytic dewaxing (IHCD) unit and an 850 000 tpy solvent deasphalting (SDA) unit. These units form a major part of HPCL's LMBU project and will be integrated within the operating Mumbai Refinery.

The project will modernise HPCL's production of lube oil base stocks, key components used in the manufacture of automotive engine oils and industrial lubricants. It will also upgrade heavier refinery streams into higher-value products, improving resource utilisation and supporting the refinery's long-term competitiveness.

China | North Huajin, Panjin Xincheng, and Aramco announce first Arabian crude oil shipment to HAPCO

North Huajin Chemical Industries Group Corp. (North Huajin), Panjin Xincheng Industrial Group Co., Ltd (Panjin Xincheng), and Aramco have announced the arrival of the first Arabian crude oil shipment to Huajin Aramco Petrochemical Co., Ltd (HAPCO), an integrated greenfield refinery and petrochemical complex that is currently in the pre-production preparation phase in Panjin China's Northeast Liaoning Province.

The first Arabian crude oil feedstock shipment marks a decisive milestone that advances long-term downstream growth, reinforces energy security, and supports China's high-quality development through advanced, efficient, and sustainable energy solutions, underscoring resilience and continuity.

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A SHORT-LIVED SILVER LINING?



Disruption in the Middle East has provided conventional oil and gas refining with a short-term financial boost. **Gordon Cope, Contributing Editor,** considers if this trend is likely to persist across the European refinery sector.

When Iran closed the Strait of Hormuz in February 2026, it led to the worst disruption of energy trade in modern history. Overnight, 20% of the world's crude exports (and 20% of LNG exports) ceased to exist; the result was a shock wave that reverberated around the world.

Europe, in particular, was hit hard. Since the start of the Ukraine war in 2022, the destruction of the Nord Stream gas pipelines and sanctions led to the cessation of over 100 billion m^3 of cheap Russian gas imports. Since then, the continent has been struggling to replace the foundations of its energy network. Demand destruction, LNG imports, and a resurgence in coal in the aftermath of the Ukraine war helped to cauterise the damage, but the continent's economy was left damaged and vulnerable.

The immediate result of the subsequent Hormuz disruption was a spike in energy prices. Within days,



Brent crude prices rose by 50% and spot gas by 70%, adding over €10 billion to European import costs per month. In April 2026, the European Commission (EC) enacted the AccelerateEU emergency plan in order to allow members to coordinate gas storage, purchasing, and crude reserve releases. Several million barrels of crude were subsequently released from strategic reserves, and new sources in Brazil and Guyana were tapped.

The silver lining

As Churchill was (apocryphally) quoted; "never let a good crisis go to waste." Ironically, the closure had a lucrative benefit for the refinery sector. The EU relies on approximately 140 000 bpd of jet fuel and 1 million bpd of diesel imports from the Middle East; the result was immediate shortages of both products. The price of jet fuel and diesel temporarily rose over US$200/bbl on spot markets.

As the crisis deepened, refinery crack spreads increased to over US$14/bbl. EU operators postponed periodic maintenance and switched product slates to aviation fuel and diesel. In 2Q26, the immediate financial quarter following Hormuz, total year-to-year profits for its refining and chemicals operations surged 300%, to US$1.8 billion. Other large refiners, like BP and Repsol, saw similar profit blowouts.

How much longer will Europe's refineries enjoy increased profit margins due to a constrained supply? The return of Middle East competitors to the marketplace is predicated on three circumstances. The first is the cessation of hostilities and the re-opening of the Strait. This is based on both diplomacy and the physical removal of shipping hazards such as mines. The second circumstance is the re-starting of production facilities; idled refineries often take months to bring back to even partial-capacity, let alone full utilisation. The third condition will be the repair of facilities and infrastructure; the damage to Qatar's LNG plants may take up to five years to facilitate.

This raises some interesting scenarios. Over the last decade, Europe has been closing ageing and obsolete refineries; electric vehicle (EV) growth has left diesel and petrol demand stagnant, while high taxes and upgrades required by climate legislation reduce profitability. Since 2024, over 400 000 bpd of conventional capacity on the continent has been shut in.

- The Grangemouh Refinery in Scotland was closed in early 2025; it was converted by owner Petroineos into a fuel-import terminal.
- The Wesseling refinery in Germany ceased crude processing in early 2025 when Shell began converting it into a sustainable aviation fuel (SAF) plant.
- The Prax Lindsey oil refinery, located in Lincolnshire, UK, went bankrupt in mid-2025 and ceased operations (Phillips 66 subsequently purchased the site).
- Eni's Livorno refinery, located in Italy, was converted to a hydro-treated vegetable oil (HVO) plant with the intention of producing biofuels to service the European legislated market for low-carbon diesel, LPG, and naphtha.

Will the resurgence inspire operators to reverse recent closures? The short answer is no; closure of fossil fuel trains was largely dictated by economics and legislation. The plants are equipped with antiquated machinery and processes; the Grangemouth refinery is over a century old, and the Livorno site was commissioned prior to WWII. Upgrading them to increase efficiency and meet EU clean-fuel requirements would require billions of euros. As of the time of writing, owners have expressed no interest in re-opening any of the facilities.

PKN Orlen is one of the few major operators with new capacity under construction that will benefit from the positive market. The Polish company is investing heavily in its 326 000 bpd refinery in Płock in order to modernise the facility and increase output. Work includes hydro-desulfurisation, new hydrogen and oxygen production units, and hydro-cracking improvements. The upgrades are expected to add 200 000 tpy of diesel capacity.

Rather than building new capacity, however, most operators are likely to continue the current trend of dedicating capital budgets towards renewables output. Eni, which converted its 100 000 bpd Gela refinery in Sicily into a bio-refinery plant several years ago, recently commissioned a 400 000 tpy SAF train. TotalEnergies is upgrading its Donges refinery in France, its facility in Antwerp, Belgium, and its assets in Germany to add low-carbon fuels. Hellenic Petroleum converted its 106 000 bpd Elefsina refinery in Greece to a modern hydrocracking facility with a slate of zero-carbon fuels. Shell Deutschland's Wesseling facility in Germany is converting to the manufacture of 300 000 tpy of Group III base oils for high-quality engine lubricants, slating first production by 2028.

Petrochemicals

Refineries were not the only sector impacted by Hormuz; petrochemical plants also experienced major upheavals. Manufacturers of plastics, chemicals, and fertilizers worldwide rely heavily on naphtha and LPG as feedstock. The Middle East normally supplies over 6 million tpy of naphtha and 11 million tpy of LPG; amid shortages, prices jumped 50% to approximately US$1000/short t. European petrochemical plants rely on naphtha for over 75% of its feedstock; BASF quickly announced a 30% increase in prices for industrial and consumer products, as did Wacker Chemie. In spite of surging input costs, Dow's 2Q26 financial report showed net income rising to US$802 million, from a loss of US$801 million the year before.

But the bounce is expected to be short-lived; long-term structural issues affecting profitability have not disappeared. Since 2024, Europe's petrochemical sector has experienced an extended structural downturn fuelled by high energy costs and fierce competition from cheap Chinese products that are flooding the EU market. Major producers have initiated significant production reductions and plant closures. Dow, which is undergoing a basic restructuring of its European assets to eliminate older, high-cost, energy-intensive assets, confirmed that the closure of the Strait of Hormuz reaffirmed its decision to shutter the Bohlen ethylene cracker and the


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Schkopau chlor-alkali plants in Germany and the Basics plant in Wales, UK.

In order to survive in the long-term, Europe's petrochemical producers will have to adopt a multi-pronged strategy. First on the list is shifting away from crude-based feedstock; steam-crackers need to be re-engineered to process liquefied petroleum gases like propane and butane, which can be more reliably sourced and imported from the North Sea and US. Recycling also holds promise; plastic waste can be converted to naphtha feedstock using pyrolysis. Eliminating high-energy products (like ammonia), and focusing on high-margin products used in electronics and advanced polymer applications will enhance the bottom line. Finally, companies will invest capital in ethane-rich, lower-risk safe-haven jurisdictions (like Dow's Path2Zero expansion in Canada).

The nitrogen fertilizer sector relies completely on natural gas as a feedstock and energy source; it amounts to approximately 75% of operational costs, with no economical substitutes. In March 2026, Germany's SKW reported that its plants were operating under severe supply pressure. Yara issued a warning that there would be a major supply squeeze on ammonia and urea; as the critical spring planting season began, prices rose 30%.

Challenges

In order to guarantee a viable future, the refining sector needs to come to grips with its carbon footprint. The record-breaking heat waves of the last several years have underlined to European citizens and governments the need for climate action. In spite of the Hormuz energy crisis, the EC did not relax its environmental goals; EU legislation mandates a net zero target by 2050.

While technological innovations of catalysts and cogeneration nibble around the edges, hydrogen remains the principle Achilles heel. It is a primary component of both fossil fuels and petrochemical manufacturing. Production of the gas using steam methane reforming (SMR), for instance, can add up to 50% of CO_2 emissions per kilogram of output in complex refining operations.

A major realignment of the energy sector is underway as the continent shifts towards renewable wind, solar, and green hydrogen. To establish a green hydrogen economy, the EU reckons that over €450 billion will be needed; utilities and private corporations have announced ambitious programmes. The AquaVentus initiative envisions 10 GW of offshore wind turbine capacity that will be used to produce up to 1 million tpy of green hydrogen using electrolysis; the output will then be piped ashore in dedicated pipeline networks. All in, the AquaVentus project is estimated to cost approximately €50 billion; GASCADE, a German gas transmission operator, estimates that the system will enter service by 2035.

Buyer hesitation is a major impediment to swapping grey hydrogen out for green, however; a kilogram of the latter is up to an order-of-magnitude more costly, which makes EU output uncompetitive against international operators unconstrained by greenhouse gas (GHG) mandates.

That said, a potential solution sits tantalisingly on the horizon. Naturally-occurring hydrogen (also known as white hydrogen), appears to be abundant on the continent. Scientists at the University of Lorraine have identified as much as 92 million t sitting beneath the Alsace Lorraine region of eastern France. In June 2026, European energy company FDE confirmed that its 3600 m exploration well in the Trois Evêchés prospect in Lorraine penetrated an aquifer that contained up to 50% dissolved hydrogen. While significant technical and logistical details need to be worked out, they are not insurmountable; current technology has the potential to deliver GHG-free hydrogen to industrial consumers at prices comparable to that paid for domestically-produced natural gas. FDE and partners are studying infrastructure facilities with the goal of first commercial production in late 2027.

The future

Middle East operators will eventually return to the international fuel market. The trillions of dollars invested in the proven, low-cost assets of Gulf nations will ensure that Saudi Arabia, Qatar, and the UAE will continue to be a significant source of crude, fuels, and LNG. The increased risk premium in jurisdictions vulnerable to future closures of the Strait of Hormuz, however, will entice investment into alternative basins with less geopolitical exposure. The oil sands in Canada, unconventional plays in the US and Argentina, and deep water exploration in Brazil and Guyana will see greater investment, but previously marginal or politically-sensitive sources will also see renewed interest.

In Europe, enhanced oil recovery (EOR) in North Sea fields is an obvious choice to increase nearshore crude supplies. In the aftermath of Hormuz, Equinor saw a multibillion dollar surge in profits. In June 2026, the Norwegian company restructured its US$13 billion annual investment budget away from green energy toward EOR projects in its mature Snorre and Johan Sverdrup offshore field assets. Other companies, like Ithaca Energy in the UK, are seeking to enhance existing EOR projects in the North Sea.

In conclusion, the closure of the Strait of Hormuz has created a short-term financial boon to the fuels sector in the EU, and analysts expect a period of the next year or so in which European refineries can operate profitably in a supply-restricted environment. It will not result in fundamental structural changes, such as re-opening mothballed facilities or commissioning of new capacity, however. Conversion of refineries to renewables remains the most viable avenue to extending the life of existing facilities for the foreseeable future; waiting for technical breakthroughs that will make green or white hydrogen economically viable remains in the next-decade territory. While security-of-supply issues will ensure that a baseline of domestic capacity remains in some form on continental Europe, the sector can expect slow, inexorable erosion for the foreseeable future.

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Proving FCC co-processing at scale

Febronio Panarello, Stefano Corti, and Silvia Scanu, Sarlux Refinery, alongside Claudia Janse van Rensburg, W. R. Grace & Co., explore how co-processing vegetable oils in fluid catalytic cracking units can offer a hydrogen-free route to renewable gasoline production.

In a market defined by decarbonisation mandates, disrupted global energy markets, and the strategic pursuit of energy independence, co-processing offers refiners a practical and scalable route to lower-carbon fuel production. The EU's Renewable Energy Directive III (RED III) is a critical component of the region's energy transition strategy, establishing ambitious 2030 targets for renewable energy deployment, transport-sector decarbonisation, and the adoption of advanced renewable fuels. RED III limits reliance on conventional food-based biofuels while encouraging advanced biofuels derived from wastes, residues, lignocellulosic biomass, and other sustainable sources. More specifically, RED III requires Member States to achieve a 42% renewable energy share in industry by 2030, while simultaneously mandating a minimum 5.5% contribution from advanced biofuels and RFNBOs.[1]

The role of the FCC in co-processing bio-feeds

Many existing refinery initiatives are heavily focused on sustainable aviation fuel (SAF) and renewable diesel. However, a fluid catalytic cracking (FCC) unit offers a route to produce renewable gasoline, which in this case provides a direct pathway to meet specific obligations on gasoline within existing refinery operations.

From an operational perspective, the FCC is particularly well-suited to co-process bio-feeds due to its flexibility in handling diverse feedstocks, the agility with which operating parameters can be adjusted to manage product yields, and its unique heat management system, which does not require additional heat removal. The reaction chemistry of an FCC unit also means that while hydrogen redistribution occurs, no additional hydrogen is required – feed and oxygen from air are the only reactants.[2] In addition, catalyst contaminants can be addressed online either through adjusting catalyst technologies or by adjusting catalyst addition rates. Lastly, FCC units already have sophisticated product separation and treating systems, thus minimising the capital investment required for bio-feed co-processing.

Driven by a favourable European regulatory environment, the availability of bio-based feedstocks, and operational



flexibility provided by co-processing in the FCC, Sarlux initiated a study to evaluate, trial, and ultimately continuously co-process vegetable oils in its FCC unit.

Risk management through laboratory testing

To support this study, Sarlux approached Grace to partner as the FCC catalyst technology provider.

Sarlux provided both hydrocarbon feed and vegetable oil samples for Grace to perform detailed feed analysis and pilot plant studies at its research facility in Worms, Germany.

The bio-feed selected by Sarlux was Palm Oil Mill Effluent (POME), which is a byproduct from the industrial processing of palm fruit. POME had already been selected as the bio-feed for operational co-processing activities carried out since 2019 in the refinery's mild hydrocracker (MHC) and diesel hydrotreating units, based on its availability, favourable economics, and proven operational performance. The experience gained demonstrated that POME is also a suitable feedstock for co-processing in the FCC unit, making it a natural choice for this evaluation.

Through extensive evaluations of various types of bio-feeds from multiple sources, Grace has developed a strong understanding of the typical challenges to be expected when co-processing such feeds. Primary concerns often include elevated oxygenates content and potentially high levels of Na, Mg, K, Ca, and P.

Grace performed the catalytic testing using its Single Receiver Short Contact Time Microactivity (SR-SCT-MAT) method because it quantifies water, CO, and CO_2 – the three components that are the main products of the oxygenates in bio-based feedstocks.

While the target for co-processing in the unit was 2 - 5 wt%, the laboratory tests were carried out at 20 wt% POME content on feed to enhance the effect differentiation. Table 1 presents a comparison of the key properties of POME and the refinery's conventional FCC feedstock, a blend of vacuum gas oil (VGO) and atmospheric residue (AR).

Table 1. POME and FCC unit VGO/AR feed qualities

	POME		VGO/AR feed	
	Typical	Maximum	Typical	Maximum
Distillation range, initial boiling point to final boiling point (°C)	350 - 720		350 - 720	
Density (kg/m^3)	920	950	905	915
Sulfur (mg/kg)	40	100	1800	2400
Nitrogen (mg/kg)	100	-	800	1200
Total metals (mg/kg)	20	40	15	-

Table 2. SR-SCT-MAT yield changes for the base feed compared to an 80:20 blend with POME at constant severity

Parameter	Base vs 80:20 base + POME (measured in wt% fresh feed)
Standard conversion	+0.3
Hydrogen	-0.1
LPG	+0.5
Standard gasoline (C5 - 221°C)	-2.3
Standard LCO + HCO (221°C+)	-0.1
Research octane number	+0.5
Total oxygen compounds	+2.4
CO_2	+0.2
CO	+0.2
H_2O total	+2.0

The SR-SCT-MAT used equilibrium catalyst (Ecat) samples from the unit to compare the base case VGO/AR feed with a 20 wt% POME blended feed. At constant cracking severity, the study showed a similar dry gas yield and coke make compared to the base feed (Table 2). Hydrogen yield was slightly lower due to its consumption in deoxygenation reactions of the lipidic bio feed. However, it is well understood that hydrogen yield in a pilot plant test is significantly different from commercial operation. Both propylene and butylene yields increased, leading to higher overall LPG olefinicity. An increase in gasoline aromatics was also observed. As expected, oxygenates, CO_2, and water increased.

Full scale in-unit trial and stable process performance

Given the confidence provided by comprehensive laboratory analyses, as well as pilot plant testing and the product shifts observed at 20 wt% POME blend ratio, Sarlux decided to proceed with scale-up to a full-scale co-processing trial in its FCC unit. Before initiating the industrial trial, the greenhouse gas emissions associated with FCC co-processing were calculated and certified in compliance with the RED III requirements previously described in this article.

The Sarlux FCC unit is a 90 000 bpd unit based on a side-by-side design. Typical feed is a blend of approximately 40% vacuum gas oil (VGO) from the MHC and approximately 60% AR. For the trial, Sarlux targeted an initial POME rate of up to 5 wt% of feed.

The trial was initiated at 3% and the unit stabilised for four days, after which POME was increased to 5% and held for eight days. It was found that POME up to 5% concentration in the FCC feed did not disrupt product yields or key operating parameters. Furthermore, analysis confirmed the homogeneous presence of the bio-based carbon across all products.

The FCC unit reactor-regenerator thermal balance and catalyst circulation remained stable, confirming robust process operation. No significant adjustments to process operating parameters were required to maintain the desired yields.

A slight increase in sulfur in the LPG and light cycle naphtha (LCN) streams was observed and was mitigated by optimising the refinery's existing treatment unit.

Sour water quality was constantly monitored to highlight any chemical changes as a checkpoint for identifying abnormal conditions. No changes were observed in quality but a modest increase in sour water flow rate, which was expected based on the higher water yield observed in the pilot plant study.

Consistent with the findings of the laboratory and pilot plant studies, the industrial trial confirmed that no significant operational or catalyst-related concerns were identified at the evaluated co-processing rate. FCC operation remained stable throughout the test, with product yields and overall unit performance remaining consistent with expectations. The trial also confirmed the suitability of POME as a co-processing feedstock, supporting its integration into existing refinery operations.

Due to previous investments that enabled co-processing in other refinery units, only limited hardware modifications, including logistic infrastructure, were required to implement POME co-processing in the FCC unit. As a result, the FCC implementation was completed with minimal additional capital expenditure.

From evaluation to implementation

Driven by favourable trial results, the availability of bio-based feedstocks, and the operational flexibility of FCC co-processing, Sarlux is advancing its renewable feedstock strategy beyond the initial POME evaluation. The laboratory work provided valuable data for Sarlux to evaluate and mitigate potential risks associated with introducing a new bio feed to the unit. It also provided a preview of the expected yields, enabling the refinery to anticipate potential adjustments during the trial.

The execution of full scale trial to co-process POME in the FCC provided Sarlux with the confidence to further increase the POME blending percentage and co-process on a continuous basis. In 2025, Sarlux processed approximately 20 000 t of POME, with plans to double this figure in 2026. Furthermore, Sarlux is actively scouting for additional suitable feedstocks.

Grace continues to support Sarlux by conducting laboratory analysis on alternative feed blend ratios, developing tailored catalyst and additive formulations, and providing technical recommendations to support Sarlux's future operating objectives.

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Refining in the age of decarbonisation

Guillaume Vincent, Lucas Dorazio, and Corbett Senter, BASF,
discuss how co-processing in fluid catalytic cracking units can offer a strategic pathway to produce lower-carbon fuels.

In much of the world, the refining industry stands at a crossroads. As global climate reduction targets intensify and regulatory frameworks tighten, refiners are under increasing pressure to reduce the carbon intensity of their products. Traditional fossil-based feedstocks, while reliable and energy-dense, contribute significantly to greenhouse gas emissions with CO_2 from fluid catalytic cracking (FCC) being a large contributor. To remain viable in a low-carbon future, refiners must adopt innovative strategies that align with sustainability targets – without compromising operational efficiency or profitability.

One such strategy gaining traction is co-processing renewable and recycled feedstocks in FCC units. FCC, a mature and widely deployed refining process, offers a unique opportunity to produce lower-carbon fuels by integrating renewable and recycled carbon sources into existing refinery operations. This article explores the different feed options, catalytic and operational implications, and commercial potential of FCC co-processing, drawing on recent research and industrial trials to highlight a potential role for an FCC in the energy transition.

Regulatory drivers and commercial integration driving low carbon fuels

Global and regional regulations are accelerating the adoption of low-carbon refining practices. In Europe, the Renewable Energy Directive III (RED III) mandates a 29% share of renewables in transportation energy by 2030. In the US, the Renewable Fuel Standard (RFS) incentivises blending of renewable fuels through Renewable Identification Numbers (RINs). Canada's Clean Fuels Regulations (CFR) has the target of reducing the carbon intensity of gasoline and diesel by 15%; similarly, a few South American state oil companies have set carbon reduction targets. While most mandates in Asia centre around direct blending of lower carbon stocks such as ethanol or palm oil, several countries also have carbon tax or Emissions Trading Systems (ETS) systems which could incentivise co-processing in the future.

FCC co-processing offers a cost-effective and scalable pathway to meet these requirements. It allows refiners to reduce fossil carbon usage, incorporate renewable carbon into fuel products, leverage existing infrastructure, and avoid the need for hydrogen-intensive upgrades. Catalyst suppliers, FCC licensors, pyrolysis producers,



and technology providers are actively collaborating to ensure the smooth integration of alternative feedstocks into FCC units to facilitate this transition.

FCC and co-processing: a natural fit

FCC is a catalytic process used to convert heavy fractions of crude oil into lighter, more valuable products such as gasoline, diesel, and precursors for making plastic or petrochemical products. Its design features – including continuous catalyst regeneration, high thermal efficiency, and flexible feedstock handling – make it particularly well-suited for co-processing alternative or renewable feeds. The feeds can come from different sources such as plastic pyrolysis oils (from mixed plastics), biomass-derived oils (from wood and/or agricultural residues), or plant-based lipids and animal fats.

These feedstocks contain renewable and recycled carbon, meaning their use does not contribute to net atmospheric CO_2 accumulation. By co-feeding them into FCC units, refiners can produce many products (including transportation fuels) with a lower carbon footprint, helping to meet sustainability targets and regulatory mandates (Figure 1).

Unlike hydroprocessing units, FCC does not require additional hydrogen, making it more cost-effective and less sensitive to hydrogen availability. Moreover, FCC catalysts can be customised to optimise product yields, manage contaminants, and direct reaction pathways – critical capabilities when dealing with diverse and unconventional feedstocks.

Feedstock chemistry: the foundation of low-carbon fuel production

The success of FCC co-processing hinges on the chemical nature of the feedstocks. Two key metrics help assess their suitability.

- Effective hydrogen index (EHI): reflects the hydrogen-to-carbon ratio adjusted for heteroatoms like oxygen and nitrogen. Higher EHI values indicate better upgradability and lower coke formation.[1]
- Conradson carbon residue (CCR): measures the tendency of a feedstock to form coke. Lower CCR values suggest reduced coke yield and better heat balance.

Mixed polyolefins (MPO), such as low-density polyethylene (LDPE) and polypropylene (PP), are particularly well-suited for FCC co-processing due to their inherently high hydrogen content and predominance of aliphatic hydrocarbons in the resulting pyrolysis oils. This favourable chemistry – characterised by EHI values near 2.0 and negligible CCR – enables straightforward blending with conventional FCC feeds. In fact, the high hydrogen and aliphatic content of MPO-derived oils can improve the processability of typical gasoils, supporting efficient conversion to gasoline and LPG with minimal operational disruption. The low level of contaminants and coke precursors further facilitates integration, making MPO pyrolysis oils an attractive, refinery-compatible feedstock for advancing circularity and decarbonisation goals.

Plant oils, such as soybean, corn, or used cooking oils, have moderate EHI (~1.6) and low CCR. While they contain oxygen in the form of triglycerides, they are generally miscible with fossil feeds and can be cracked efficiently in FCC units.

Biomass-derived oils, especially those from lignocellulosic sources like wood or agricultural waste, pose some challenges. Their EHI can be as low as 0.5, and CCR values may exceed 20%, indicating lower crackability and a high tendency to form coke. These oils often require dilution with conventional gasoil or pretreatment to be viable for FCC co-processing.

Recent studies have mapped feedstock properties, including EHI and CCR, to assist refiners in more accurately predicting upgradability and tailoring feed blends accordingly. The closer a feedstock's profile is to conventional gasoil, the easier it is to integrate into FCC operations.

Catalyst design: enabling efficient co-processing

Appropriate catalyst selection is critical to optimised FCC operation, and this remains the case when determining the strategy of co-processing a renewable or recyclable feed. Catalyst composition, structure, and acidity determine how effectively they convert feedstocks into desired products, such as lower carbon fuels, and how well they tolerate contaminants.

The FCC catalyst manufacturing method can strongly influence the ability to co-process alternative feeds, and catalysts produced using the in-situ method have shown some advantages, including:

- High surface porosity: this supports better tolerance to contaminants such as Fe, Ca, and Mg – common in renewable feedstocks and known to plug catalyst pores.

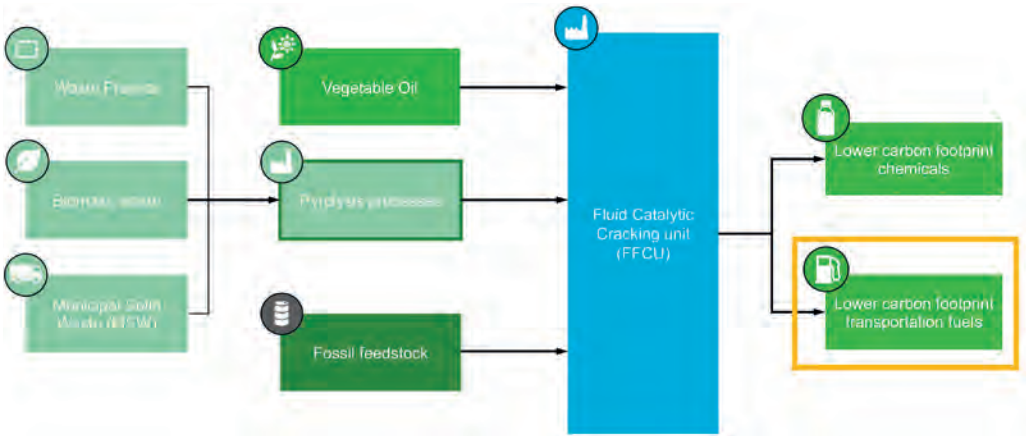
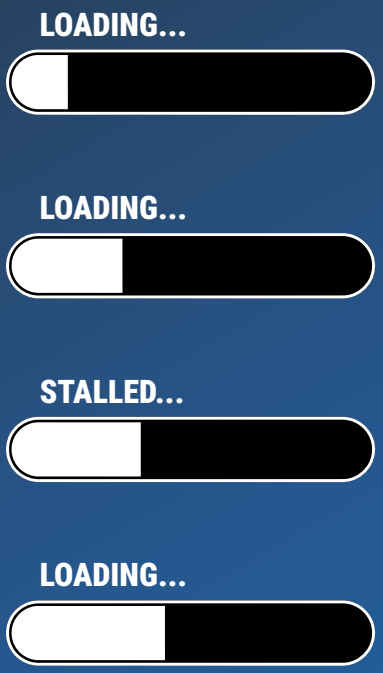


Figure 1. Partially replacing fossil feedstocks with waste or renewable sources for production of lower carbon footprint products (including fuels).

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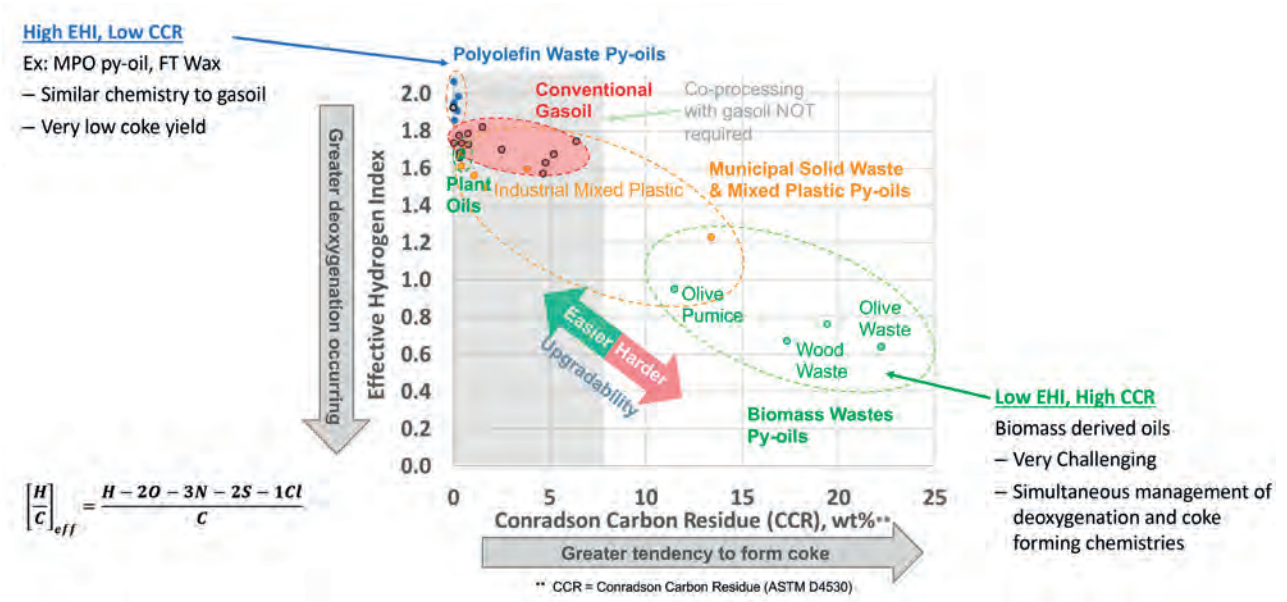


Figure 2. Upgradability of different sustainable feedstocks characterised by EHI and CCR.

- Low Na content: certain alternative feeds have elevated alkali levels which can lower catalyst activity.
- High zeolite surface area that facilitates coke-selective cracking activity, influencing coke formation in co-processing environments.
- No use of external binders, limiting chloride introduction into the FCC unit. This mitigates risks related to nickel reactivation, leading to more hydrogen and delta coke, and ammonium chloride salt deposits; therefore, high-Cl containing feeds can be used.
- Highly flexible customisation, allowing for tailored catalyst solutions for various co-processing needs, including bio-oils, MSW pyrolysis oils, or plastic-derived feeds.

A few recent studies provide evidence of the success that zeolite-based FCC catalysts can have in a wide variety of co-processing applications. These catalysts can be engineered to maximise transportation fuels or chemicals, enhance olefinicity and aromaticity for petrochemical applications, or maximise gasoline octane, minimise coke formation, and direct deoxygenation pathways to preserve renewable carbon.

In one example focusing on upgrading plastic derived oils, two different BASF catalysts were tested on waxy LDPE pyrolysis oil. The first catalyst was designed to maximise naphtha production, while the second catalyst targeted LPG olefins production. Both catalysts successfully converted the pyrolysis oil into high-value transportation fuels or chemicals, with low coke yields and high selectivity.[2]

In another study, five pyrolysis oils derived from municipal solid waste (MSW) and biomass sources such as olive pits were co-processed at a 10% loading rate in FCC units. The results indicated a slight increase in gasoline yield and a slight decrease in LPG yield compared to conventional operation. Importantly, there was no significant change in coke selectivity, and only minimal impact was observed on dry gas production and olefinicity.[3] These findings confirm that catalyst design can be fine-tuned to align product slates with refinery objectives, whether the goal is maximising fuel or chemicals with lower carbon intensity.

Operational challenges and mitigation strategies

While co-processing in FCC shows potential and catalyst design must be considered, introducing these new feeds can also lead to multiple different operational challenges that must be addressed to maintain reliable FCC operation producing an optimised product slate.

As mentioned previously in this article, alternative feedstocks may contain chlorine which can increase coke and hydrogen yields or cause deposits in downstream fractionators, alkali metals which reduce zeolite catalyst activity, or oxygenates (particularly common in biomass-derived feedstocks which can reduce feed miscibility and stability as well as lead to equipment corrosion). Additionally, high CCR feedstocks can disrupt the heat balance of an FCC. All of these could disrupt the production of lower carbon refined products (including fuels).

Mitigation strategies do exist:[4]

- Pretreatment of alternative feedstocks before FCC processing can involve hot filtration, degumming, mild hydrotreating, and purification with adsorbents can be an effective means of reducing levels of many of the listed contaminants.
- Issues with miscibility or stability of alternative feeds can be solved through appropriate equipment such as dedicated injection systems. These can improve dispersion, reduce fouling, and enable precise feed delivery.
- Corrosion can be avoided through appropriate equipment material selection (such as high-chromium alloys), use of corrosion inhibitor packages, or careful feed and catalyst management to limit chloride introduction.
- High CCR can be mitigated by co-processing with lower-CCR feeds or by using a catalyst formulation which mitigates coke selectivity.

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Plastic waste – a source for low carbon fuels?

There is also increased governmental and industry focus on recycling plastic waste, and the impact that regulations surrounding the recycling of plastics in refineries and FCCs could have on the production of lower carbon fuels must also be considered. Chemical recycling of plastic waste through FCCs is increasingly emerging as a viable means of processing hard to recycle plastics that would otherwise be recycled mechanically, and the production of plastics using chemically recycled plastics is incentivised through strategies such as ISCC PLUS certification. However, the impact of plastic recycling targets and incentives on the production of lower carbon fuels is not so clear. Depending on how legislation is applied, a push to process more plastic waste through refineries and/or FCCs could have different impacts on renewable fuels production. For example, certain US states allow conversion of plastic to fuel to be considered recycling, but this fuel would not automatically qualify for credits as a renewable fuel using the RIN system. The refiner would merely get credit for recycling plastic. Conversely, current EU legislation excludes producing fuels from plastic waste as a route for recycling plastic, but this fuel could be considered lower carbon fuel if it could be proven that this plastic is unsuitable for recycling via other means. Thus, refiners in this case would not get credit for recycling plastic but might gain credit for producing a lower carbon fuel. As a result, more clarity and precedent will be needed to determine if plastic pyoil is a valid feedstock for refiners who wish to increase the amount of lower carbon fuel they produce and how incentives for recycling plastic might increase or decrease lower carbon fuels production.

Conclusion: FCC co-processing as a decarbonisation lever for fuels

FCC co-processing is more than a technical innovation – it is a strategic lever for producing lower carbon refined products, including transportation fuels. By integrating renewable and recycled feedstocks into existing refinery operations, refiners can produce lower carbon fuels and chemicals, support circular manufacturing and waste valorisation, comply with evolving sustainability regulations, and maintain operational flexibility and economic viability.

As catalyst technologies advance, feedstock supply chains mature, unit/hardware modifications are adapted, and regulatory frameworks evolve, FCC co-processing will play a central role in shaping the future of low-carbon refining and the maximisation of alternative fuels production. It offers a pragmatic, scalable, and impactful solution for the energy transition – one that leverages the strengths of existing assets while embracing the imperatives of sustainability.

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UNLOCKING THE NEXT FRONTIER



Kurt Du Mong, Zeopore, alongside Markus Hartung, Evonik, explore how meso-zeolites can keep refining operations profitable by rendering active sites located in the zeolite structure more accessible, thereby increasing catalytic efficiency while producing top quality fuels.

Stricter environmental rules and new climate targets force refiners to face a double challenge. They must adopt sustainable processing methods while keeping their operations high-yield and cost-efficient. As a vital step in producing fossil fuels, sustainable aviation fuel (SAF), and advanced biofuels, catalytic dewaxing requires continuously more performant catalysts. However, traditional zeolites are limited by structural performance bottlenecks.

Modern dewaxing and the rise of SAF

Catalytic dewaxing changes fuel molecules to improve their fluid properties like cloud and pour point. It either cracks or isomerises (branches) heavy – mostly linear – paraffin waxes, that would otherwise freeze or thicken at low temperatures.

Today, this same technology applies to green energy. The rapid growth of SAF is a major driver. To cut carbon emissions, the aviation sector relies on alcohol-based or synthetic feeds derived from hydro-processed oils and fats, or even from CO_2-based oils via the reverse-water-gas-shift and Fischer-Tropsch route.

More than fossil-based streams, renewable fuels are heavier and more linear, and accordingly require more extensive dewaxing to meet strict international quality standards. At the same time, these bio-oils vary wildly in quality and composition compared to crude oil. Therefore, a robust high-performance dewaxing catalyst is required, which is able to deliver large reductions in cloud and pour points, while maximising product output and lifetime under a broad range of process conditions.

In both sustainable and traditional refining, the main goal is to protect valuable heavy molecules. Standard zeolite-based catalysts often destroy a significant part of these precious molecules by (over)cracking them into undesired lighter fractions. Modern operators need catalysts that predominately isomerise instead of crack, increasing liquid yields and reducing reaction temperatures.

Table 1. Zeolites offer tunable surface area and pore volume levels, which reduce the zeolite amount in the overall catalyst

Dewaxing zeolite	Total surface area (m^2/g)	Mesopore volume (ml/g)	Amount of zeolite in catalyst (%)
Industrial reference	175	0.25	70
Zeopore - Evonik	200 - 350 (tunable)	0.50 - 0.75 (tunable)	50

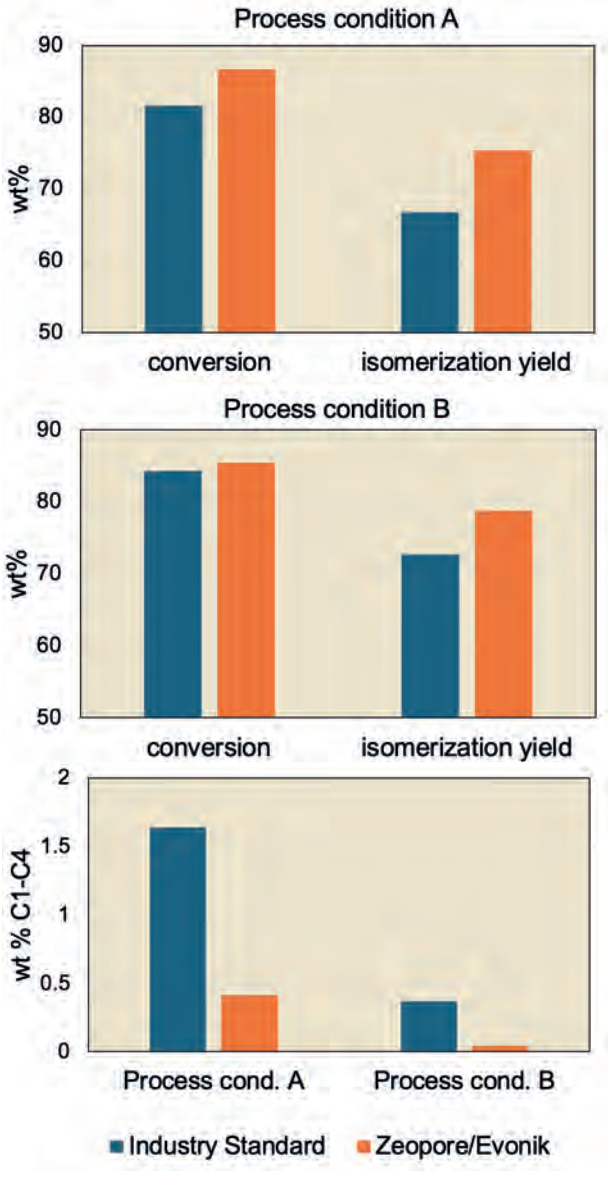


Figure 1. The improved performance of the Zeopore/Evonik catalyst as compared to an industrially deployed reference dewaxing catalyst, for two representative process conditions.

How meso-zeolites resolve porosity bottlenecks

To understand why standard catalysts struggle, operators must look inside traditional zeolites. Their structured and well-defined pores are tiny, under one nanometre in diameter, and hold the active sites where the dewaxing chemistry happens.

In catalytic dewaxing by hydro-isomerisation, uni-directional zeolites, such as ZSM-22, ZSM-48, and EU-2, are established as a preferred choice to selectively convert linear paraffines into branched ones. Yet, even for these advanced zeolites, their performance remains suboptimal, as the feedstock molecules encounter access and diffusion limitations in the narrow pore structure, leading to sub-optimal activity and sizable overcracking towards lower-value byproducts.

Within this setting, Zeopore has managed to address some of these limitations. Proprietary modifications technologies are applied to widely-available conventional zeolites, to introduce a secondary network of larger pores, typically size between 5 - 30 nm, called 'mesopores'. These mesopores enlarge the external surface and increase the number of pore mouths. Accordingly, the number of active sites is effectively enlarged and mass transfer limitations are overcome, enabling reactants to reach active sites quickly and let desired products exit immediately.

In hydroprocessing, this maximises isomerisation yield and minimises cracking to less wanted fractions. The technology platform creates these channels without damaging crystal stability, without reducing the active sites concentration or damaging the overall integrity of the zeolite. Crucially, it also uses affordable and scalable ingredients and unit operations.

A shared vision for industrial efficiency

Over recent years, Zeopore has intensified development and has been scaling up its own in-house industrial production of meso-zeolites up to ton scale.

To be able to commercialise meso-dewaxing-catalysts, the high performance zeolites are integrated in Evonik's new dewaxing catalyst product line, combining Zeopore's meso-zeolite technology with Evonik's catalyst design and precious metal expertise. In April 2026, Evonik officially launched this new generation of high-performance iso-dewaxing catalysts incorporating Zeopore's mesoporisation technology.[1]

By integrating Zeopore's technology into its global catalyst portfolio, Evonik is helping refiners and renewable fuel producers significantly lower their carbon dioxide emissions, handle increasingly difficult feedstocks, and achieve up to a five-fold reduction in product losses during diesel dewaxing.

Custom catalyst tuning to meet exacting needs

Before launching these new catalysts, both companies closely collaborated in extensive testing campaigns

studying a variety of zeolite properties, process conditions, and catalyst formulations. This enabled Evonik to deepen process knowledge, find the best operating conditions, and prove that the custom catalyst offering is suitable for a wide mix of feeds, from standard fossil fuels over lubricants to SAF and renewable diesel.

Zeopore's advanced tuning capabilities are a key strength of its offerings. The company customises the structure of the meso-zeolites to fit exact customer needs. It can change mesopore volume and size to alter diffusion, tune acidity, and place active sites precisely to boost isomerisation (Table 1).

This flexibility enables custom catalyst recipes to be built that match the specific goals, feedstocks, and installations of each customer. It allows customers to reach the optimum of process efficiency, product quality, and environmental sustainability.

Catalyst test results confirming high value

Zeopore produced a range of different dewaxing zeolite types, porosity, and composition variations from which Evonik made a range of catalysts formulations. To reveal how these modified catalysts perform under realistic operating conditions, a series of rigorous trials has been initiated in the Evonik Catalyst Testing Center in Singapore.

On both activity (conversion) and selectivity (isomerisation yield), the Evonik catalyst performs substantially better, yielding up the 8 $wt\%_{abs}$ more isomers (Figure 1). This reduced over-cracking and also relates to a four-fold reduction in the output of undesired C1 - C4 molecules.

The enhanced isomerisation comes at the expense of undesired cracking, as becomes evident from the distribution of linear and branched species in the total liquid product, displaying a pronounced increase of branched isomers of higher carbon numbers (Figure 2).

Moreover, the product slates show that the hydrogen consumption halves from ca. 0.30 wt% (reference) to ca. 0.15 wt% (Zeopore/Evonik), a major cost reduction in dewaxing operations.

Finally, the resulting fuel quality is of utmost relevance.

More than fossil-based streams, renewable fuels are often heavier and more linear, and accordingly require more extensive dewaxing to meet strict international quality standards, such as cloud point (Table 2).

Making sustainable dewaxing economically viable

Whether used in traditional fossil refining, high-value lubricants, or green pathways like SAF, the combination of optimised mesopore engineering with industrial manufacturing creates a true plug-and-play solution. Alongside increased reaction efficiency and reduced byproducts and waste streams, this approach achieves a lower carbon footprint across the chemical industry.

Upgrading a dewaxing catalyst is no longer just a routine refining cost centre. Now, it is a high-value yield-optimisation step positioned at the core of the decarbonised fuels and advanced materials innovations. It sits at the very centre of global industrial resilience roadmaps for refining and sustainable fuels.

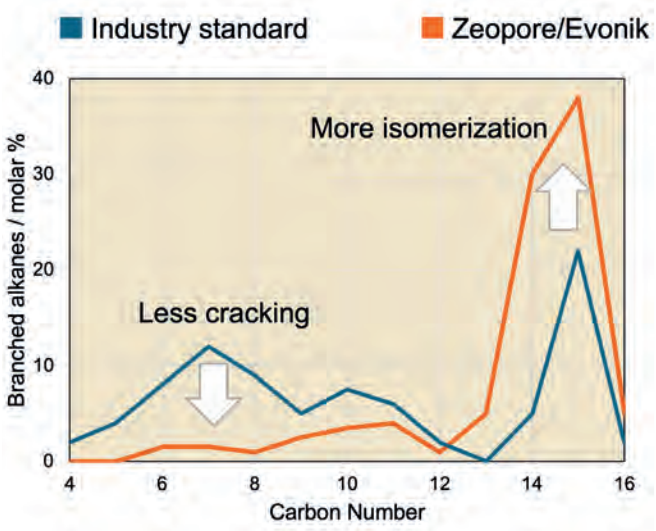


Figure 2. Branched alkanes as a function of carbon number, revealing more isomerisation and less cracking for the Zeopore/Evonik catalyst.

Table 2. Aviation fuel specifications for Jet A / Jet A1 kerosene require a cloud point below -40°C / -47°C, respectively

	Industrial reference	Zeopore-Evonik
Cloud point (°C)	-34	-47

Meso-zeolite-based catalysts attract the attention of dewaxing-focused refiners for multiple reasons:

- High dewaxing conversion and isomerisation yield.
- High jet fuel retention.
- Excellent cold flow properties.
- Lower hydrogen consumption.

Global market response and demand

Market reaction is widespread and swift. Following Evonik's announcement, global refiners and technology licensors showed pronounced commercial interest. Hence, the market is in need of high-performance dewaxing catalysts, and especially those offering neutrality towards different dewaxing processes and configurations, as well as the customisation for individual feeds and product demands.

For traditional diesel and lube dewaxing, these meso-catalysts lower operating temperatures to save energy while boosting premium base oil yields. In SAF production, Zeopore's meso-zeolites maximise revenue by converting more precious bio or CO_2-derived feedstock into high-value jet fuel, reducing hydrogen consumption, and minimising the output of low-value side-products.

Reference

1. https://www.evonik.com/en/news/press-releases/2026/04/evonik-and-zeopore-launch-highperformance-isodewaxing-catalysts-.html).

BREAKING FREE



Roman Bobka, Frank Grossmann, Sara Sabater Lopez, and Catherine Basilides-Schwarz, Clariant, Germany,
discuss the development of a chromium-free hydrogenation catalyst platform that has moved from four decades of research and development into commercial scale deployment.

For 40 years, a single question has driven a quiet but persistent effort within Clariant's catalyst research and development (R&D) facilities: could catalytic hydrogenation ever be freed from hexavalent chromium Cr(VI) without giving up the performance the industry had come to rely on? Today, that answer is already running in plants across multiple continents at commercial scale – not merely eliminating Cr(VI) but absolutely removing all traces of chromium.

Across the hydrogenation industry, the pressure to move away from Cr(VI) in catalysts is building steadily, driven by tightening regulations across Europe, the UK, the US, and Asia. There is now a way forward: a chromium-free catalyst that matches the copper-chromium (CuCr) benchmarks, already running commercially across commodity petrochemical, oleochemical, and specialty chemical applications.

The false trade-off

Copper chromite catalysts have been the industry standard for hydrogenation for 60 years, trusted for their activity, selectivity, chemical stability, and versatility, from bulk petrochemical and oleochemical production through to specialty and fine chemical applications. But that trust comes with a catch: these catalysts depend on Cr(VI), classified as a Substance of Very High Concern (SVHC) under REACH.

For years, that trade-off held the industry back, built on the assumption that eliminating chromium meant accepting a performance penalty. That assumption is now being

FROM CHROMIUM



directly challenged, and commercially disproven for several applications.

Why the industry must act

The case for moving away from chromium is no longer just a chemistry problem. It has become a risk management problem, and that risk is accelerating faster than many operators may realise. At the centre of it is REACH, the EU's chemical safety framework, under which a number of Cr(VI) compounds are classified as SVHC. That classification alone signals how seriously regulators now treat this chemistry. Under REACH, the use of certain Cr(VI) substances above applicable thresholds requires special authorisation, one that companies cannot count on indefinitely. Sunset dates keep arriving, each one narrowing the window for continued use, and the overall direction points toward an eventual phase-out rather than a lasting arrangement. What started as a structured compliance process has, in practice, become a moving deadline that gets harder to plan around with every passing year.

This pressure is not confined to Europe, and that is precisely what makes it so difficult to ignore. The UK maintains its own version of REACH, built on the same underlying logic and enforcing many of the same restrictions on Cr(VI), even as it charts an increasingly independent regulatory path post-Brexit. In China, environmental standards developed under the country's 'Beautiful China' initiative are steadily tightening controls on Cr(VI) use and disposal, reflecting a broader national push toward cleaner industrial practices. South Korea runs a parallel system of its

own, K-REACH, modelled closely on the EU's approach and explicitly restricting Cr(VI) compounds across a range of applications. Four major regulatory regions, each independently arriving at the same conclusion. This kind of convergence rarely happens by coincidence. It happens when the underlying hazard is serious enough that regulators across very different political and economic systems feel compelled to act on it, largely in parallel.

For a plant operator, this convergence has practical implications for long-term planning. In the past, differences between regional rules sometimes gave operators more flexibility in how and where they managed compliance timelines. As similar restrictions take shape across multiple regions at a similar pace, that flexibility naturally narrows. Wherever a hydrogenation asset sits today, whether it feeds petrochemical output in Europe, oleochemical production in Asia, or specialty chemical supply chains elsewhere in the world, the practical takeaway is the same: planning for a transition away from chromium chemistry is becoming a matter of when, not whether, regardless of location.

The risk, though, runs deeper than paperwork and permits. Cr(VI) exposure is a hazard at every point in a catalyst's working life, not just during use. It is present during the manufacture of the catalyst, during transport, during the physical handling and loading of catalyst into reactors, throughout day-to-day operation, and again at the end of the catalyst's life, when spent CuCr catalysts typically must be handled and disposed of as hazardous waste. Each of those touchpoints carries its own safety and cost considerations, which do not always appear on a single compliance checklist but tend to show up over time across EHS budgets, workforce training, and disposal contracts.

That is why, in many organisations, it is no longer regulation alone that is driving the shift away from Cr(VI). Corporate sustainability commitments, particularly around reducing waste, cutting pollution, and increasing circularity, are pushing plant-level decisions to move faster than any regulatory deadline requires. Boards and sustainability teams are increasingly unwilling to wait for a sunset date to force their hand when a viable, safer alternative already exists. This chemistry was deliberately designed to eliminate all chromium – not only Cr(VI) – a more ambitious and technically demanding development path, but a necessary one: wherever chromium is present in any oxidation state, the risk of Cr(VI) forming during application cannot be fully excluded. It is an answer for plant operators who want to stay ahead of evolving regulatory and sustainability expectations, protect their workforce, and support their own sustainability goals. By eliminating chromium from the catalyst system, it also helps remove a long-standing operational and environmental liability before it becomes a more significant business risk.

40 years of trial, error, and a breakthrough

Developing this chromium-free catalyst chemistry, though, was never a matter of foresight alone. It took four decades of sustained research, much of it marked by setbacks rather than clear progress.

The first attempts – copper-alumina-manganese formulations developed in the 1980s under Clariant's Süd-Chemie heritage – proved that a chromium-free catalyst could exist (Figure 1). Early versions, however, fell short of the copper chromite benchmark in several applications on activity, selectivity, mechanical strength, or acid resistance and often on more than one at a time. Through the late 1980s and into the 2000s, researchers kept returning to the same basic formulation with adjustments: refining promoter content, adjusting preparation methods, testing variant after variant, only to find that no single adjustment could resolve all limitations across different applications at once.

What ultimately shifted the trajectory was a change in approach, not a single breakthrough discovery. Between 2000 and 2011, the work moved beyond incremental tweaks to a broader search, exploring promoted copper catalysts alongside further-refined copper-alumina chemistry, and testing structural promoters that could stabilise the copper crystallites driving catalytic activity without sacrificing the mechanical strength the industry demanded. Many of these paths led nowhere. A few led somewhere unexpected, and it took years of patient, largely unglamorous testing to tell the difference.

Enough of those unexpected results had accumulated by the early 2010s that Clariant formalised the effort into a dedicated chromium-free programme, shifting from opportunistic exploration to structured, resourced development. Even then, the work was far from finished. Nearly a decade more of thorough recipe refinement and in-house performance testing followed before the chemistry was ready to leave the laboratory.

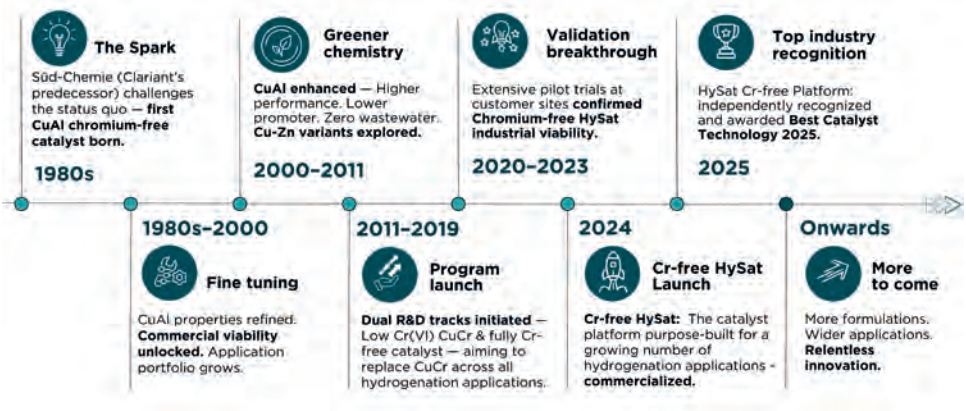


Figure 1. From innovation to chromium-free hydrogenation. A development timeline that spans over 40 years – from an idea to a commercially proven chromium-free catalyst platform. (Source: © Clariant).

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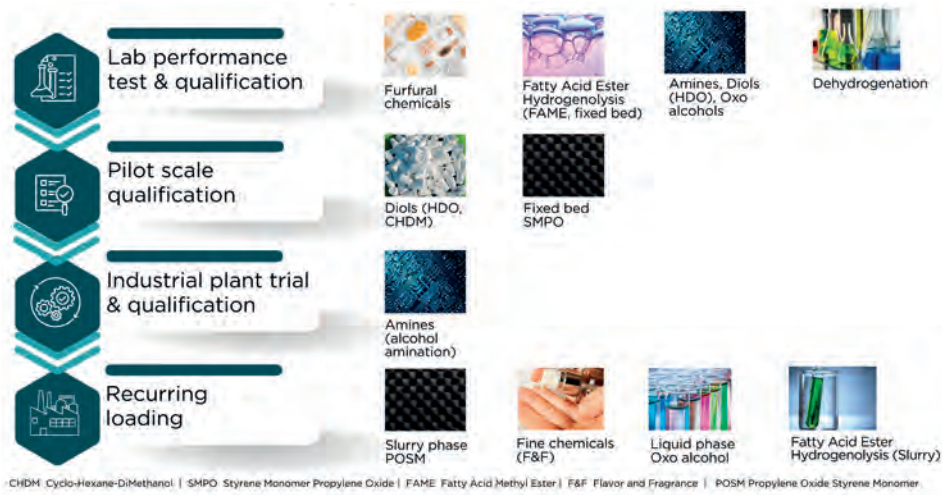


Figure 2. An application portfolio that reflects the breadth of the Cr-free HySat platform – from lab qualification to recurring commercial loadings across diverse hydrogenation processes and industries. (Source: © Clariant).

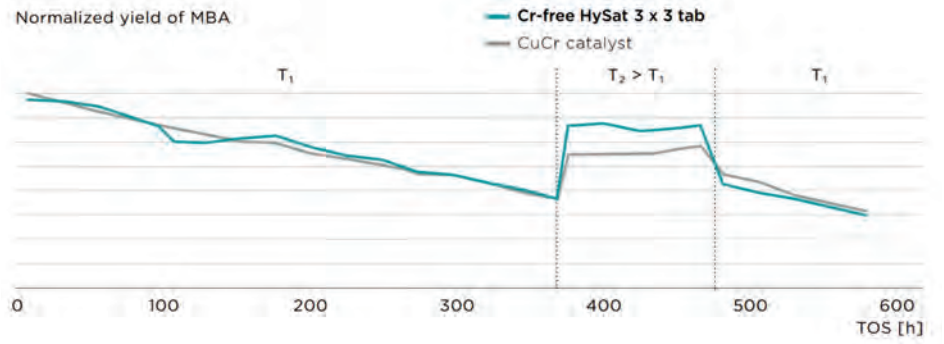


Figure 3. Sustained high performance at severe conditions. In continuous fixed bed SMPO tests (hydrogenation of acetophenone to methyl-benzyl-alcohol [MBA]), Cr-free HySat matched copper-chromium performance at standard temperatures and delivered 10% higher yield at elevated temperatures. (Source: © Clariant).

The real test came next: extensive pilot trials at customer sites between 2020 and 2022, run under live plant conditions rather than controlled laboratory environments. Every earlier generation of chromium-free chemistry had fallen short of the expected long-term performance at this exact stage. This time, laboratory scale promise held up against plant scale reality. The resulting catalyst family launched commercially in 2024 as the chromium-free HySat™ platform.

The platform: chemistry and versatility

The platform is built on copper-based formulations, engineered with structural promoters that stabilise the highly dispersed copper crystallites responsible for its activity, while also improving selectivity, extending catalyst lifetime, and inhibiting sintering. It is available in a range of physical forms to suit different reactor designs, and it delivers notably high side crush strength and acid resistance, giving it strong mechanical stability and producing markedly fewer fine particles under prolonged operational stress.

What matters more than any single specification is breadth. This is a closely related family of chemistries built to perform reliably across a genuinely wide span of hydrogenation processes (Figure 2), including fatty alcohol and diol production, acetone-to-isopropanol conversion, oxo-alcohols, co-production processes of styrene monomer and propylene oxide (SMPO/POSM)*, flavour and fragrance chemistry, amines, fatty alcohols, and furfural hydrogenolysis. That breadth is a precondition for practical industrial performance.

Hydrogenation plants rarely run one static process for the life of an asset. Feedstocks shift, product specifications evolve, and many operators run several product lines through overlapping equipment. A catalyst that only performs well in one narrow application forces a costly choice: qualify and stock multiple catalyst systems or accept a performance compromise somewhere in the portfolio. Versatility removes that choice, letting a single, well-understood chemistry follow an operator across process changes without triggering a new qualification cycle every time conditions shift. That is why the performance data below matters: it proves that the chemistry holds up across a genuinely diverse set of industrial conditions, which is the real test any chromium-free catalyst must pass.

Performance against the chromium-containing benchmark

Higher yield

The platform's performance was first proven through rigorous R&D testing well ahead of its commercial introduction. In a fixed-bed SMPO test, the catalyst matched the CuCr benchmark at standard operating temperatures and delivered a 10% yield uplift at elevated temperatures, sustained over hundreds of hours on stream (Figure 3). That yield gain alone changes the economics of a run, enabling customers to reduce their Scope 1 and 2 emissions.

Faster startup, less downtime

Reduction time drops by approximately 40%, nearly halving the time a reactor sits idle before it can run. The catalyst also tolerates significantly higher hydrogen concentrations

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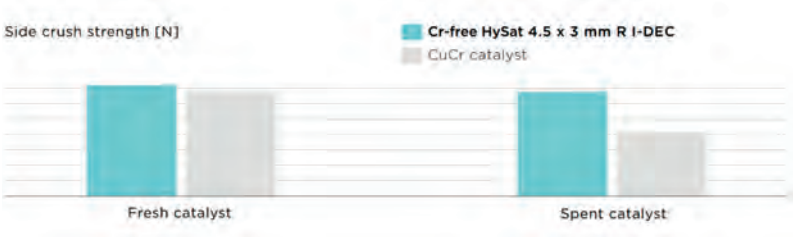


Figure 4. Greater stability proven in industrial setting. A 20-month basket test in a commercial liquid-phase oxo-alcohol plant confirmed Cr-free HySat's higher side crush strength and robustness against damaging industrial feeds. (Source: © Clariant).

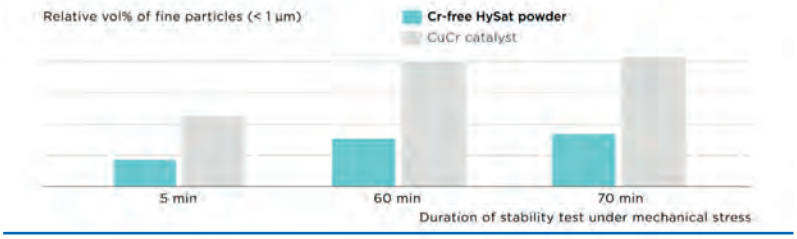


Figure 5. High mechanical stability enables improved filterability. Under prolonged mechanical stress, Cr-free HySat produced significantly fewer fine particles, demonstrating excellent durability. (Source: © Clariant).

during reduction, giving operators more margin at a stage where mistakes are costly. Heat release during the reduction step is also substantially lower compared with Cr(VI)-containing catalysts, specifically for those containing CrO_3, making temperature control easier and reducing the risk of a runaway reaction. With CuCr catalysts, fine powder carried into the tank during filling can introduce chromium contamination into the reduction process itself – a risk that a chromium-free formulation eliminates entirely.

Mechanical durability under industrial conditions

A basket test at a liquid-phase oxo-alcohol plant confirmed higher side crush strength than the CuCr benchmark over 20 months of exposure to demanding industrial feeds (Figure 4). A full reactor load running in the same commercial process for more than two years until a targeted catalyst change-out further confirmed its long-term stability under real operating conditions.

When subjected to prolonged mechanical stress testing in POSM slurry applications, the catalyst also generated significantly fewer fine particles than a CuCr catalyst, demonstrating greater resistance to attrition and reinforcing its durability advantage during routine handling (Figure 5).

Operational and HSE benefits

With zero chromium in the chemistry, loading, operation, and spent catalyst disposal are all simplified, removing a significant HSE burden from plant teams. The result is a drop-in replacement requiring no equipment modifications, so every one of these gains comes without a capital project attached. The absence of chromium SVHC substances also supports a more favourable regulatory and operational profile for the platform relative to chromium-containing products, a factor increasingly considered alongside performance and compliance in procurement decisions.

From performance to scale

That combination of proven performance and operational relief is what has driven adoption. Since 2020, the platform has moved from validated development into sustained commercial growth, establishing a clear market presence. The trajectory toward 2030 points to continued acceleration, reflecting a market that is increasingly ready to make the switch.

A growing application portfolio

Commercial momentum for the platform is spreading across an increasing number of processes. Four applications – liquid-phase oxo-alcohol production, fatty acid ester hydrogenolysis, and flavour and fragrance manufacturing, and slurry-phase POSM – are already in recurring commercial loading with operators across Europe and Asia. Four more are in active industrial plant trials spanning the petrochemical, oleochemical, and specialty chemical sectors, including alcohol amination for amines and fixed-bed SMPO, with additional diol and oxo-alcohol routes moving through pilot and lab qualification. Deployment now spans Europe, the US, China, and Southeast Asia, and each new qualified application adds further proof that this is a platform still expanding its reach, not a single isolated success.

Conclusion: a new hydrogenation standard

This expanding reach is the clearest evidence of what four decades of work have achieved: proof that sustainability and high performance do not have to be a trade-off but can advance the same goal. The transition away from CuCr is no longer a question of whether it will happen, but when, as regulatory, safety, and corporate sustainability trends all converge in the same direction. With eight applications proven or in active trials and multi-continent commercial validation, this represents a platform strategy, not a single product fix, and the pipeline keeps growing, with amines, cyclo-hexane-dimethanol (CHDM), furfural, and dehydrogenation all in active development.

The industry no longer has to wait for a chromium-free future. That future is already running, today, at commercial scale.

Note

- *Styrene monomer propylene oxide (SMPO) and propylene oxide styrene monomer (POSM) are two industry acronyms for the same co-production process, referenced here to ensure clarity across terminology used by various process operators in the field.

ADVANCING HYDROGENATION WITH NICKEL FOAM CATALYSTS

Bettina Munsch and Christoph Kins, Evonik Catalysts, discuss how nickel foam catalysts can advance more efficient hydrogenation processes.

The chemical industry is under sustained pressure from economic instability, geopolitical tensions, and climate-related disruption. Demand has remained slow, and companies are prioritising cost reduction, waste minimisation, and operational efficiency. The focus is shifting toward process technologies that strengthen competitiveness while supporting more sustainable operations.

This is particularly relevant in catalytic hydrogenation – a core process behind everyday products in food, pharmaceuticals, and petrochemicals. Here, catalyst selection directly impacts performance, selectivity, and profitability.

Activated nickel foam offers a practical route to more efficient hydrogenation. By delivering high catalytic activity and selectivity with a carrier-free, non-precious-metal format, it can help producers improve process performance while avoiding the investment associated with precious metals such as palladium or platinum.

Conventional activated nickel catalysts

Activated nickel catalysts are produced by selectively leaching aluminium from a nickel-aluminium alloy, creating a highly porous, high-surface-area nickel structure. This material has long been the standard for slurry hydrogenation, especially in batch processes where flexibility and catalyst exchange are essential.

The most established form is activated nickel powder – a metal-only catalyst containing up to 95% nickel with a small residual aluminium fraction. Since it is not deposited on an inert support such as alumina, silica, or carbon, the entire material can be reclaimed after use, supporting circularity and efficient metal recovery.

Batch reactor suitability

The choice of activated nickel catalyst heavily depends on the application and reactor design that a plant uses. In the pharmaceutical industry, smaller plants typically use batch reactors, where campaigns are relatively short, product changeovers are frequent, and manual catalyst handling is manageable. These reactors align well with powder catalysts, which can be charged and discharged between batches with relative ease.

Fixed bed reactor requirements

Large scale, high-throughput plants more commonly use fixed bed reactors, where the catalyst does not move inside the reactor, and feedstock flows continuously through the bed. This reduces catalyst handling time and improves operational efficiency, but it also limits product change flexibility and places higher demand on catalyst lifetime, mechanical robustness, and pressure drop performance.

Historically, activated nickel has not been suitable for fixed bed use, except in niche cases where activated nickel granules can be applied, such as the hydrogenation of butynediol to butanediol. In a few specialised petrochemical processes, such as hexamethylene diamine and toluene diamine, powder catalysts have been used in continuous systems, despite the significant effort required to continuously separate, recover, and recycle the catalyst.

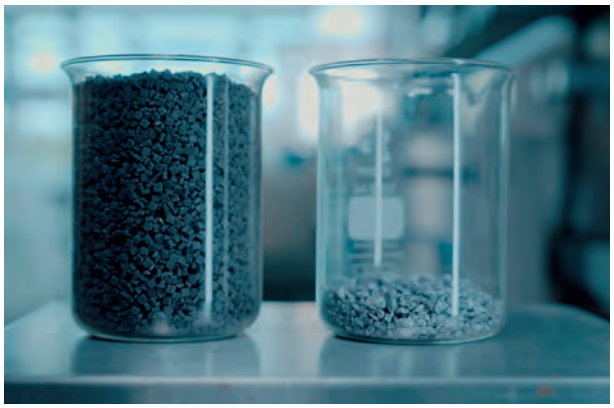


Figure 1. Nickel foam* and nickel granules.

As a result, fixed bed applications have largely relied on supported nickel catalysts, where nickel is deposited on oxidic carriers. While widely used, these materials present challenges such as high pressure drop, safety concerns during handling, and support degradation over time. All of these can affect performance, reliability, and lifecycle cost.

The evolution of an innovative foam

Interest in metal foams accelerated in the early 2000s and has continued to grow as industries explored their application in battery electrodes, heat exchangers, energy absorbers, filters, flame arrestors, and biomedical implants. Yet for hydrogenation chemistry, conventional non-activated nickel foams offered too little surface area to function as effective catalysts, restricting their use to non-hydrogenation applications.

Until recently, industrial adoption of metal foams as chemical catalysts was relatively rare; only a handful of processes, such as steam methane reforming (SMR), partial oxidation of methanol to formaldehyde, and biogas desulfurisation, demonstrated their viability at scale.

Evonik transfers activated nickel technology from powder catalysts into a fixed bed format, to create activated nickel foam. Manufactured under licence from Alantum Europe GmbH, this material is lightweight, carrier-free, and made almost entirely of nickel. It eliminates the aluminium-heavy support structure found in granules, reducing waste and improving catalytic efficiency.

The foam's high surface area and unique geometry increase contact between reactants and catalytic sites. This has been shown to deliver reaction rate orders of magnitude higher than those achievable with conventional fixed bed catalysts. The porosity and structure of the foam is adaptable, enabling operators to redesign the internal reaction space of existing plants without altering reactor shells, downstream equipment, or broader infrastructure. This simultaneously unlocks improvements in time efficiency with minimal disruption. The vast reactive surface to weight ratio means less quantities of catalyst are needed to maintain the same product output. Despite its porous architecture, the material exhibits excellent mechanical stability and abrasion resistance.

Unlike powder or granule form catalysts, the shape and size of activated nickel foam can be customised to meet specific process requirements. This flexibility reduces undesired by-products, extends catalyst lifetimes, and broadens the range of viable applications. It has already demonstrated suitability for diverse hydrogenation reactions including butynediol to butanediol, aldehyde conversion to oxo alcohols, and sugar hydrogenation to polyols. In comparative hydrogenation tests for butynediol to butanediol, Metalyst® 911 delivered higher conversion and selectivity than incumbent granule catalysts at the same reactor bed volume.



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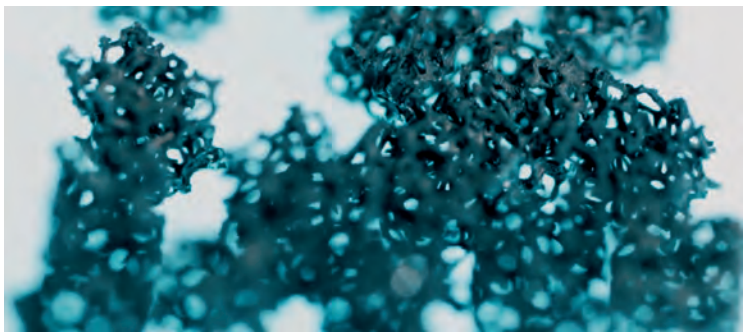


Figure 2. Nickel foam.*

Evonik's Metalyst 9 series of activated nickel foam catalysts are currently in the pilot phase, with customers evaluating performance under commercial operating conditions.

The case for foam catalysts

Nickel foam catalysts introduce a step change in practicality and sustainability for fixed bed hydrogenation. While conventional fixed bed catalysts can be reclaimed, the absence of an oxidic carrier (support) in nickel foam makes refining and reclamation notably faster and simpler. The material's extremely low pressure drop and reduced abrasion also help in reducing a plant's environmental footprint, lowering energy demand, and minimising wear on downstream equipment.

The foam arrives ready for use, eliminating activation steps and avoiding plant downtime. The absence of dust makes handling cleaner, safer, and more efficient than with traditional activated nickel catalysts.

Nickel foam vs nickel granules

The difference between nickel foam and nickel granules is rooted in their unique structures and how this shapes their catalytic performance.

Nickel foam is an open cell, lightweight material with a 4 × 4 × 2 mm geometry, defined by a highly porous, interconnected network that maximises accessible surface area. This design results in a filling density of around 0.35 kg/l, making the foam dramatically lighter than traditional granules. Nickel foam contains approximately 85% nickel and less than 15% aluminium. Produced without an oxidic support, the material is almost entirely catalytic metal, enabling faster reclamation and more efficient use of resources.

In contrast, nickel granules are compact pellets typically sized 2 - 3 mm or 4 - 8 mm, depending on the application. Their dense structure leads to a filling density of roughly 1.7 kg/l, almost five times that of nickel foam. Granules contain a significantly lower proportion of nickel – around 45 - 55% – balanced by an equivalent amount of aluminium. Unlike foam, granules are typically activated in situ, requiring additional processing steps before they can be used effectively.

These differences lead to distinct performance characteristics. The open cell architecture of nickel foam supports greater reactant-catalyst contact, lower pressure drop, and reduced abrasion, while the higher nickel content enhances catalytic activity and simplifies metal recovery. Granules remain a familiar option for many plants, but their heavier structure, lower nickel content, and activation requirements make them less flexible and less efficient for modern fixed bed hydrogenation.

Unlocking new process possibilities

Activated nickel foam creates opportunities to design and adapt processes around the catalysts' high activity and low bed volume requirements. Plants can tailor operating conditions and reactor geometries to make better use of the foam's performance characteristics. Since the catalyst performs effectively at lower pressure and with reduced energy input, next generation reactors can be smaller, more efficient, and more cost-effective to build and operate. This shift unlocks both sustainability gains and profitability improvements.

Performance in INAL hydrogenation

When applied in the hydrogenation of isononanal (INAL) to isononanol (INA), the Metalyst 9 series demonstrated excellent activity, selectivity, and long-term stability.

Testing was conducted in a two-stage reactor system:

- An upstream cycle reactor equipped with a Metalyst 981 foam fixed bed.
- A downstream finishing reactor containing a continuous catalyst.

Stress tests ran for over 3000 hours, with deliberate variations in temperature and feed load. Throughout these conditions, the system showed no meaningful performance degradation. Metalyst 981 consistently performed due to its unique physico-chemical properties, high surface area, and enhanced catalytic activity.

Conclusion

As chemical producers continue to balance cost pressure, energy efficiency, and sustainability expectations, catalyst technology is becoming an increasingly important factor in process improvement. Activated nickel foam catalysts offer a practical route to more efficient, reliable, and resource-conscious hydrogenation.

By combining high catalytic activity with a ready-to-use, support-free format, nickel foam can help simplify handling, improve safety, reduce pressure drop, and support easier reclamation. Its performance also creates opportunities to rethink reactor design, enabling smaller, purpose-built systems that can reduce energy use, save time, and lower capital requirements.

With demand for activated metal catalysts continuing, supply reliability remains critical and activated metal catalyst manufacturers can help customers manage this demand and advance more efficient hydrogenation processes.

Note

*This novel catalyst type is manufactured under a license from Alantum Europe GmbH.



MAXIMISING MATERIALS

After nearly a century of steam reforming innovation, catalyst science is still evolving. **Jumal Shah, Honeywell Technologies,** charts the evolution of steam methane reforming and important considerations that lie ahead for catalyst development.

Steam methane reforming (SMR) has been the foundation of industrial hydrogen production for almost 90 years. It continues to supply the hydrogen required for ammonia, methanol, and refinery operations, supporting industries that remain essential to modern agriculture, manufacturing, and energy. While new hydrogen production pathways continue to emerge, the reality is that steam reforming will remain responsible for a substantial proportion of global hydrogen production for decades to come.

The longevity of SMR technology reflects an ability to evolve. Improvements in furnace design, process integration, and heat recovery have steadily increased plant efficiency, while catalyst innovation has enabled reformers to become larger, more reliable, and more energy efficient. Throughout the history of steam reforming, advances in catalyst technology have consistently addressed the industry's changing engineering priorities.

Over the last 90 years, reforming catalyst development has progressed from establishing reliable large scale hydrogen production to improving mechanical strength, reducing pressure drop, extending catalyst life, and enhancing energy efficiency. Today, however, the industry's priorities are changing again. Operators are expected to improve plant performance while simultaneously reducing operating costs, lowering emissions, and making more efficient use of critical raw materials.

For many existing reformers, operators are therefore looking for incremental improvements that maximise the performance of installed assets without requiring major capital investment. Catalyst technology remains one of the most effective ways of achieving those gains because catalyst selection influences feed conversion, pressure drop, fuel consumption, catalyst life, and overall operating economics, while allowing upgrades during routine turnarounds without major modifications to the reformer itself.

One material has become central to that challenge. Nickel has long been the preferred active metal for steam reforming because it offers an excellent combination of catalytic activity, durability, and cost-effectiveness. However, nickel-price volatility

and increasing sustainability requirements have prompted catalyst developers to rethink how efficiently the metal is used. Rather than simply increasing nickel loading to improve performance, the focus is shifting towards ensuring that every gram of nickel delivers the greatest possible value.

This change represents the latest stage in the evolution of reforming catalyst technology. It reflects a broader transition from developing more active catalysts to engineering smarter ones, using advances in materials science, manufacturing, and reaction engineering to improve both plant performance and resource efficiency.

From catalyst activity to catalyst utilisation

The chemistry of SMR has changed little over the past nine decades, but the engineering requirements placed on reforming catalysts have evolved considerably. Each generation of catalyst development has addressed the engineering priorities of its time.

The earliest commercial catalysts established nickel as the preferred active metal for large scale hydrogen production, enabling the rapid expansion of ammonia and methanol manufacturing. As demand increased, reformers became larger, operating temperatures rose, and plants sought longer production campaigns. Catalyst development therefore evolved from simply providing sufficient activity to maintaining reliable performance under progressively more demanding operating conditions.

Mechanical strength became a key priority. Steam reformers are exposed to repeated thermal cycling during start-ups, shutdowns, and operational disturbances. Catalyst pellets that fracture generate fines, increasing pressure drop and restricting gas flow through the reformer tubes. Improved support materials and manufacturing techniques therefore focused on producing catalysts capable of maintaining their integrity throughout operating cycles that today frequently exceed five years.

Catalyst geometry also evolved. Smaller pellets increase surface area but also increase resistance to gas flow resulting in higher pressure drop across the catalyst bed. Multi-hole and QUADRALOBE™ geometries increased the surface area and hence the activity, and improved heat and mass transfer while maintaining acceptable pressure drop. At the same time, advances in catalyst chemistry enhanced hydrothermal stability and resistance to carbon formation, allowing catalysts to maintain activity over progressively longer operating cycles and lower steam to carbon ratios.

These developments transformed reformer performance, but they also revealed a more fundamental opportunity. Advances in computational modelling and catalyst characterisation demonstrated that many industrial reformers operate under diffusion-limited conditions. Although methane reacts rapidly once it reaches an active nickel site, it takes time for reactant molecules to diffuse through the pore network within each catalyst pellet. Consequently, much of the reforming reaction occurs within the outer region of the pellet.

This represented an unavoidable consequence of conventional manufacturing methods, which typically distribute nickel throughout the pellet. Without targeted deposition, however, not all the active metal is utilised during operation.

As operators placed greater emphasis on resource efficiency and lifecycle sustainability, this distinction became increasingly important. The challenge was no longer simply to develop a more active catalyst, but to make more effective use of the nickel already present within it and even reduce the metal content. This required a fundamentally different approach to catalyst design.

Engineering nickel utilisation

Improved understanding of catalyst behaviour has fundamentally changed the philosophy of reforming catalyst design. Rather than measuring catalyst performance solely by the quantity of active metal it contains, now the focus is on where that active metal is located and how effectively it participates in the reforming reaction.

Honeywell Technologies' NiVARA™ technology has been developed around this principle. Instead of distributing nickel uniformly throughout the catalyst pellet, the technology concentrates the active metal within the outer region of the catalyst pellet, where the reaction takes place. By placing more nickel within this mass transfer-active zone, a greater proportion of the available nickel participates directly in

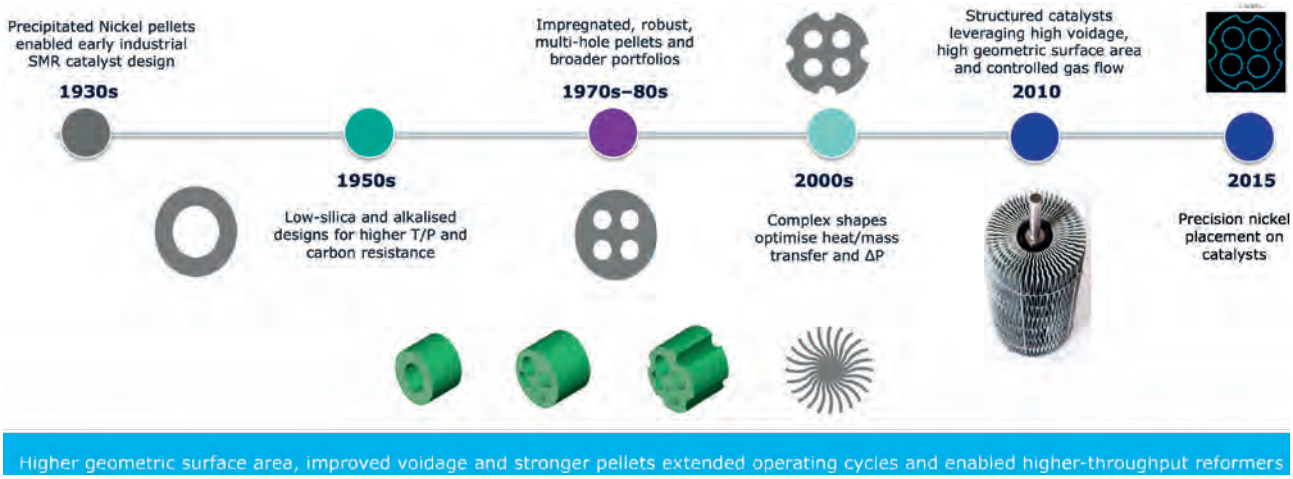


Figure 1. Evolution of steam reforming catalyst design.

methane conversion, significantly increasing the nickel utilisation.

The development of this approach has been supported by advances in computational modelling, catalyst testing facilities, and advanced catalyst characterisation, which have provided a much deeper understanding of mass transfer and catalyst behaviour under diffusion-limited reforming conditions. These insights have enabled identification of the most effective location for the active metal within the catalyst pellet.

Achieving this level of precision has required advanced manufacturing control and carefully tailored metal-support chemistry to manage the location, dispersion, and density of nickel within the catalyst pellet. These capabilities enable precise control over nickel distribution within the mass transfer-active zone.

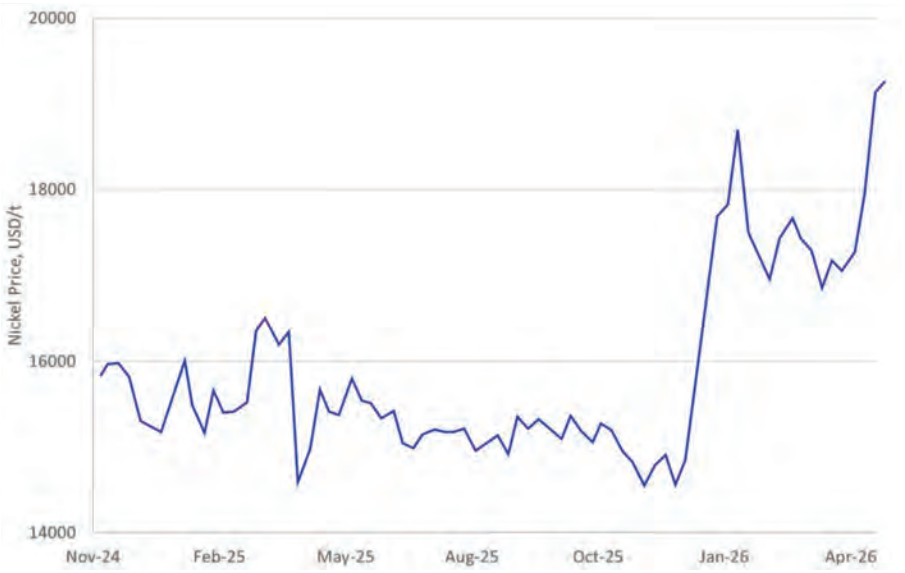


Figure 2. Recent nickel price volatility.

The implications extend beyond catalyst activity. Nickel is an important industrial raw material used across sectors ranging from stainless steel production to battery manufacturing. Improving nickel utilisation therefore reduces dependence on a critical material while also lowering the environmental impact associated with catalyst manufacture. Compared with conventional fully impregnated catalysts, the lower nickel inventory can reduce the catalyst manufacturing carbon footprint by up to approximately 30%. Operational performance and resource efficiency become complementary rather than competing objectives.

Commercial experience has demonstrated the practical value of this approach. Since initial field trials began in 2015,

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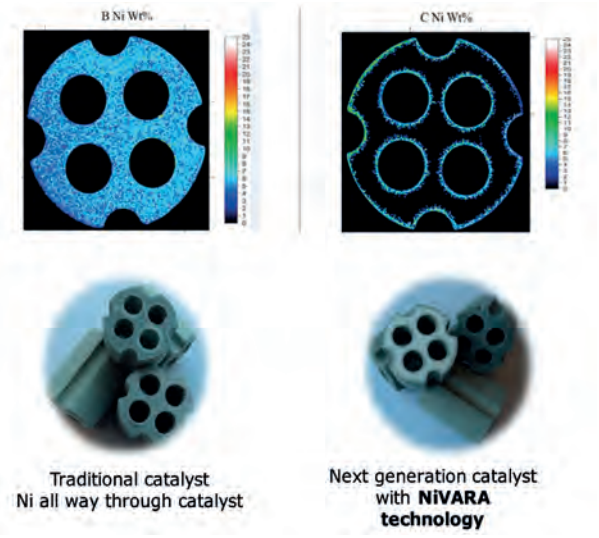


Figure 3. By concentrating nickel at the surface of the catalyst pellet, a greater proportion of the available nickel participates directly in methane conversion. Lower nickel inventory can reduce the catalyst manufacturing carbon footprint by up to approximately 30%.

catalysts incorporating NiVARA technology have been installed over 200 times in ammonia, methanol, and hydrogen plants. Operating data has shown that precision nickel placement can achieve methane slip and approach-to-equilibrium performance comparable with conventional catalysts containing substantially higher nickel loadings. For many operators, this translates into lower catalyst fill costs while maintaining the reliability required for long operating campaigns.

Importantly, these benefits can be realised without modifying the reformer itself or the operating conditions. The technology has been developed as a direct replacement for conventional reforming catalysts, allowing operators to introduce it during routine catalyst replacement without changes to reformer hardware, loading procedures, or operating philosophy.

However, precision nickel placement represents only part of a much broader evolution in reforming catalyst engineering. Conditions vary significantly along the length of every reformer tube. Gas composition, reaction equilibrium, temperature, and carbon formation potential all change as reforming progresses. Operators are responding by designing catalyst beds that combine different catalyst formulations according to the operating conditions encountered within each section of the reformer.

Catalyst selection can also be tailored to the conditions encountered within different parts of the reformer. Promoted formulations can help address carbon-formation risks, while catalysts incorporating NiVARA technology can improve nickel utilisation in the middle and outlet sections of the tube, where diffusion limitations have the greatest influence on performance.

This integrated approach reflects the direction in which reforming catalyst development is moving. Modern catalyst engineering combines advanced materials science, precision manufacturing, and detailed process understanding to deliver solutions tailored to the specific requirements of each reformer.

The next chapter of catalyst innovation

After 90 years of continuous development, catalyst innovation continues to evolve alongside the needs of the industries served by SMR.

Advances in computational modelling, materials science, and catalyst manufacturing are allowing engineers to optimise catalyst performance with far greater precision than was previously possible. These developments are supporting the development of more tailored catalyst systems that combine optimised active metal placement, advanced catalyst architectures, and application-specific catalyst selection.

Structured catalyst technologies, such as Honeywell Technologies' CATACEL SSR™ technology, illustrate this trend. By replacing conventional packed catalyst beds with precision-engineered metallic structures, they improve radial heat transfer and activity, reduce process-side pressure drop, and promote more uniform gas flow through the reformer. These improvements help reduce furnace fuel consumption while providing greater operational flexibility and lower associated carbon emissions.

Future progress is therefore unlikely to be driven by a single breakthrough. Instead, it will come from combining precision active metal placement, advanced catalyst architectures, optimised loading strategies, and sophisticated engineering tools. Together, these developments enable operators to improve efficiency, reduce resource consumption, and extend catalyst life without fundamentally changing the steam reforming process itself.

As demand for hydrogen continues to grow, these improvements will remain highly significant. Whether supporting conventional ammonia and methanol production or enabling lower-carbon hydrogen production alongside carbon capture, existing steam reformers will continue to play a central role in the global energy system. Enhancing the efficiency of existing steam reformers therefore remains one of the most practical opportunities to reduce both operating costs and emissions across industrial hydrogen production.

Conclusion

The history of steam reforming demonstrates that even the most established industrial technologies continue to evolve. Each generation of reforming catalyst innovation has responded to the changing priorities of its time.

Today's priorities centre on resource efficiency and sustainability of manufacturing as much as catalytic activity. Innovations demonstrate how a deeper understanding of catalyst behaviour is enabling engineers to improve the utilisation of critical raw materials and reduce emissions while maintaining the performance and reliability demanded by modern hydrogen plants. Combined with advances in catalyst architecture and system-level optimisation, they demonstrate that catalyst innovation remains a powerful driver of reformer performance.

After 90 years of reforming catalyst development, the next generation of reforming catalysts will not be defined by how much nickel they contain, but by how intelligently that nickel is used to improve efficiency, reduce emissions, and maximise the value of existing reforming assets.

Performance of a revamped air cooler

Yang Quan, Fitri Juniwati, Tan HianMin, and He Zi-Qian, Sulzer Chemtech, Switzerland, alongside Yang Yuliang, Oxygen Plant of Nanjing Iron and Steel United Co., China, evaluate the performance of a direct contact air cooler revamp that demonstrated how the use of structured packing and anti-fouling internals prevented vapour and liquid maldistribution.

In 2017, the operator of a cryogenic air separation plant with a capacity of 4300 Nm^3/hr in terms of oxygen, appointed Sulzer to evaluate the feasibility of revamping its direct contact air cooler (DCAC).

The DCAC cools and scrubs compressed atmospheric air via counter-current water contact, minimising moisture and thermal load on downstream purification units.[1] As shown in Figure 1, the existing column consisted of two beds. The chilled water (generated via a chiller) and the cooling water are fed to the top of the top bed and the bottom bed respectively, while the hot compressed air is introduced at the bottom of the column.

The DCAC was originally equipped with plastic random packing or 'rings.' A site inspection was conducted in 2018 during a planned turnaround after the column had undergone washing. Physical inspection revealed that the lateral arms of the top liquid distributor were completely filled with water (Figure 2a), indicating severe blockage of the discharge orifices on the bottom plate. The plastic random packing was heavily fouled and exhibited brittleness. Furthermore, a heavy accumulation of sludge and particulate matter was found piled in the column sump and around the manhole nozzles (Figure 2b).

The operational logs indicated that the outlet temperature of the cooled air at the top of the DCAC had consistently reached up to 20°C over the preceding few years. This exceeded the typical industrial design threshold of 15 - 17°C required to adequately reduce moisture load prior to downstream processing. The original design

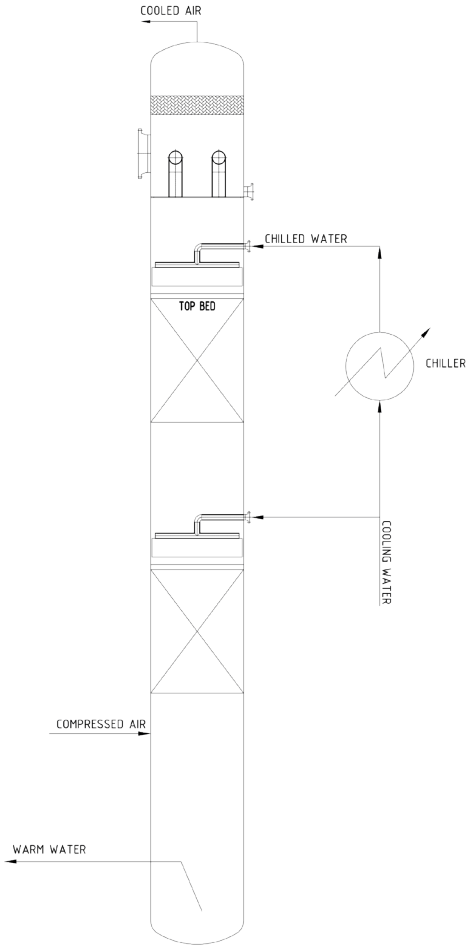


Figure 1. Schematic, the DACA column, and the chiller.



Figure 2. The existing top trough distributor with the arms full of water (left, a) and one of the column manholes (right, b).

Table 1. Original design vs pre-revamp operational data

	Flow rate			Temperature		
	Design	Operation	Unit	Design	Operation	Unit
Compressed air feed	23.8*	20.5*	kNm^3/hr	120.0	Up to 105.0	°C
Chilled water feed	9.9	10.1	tph	10.0	10.0 ~ 11.5	°C
Cooling water feed	109.0	50.0	tph	32.0	Up to 36.0	°C
Cooled air product	23.8*	20.5*	kNm^3/hr	14.0	17.0 ~ 20.0	°C
*Note: dry basis, excluding moisture content within the compressed air						

documentation was retrieved and compared against the pre-revamp operational data in Table 1.

As shown in Table 1, the operating temperature of the cooled air reached up to 20°C, representing a substantial approach temperature of more than 10°C relative to the chilled-water temperature. This elevated temperature led to a higher saturated water content in the air stream, overloading the molecular sieve vessels installed downstream for drying by adsorption. This operational bottleneck risked carrying over traces of hydrocarbons, CO_2, and moisture into the cryogenic cold box. Consequently, the adsorption vessels required more frequent thermal regeneration cycles, resulting in higher operating costs.

Additionally, the cooling water flow rate during operation had been intentionally reduced to approximately half of the design value (50 tph vs 109 tph) to lower utility costs. The operational pressure drops across the top and bottom beds were recorded at 105 mm H_2O and 55 mm H_2O, respectively, remaining safely below the vendor-specified hydraulic limits of 300 mm H_2O and 150 mm H_2O.

Existing column configuration

The original 1.5 m dia. column was equipped with a 150 mm mesh-pad mist eliminator installed at the top of the vessel. Immediately below the mesh pad was a dedicated water droplet collection compartment designed to drain the captured liquid through a drainage nozzle. The chilled water entered through an inlet pipe into a trough-type distributor with discharge orifices opened on the bottom plate. A pan-type liquid distributor was situated below the top bed to collect the chilled water and combined it with the incoming cooling-water feed. Small-size plastic 2nd generation random packings filled the top bed, whereas the bottom bed contained a mixture of larger-size plastic and metallic random packings.

Preliminary evaluations concluded that the column diameter and packing bed heights were adequate in terms of mass and heat transfer efficiency, and hydraulic capacity. Given that the beds had not reached their hydraulic capacity limit, the poor performance was attributed to severe liquid and vapour maldistribution generated by the severe fouling of the random packings and orifice plugging in the distributors. Consequently, the revamp strategy focused on implementing column internals engineered with anti-fouling features.

Revamp proposal

Process simulations and hydraulic design

Within this DCAC column, the lower bed performs bulk heat removal while the

upper bed provides polishing. The process utilises two heat transfer mechanisms: latent heat removal driven by moisture condensation and sensible heat removal driven by the temperature difference between the liquid water and the compressed air.

Low-surface-area structured packings – field-proven by Sulzer in fouling DCAC applications – were selected for the revamp. The hydraulic and mass and heat transfer characteristics of these packings were verified using industrial data and integrated into Sulzer's proprietary simulation and hydraulic rating models.[2]

Process simulations indicated that a cooling water flow rate of 50 tph was sufficient to perform bulk heat removal, validating the plant's historical operating approach. However, the overhead cooled air temperature exhibited high sensitivity to variations in the chilled water flow rate, indicating that any reduction in the chilled water throughput would severely compromise cooling effectiveness.

As shown in Table 2, the simulation also indicated that a 1°C thermal approach temperature between the exit air and inlet chilled water was achievable when replacing the existing random packing with a high-efficiency structured packing.

The calculated capacities for the top and bottom beds are 36.2% and 52.1%, with predicted pressure drops of 38.4 mm and 18.7 mm H_2O, respectively. These calculations demonstrate that replacing random packing with structured packing will yield significant additional hydraulic capacity.

Mechanical design optimisation

A new mesh pad mist eliminator was installed using the existing column attachments at the top of the tower. The redundant water-droplet collection compartment located below the mesh pad was removed, as it was no longer required.

Metallic structured packings with varying surface areas were utilised across the two beds to precisely cater to the varying volumetric vapour flow rates throughout the column.

A high-performance line-type liquid distributor was specified for the top bed. In contrast to the original trough design, this advanced distributor utilises elevated discharge orifices drilled into the sidewalls of the distributor arms, feeding secondary splash plates attached to the arms. This geometry effectively mitigates fouling by preventing suspended solids from settling directly into the flow orifices. Furthermore, the pan-type distributor above the bottom bed was redesigned specifically for the optimised 50 tph flow rate rather than the historical 109 tph design point. This modification ensured a sufficient operating liquid head within the pan, preventing liquid maldistribution and securing bulk heat and mass transfer across the bottom bed.

Commissioning and long-term performance

Commissioning phase

The revamped DCAC was recommissioned in December 2020. The plant was operated with air feed, chilled water, and cooling water circuits precisely at their design rates. The initial operating pressure drops recorded by the Distributed Control System (DCS) matched with the simulated hydraulic models. Furthermore, the overhead cooled air temperature stabilised at 12.5°C against an actual chilled water inlet temperature of 11.9°C, achieving a tight thermal approach of just 0.6°C.

Table 2. Revamp process design

Feed condition	Air feed temperature (°C)	105.0
	Air feed flow rate, dry (kNm^3/hr)	20.5
	Chilled water flow rate (tph)	10.0
	Chilled water temperature (°C)	10.0
	Cooling water flow rate (tph)	50.0
	Cooling water temperature (°C)	32.0
Product condition	Calculated temperature of the cooled air (°C)	10.7

Table 3. Cooling water quality analysis

Item	November 2023
Electric conductivity (uS/cm)	2090
Total-hardness (mg/l as $CaCO_3$)	472
Calcium-hardness (mg/l as $CaCO_3$)	300
M-alkalinity (mg/l as $CaCO_3$)	220
Chloride (mg/l as Cl^-)	461
Silica (mg/l as SiO_2)	75.87
Langelier saturation index (LSI) (at 60°C)	1.95
Ryznar stability index (RSI) (at 60°C)	4.52

Five year performance evaluation

Following three years of smooth operation (from January 2021 to December 2023), the approach temperature remained below 1°C. However, the plant observed a gradual increase in the top-bed pressure drop, while the bottom-bed pressure drop remained unchanged. Seeking technical guidance, in December 2023, the plant operators contacted Sulzer and initiated a comprehensive exchange of operating data, which included the analysis of the cooling water quality.

Cooling water quality analysis

The plant had been operating its utility water at 5.3 - 6.4 cycles of concentration (CoC). CoC expresses the degree to which dissolved calcium in the makeup water is concentrated due to evaporation. While operating at a lower CoC causes excessive water waste, higher CoC increases scaling and corrosion risks. Running at a CoC of 5.3 - 6.4 requires a high dosage of chemical dispersion polymers alongside continuous maintenance, as it tends to force scaling minerals out of solution.

Although each water quality value in Table 3 falls within standard thresholds, analysing them individually does not reflect the actual equilibrium as a mixture. Scaling is driven by an interactive chemical equilibrium where multiple variables influence their solubility. The combined impact of these variables is reflected in the indexes of LSI and RSI.

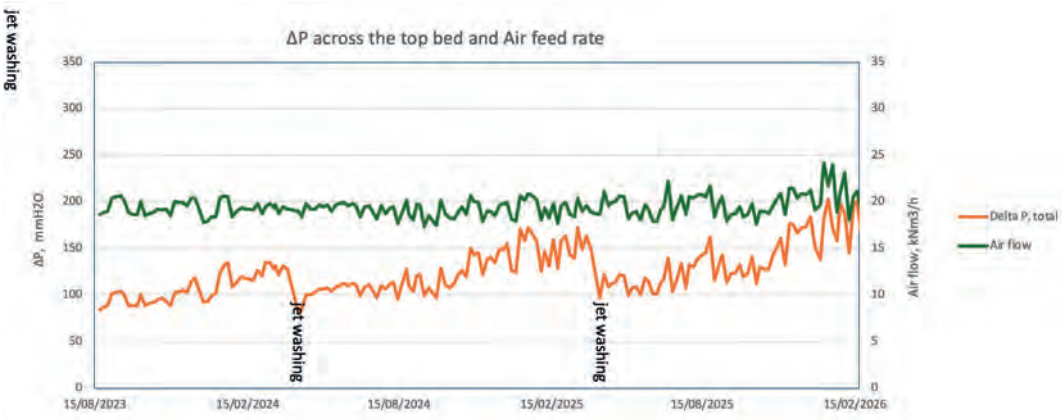


Figure 3. The air flow rate and the pressure drop of the top bed.

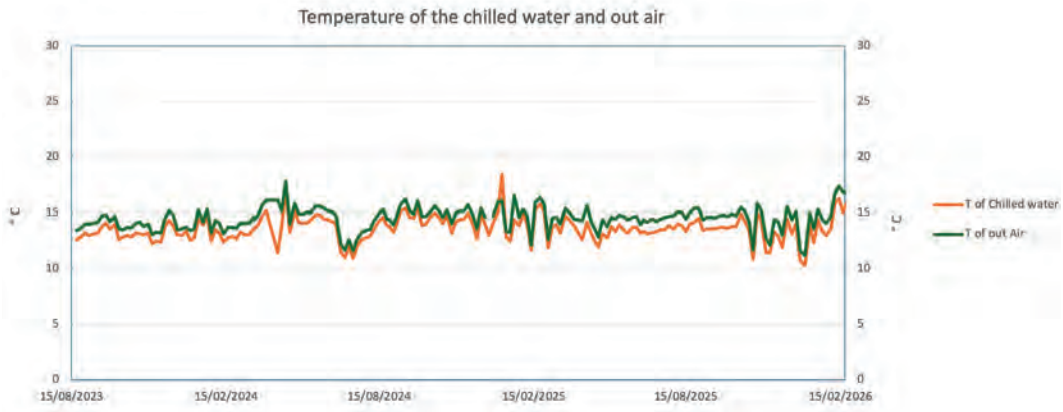


Figure 4. The temperature of the chilled water and the temperature of the cooled air.

Specifically, an LSI of 1.95 coupled with an RSI of 4.52 confirms a strong, highly concentrated tendency toward heavy calcium carbonate ($CaCO_3$) precipitation and mineral scaling.[3]

This scaling mechanism had already impaired the chiller, causing the chilled water temperature to drift above 14°C, and the plant has scheduled a full chiller replacement for 2H26. Because isolating the DCAC water circuit or installing an advanced chemical water treatment facility is not economical, the plant opted to maintain its open-loop operating configuration.

Approach temperature and pressure drop trends

The top bed pressure drop rose steadily reaching 75 mm H_2O by August 2023. In contrast, the bottom bed was largely resilient to fouling due to a six-fold higher water flow rate compared to the top bed, thus the pressure drop across the bottom bed remained stable.

In January 2024, Sulzer completed an engineering assessment confirming that the structured packing could safely tolerate a hydraulic differential up to 350 mm H_2O for the top bed before risking severe liquid entrainment and recommended high-pressure water jetting during scheduled annual shutdowns.

During the 2024 and 2025 maintenance periods, the plant executed water-jetting cycles while the packing beds remained inside the column. As shown in Figure 3, the 2024 wash effectively brought the top bed back to 75 mm H_2O. The 2025 wash was marginally less effective due to the progressive compaction of mineral scale, leaving the post-wash pressure drop at 100 mm H_2O. Sulzer has recommended executing a more specialised, chemically assisted wash during the next major turnaround.

Figure 4 tracks critical temperatures over an operational window starting from August 2023 to February 2026. Throughout this period, the approach temperature consistently held near the 1°C target. It should be noted that the observed baseline increase in the cooled air temperature was entirely driven by the performance degradation of the chiller (the inlet temperature of the chilled water is on average 3°C higher than the one during commissioning) rather than mass and heat transfer inefficiencies within the column.

Conclusions

The DCAC column revamp from random packings to high-efficiency structured packing and anti-fouling internals resolved a critical 10°C thermal approach bottleneck, stabilising it at approximately 1°C over a five year operational duration. This long-term performance demonstrates that structured packing prevents vapour and liquid maldistribution during severe mineral and particulate fouling, unlike random packings which are highly prone to failure under identical conditions. Furthermore, the extra hydraulic capacity gained from the upgrade accommodates gradual fouling build-up. To sustain these gains, regular wash cycles during scheduled maintenance are highly recommended post-commissioning, as cleaning effectiveness can degrade over extended run lengths.

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Temperature MEASUREMENT STRATEGIES



Michele Pietroni, Endress+Hauser, Italy, examines the role of temperature measurement in supporting effective heat exchanger operation, process control, and asset integrity within sulfur recovery units.

Sulfur recovery units (SRUs) are essential process systems in oil refining, gas processing, and petrochemical facilities. Their primary purpose is to convert the hydrogen sulfide (H_2S) contained in acid gas streams into elemental sulfur, reducing emissions while supporting compliance with increasingly stringent environmental regulations.

The Claus process remains the dominant sulfur recovery technology. In the thermal stage, a portion of the hydrogen sulfide is oxidised to sulfur dioxide (SO_2), while subsequent catalytic stages promote the conversion of sulfur-bearing compounds to elemental sulfur according to:

$$2H_2S + SO_2 \rightarrow 3S + 2H_2O$$

Between the reaction stages, condensers and reheaters perform essential heat management functions. Sulfur condensers cool the process gas below the sulfur dew point, typically in the range of 140 - 180°C depending on gas composition and operating conditions, enabling sulfur recovery in liquid form. Reheaters then restore the gas temperature before it enters the next catalyst bed. Together, these heat exchange steps influence sulfur recovery efficiency, catalyst activity, equipment reliability, energy consumption, and overall process stability.

Because sulfur behaviour is highly sensitive to temperature, thermal management throughout the condenser-reheater train becomes one of the most important aspects of SRU operation. Accurate temperature information is therefore required not only for process control, but also for maintaining equipment integrity and supporting long-term operational reliability.

Process challenges and the importance of temperature control

The Claus process relies on repeated cycles of cooling, sulfur condensation, and reheating. Each cycle must operate within a relatively narrow temperature window to maximise sulfur recovery while avoiding operational and mechanical problems.

Condensation challenges

The primary function of the condenser is to recover sulfur from the process gas by cooling it below the sulfur dew point. However, cooling must be carefully controlled. While the sulfur dew point typically lies between 140 - 180°C, temperatures must also remain sufficiently above the sulfur solidification region, where solid particles may begin to appear at approximately 120°C.

The most common operational consequences of inadequate temperature control include:

- Sulfur deposition and fouling.
- Increased pressure drop.
- Restricted flow paths.
- Reduced heat transfer efficiency.
- Accelerated corrosion.
- Increased maintenance requirements.

Beyond sulfur phase changes, uneven temperature distribution can generate localised thermal stresses that affect exchanger reliability over time. Operators must therefore achieve sufficient cooling to recover sulfur efficiently without creating conditions that promote solidification, excessive stress, or equipment degradation.



Figure 1. The non-invasive TM611 provides additional temperature monitoring points without process interruption, helping operators assess heat losses, condensation risk, and equipment performance.



Figure 2. Piles of elemental sulfur – a byproduct of oil refining and natural gas processing.

Reheating challenges

Following sulfur recovery, the gas must be reheated before entering the next catalytic reactor. In practice, operators typically maintain a safety margin of approximately 20 - 30°C above the expected sulfur dew point to minimise condensation risk in downstream equipment.

The reheater serves several important functions:

- Maintaining operation above the sulfur dew point.
- Preventing sulfur deposition in downstream piping.
- Preserving catalyst activity.
- Supporting favourable reaction kinetics.
- Maintaining efficient sulfur conversion.

Insufficient reheating can result in sulfur condensation within transfer lines and catalyst beds, leading to pressure-drop increases, catalyst fouling, and reduced reactor performance. Conversely, excessive temperatures may negatively affect process efficiency, increase utility consumption, and accelerate catalyst ageing.

Typical Claus reactor temperature ranges

The importance of reheater performance becomes evident when considering reactor inlet temperature requirements. Although actual values depend on process design and gas composition, catalytic reactor inlet temperatures typically fall within the following ranges:

- First catalytic reactor: 240 - 300°C.
- Second catalytic reactor: 200 - 260°C.
- Third catalytic reactor (where applicable): 200 - 260°C.

Maintaining these temperatures supports catalyst performance, reaction kinetics, and overall sulfur conversion efficiency. Because condenser and reheater performance directly influences reactor inlet conditions, temperature control throughout the heat exchanger train remains critical.

Why temperature becomes the critical process variable

Because sulfur phase transitions are governed primarily by temperature, relatively small deviations can significantly affect process performance and equipment integrity.

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Temperature directly influences sulfur recovery efficiency, catalyst performance, heat transfer effectiveness, energy consumption as well as corrosion and fouling behaviour.

For these reasons, temperature measurements are commonly incorporated into the primary control strategies of both condensers and reheaters. Tight temperature control supports stable operation, protects critical equipment, and helps maintain sulfur recovery performance across the entire unit. In critical areas, operating tolerances are often maintained within only a few degrees of the target temperature.

Temperature measurement requirements along the condenser-reheater train

Effective monitoring requires more than inlet and outlet measurements on each exchanger. A comprehensive temperature strategy should provide visibility into process conditions, equipment thermal behaviour, and heat transfer performance throughout the system.

Condenser inlet and tubesheet

Measurements at the condenser inlet establish the thermal conditions entering the exchanger and provide valuable information regarding:

- Process gas temperature.
- Thermal loading of nozzles and tubesheets.
- Refractory performance.
- Start-up and shutdown behaviour.

Additional surface temperature measurements can help identify abnormal thermal gradients that may contribute to equipment stress, distortion, or reduced service life.

Condenser tube bundle

The tube bundle and tubesheet are critical heat transfer areas where temperature distribution influences both exchanger efficiency and mechanical reliability.

Typical monitoring objectives include:

- Evaluating cooling uniformity.
- Identifying local hot spots.
- Tracking thermal gradients.
- Assessing heat transfer effectiveness.
- Monitoring potential stress concentrations, particularly on the critical welded joint between tubes and tubesheet.

The tube skin measurement approach with low invasiveness is the recommended solution to reach several detection points providing insight into heat transfer performance and evolving fouling conditions.

Condenser outlet and transfer lines

The condenser outlet represents a key process measurement point because it reflects sulfur recovery performance and determines the thermal condition of gas entering downstream equipment.

Temperature measurement technologies for SRU applications

The measurement strategy adopted in SRUs depends on process conditions, installation constraints, and monitoring objectives. In practice, operators often combine several complementary temperature measurement approaches to obtain visibility into both process performance and equipment condition. Common approaches include:

Thermowell-based process temperature measurements

Intrusive temperature measurements are typically used where direct process temperature is required for control, heat-balance calculations, and equipment protection. In SRU service, sensor assemblies must withstand:

- Sulfur-rich environments.
- Elevated temperatures.
- Thermal cycling.
- Vibration and mechanical stresses.

Applications commonly include condenser and reheater inlet and outlet nozzles, shell-side measurements, and liquid sulfur monitoring.

Tube-skin temperature measurements

Surface temperature monitoring of tubes, tubesheets, and other critical components can provide valuable information on:

- Thermal gradients.
- Heat-transfer effectiveness.
- Fouling development.
- Thermal expansion behaviour.

These measurements are particularly useful where process temperatures alone do not fully describe exchanger performance.

Non-invasive temperature measurements

Non-invasive measurement technologies can be used where additional monitoring points are required without penetrating the process boundary. Typical applications include:

- Transfer piping temperature profiling.
- Insulation-performance assessment.
- Heat-loss monitoring.
- Energy-balance calculations.

Because installation can often be performed without process interruption, these technologies can support brownfield upgrades and condition-monitoring programmes.

A combined measurement strategy

No single measurement technology can address every monitoring requirement within an SRU. The most effective approach is often a combination of measurements to provide the information required to support process optimisation, reliability improvement, and predictive maintenance initiatives.



Process improvement
is ensuring plant availability while ensuring compliance.

In the oil and gas industry, ensuring highest safety and plant availability is crucial, while achieving decarbonization goals has also become a critical imperative. Our comprehensive portfolio and expertise enable process improvements that increase operational reliability and move us towards net zero targets.

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Figure 3. An SRU in an oil refinery can reduce emissions and promote environmental sustainability.

Monitoring objectives include verification of sulfur condensation performance, identification of phase-transition conditions, monitoring liquid sulfur stability, detection of heat losses, and evaluation of recovered heat energy.

Temperature measurements along transfer piping can help identify insulation deficiencies and detect conditions approaching sulfur condensation.

Reheater inlet

The reheater inlet temperature provides an overall indicator of upstream condenser performance and heat losses occurring between process stages.

Measurements at this location can support the verification of process stability, identification of abnormal cooling conditions, assessment of sulfur condensation risk, and maintenance planning and inspection activities.

Reheater outlet and reactor feed

The reheater outlet is one of the most important temperature measurements within the SRU because it directly influences reactor inlet conditions.

Monitoring objectives include:

- Maintaining target reactor temperatures.
- Preventing sulfur condensation.
- Supporting reactor performance.
- Evaluating reheater effectiveness.
- Optimising energy utilisation.

These measurements are frequently used as primary control variables within automatic temperature-control systems.

Reheater shell and tube side

Temperature measurements throughout the reheater provide additional information regarding heat transfer performance and equipment condition.

Typical applications include:

- Monitoring heating-medium temperatures.
- Evaluating exchanger performance.
- Identifying cold spots and thermal anomalies.
- Assessing thermal expansion behaviour.
- Tracking conditions associated with corrosion or mechanical degradation.

Combining process-temperature measurements with equipment-surface measurements can provide a more complete picture of exchanger performance and integrity.

Additional measurements on the shell side, tube side, internal sealing zones, and external surfaces of reheaters can provide valuable information on heat transfer performance, thermal expansion behaviour, and equipment condition. Together, these measurements offer a more complete understanding of exchanger operation than process-fluid temperatures alone.

Temperature data as a reliability and maintenance tool

Although temperature measurement is often viewed primarily as a process-control requirement, it also provides important information regarding equipment health.

Long-term temperature trends can reveal subtle changes in heat transfer performance that may indicate fouling, insulation degradation, abnormal process conditions, or mechanical deterioration. Variations in temperature distribution may also identify developing thermal stresses, corrosion mechanisms, or operating conditions that could negatively affect catalyst performance.

For this reason, temperature measurements are increasingly incorporated into reliability and predictive-maintenance programmes. When analysed alongside process and operating data, they can provide early warning of performance degradation and support more proactive maintenance planning.

Conclusion

Condensers and reheaters perform a central role within SRUs by controlling the thermal conditions required for efficient sulfur recovery and effective catalyst operation. Their performance directly influences process efficiency, energy consumption, equipment reliability, and environmental compliance.

Accurate temperature measurement is therefore far more than a monitoring function. It provides the information required to control sulfur phase behaviour, maintain stable reactor conditions, evaluate heat exchanger performance, and protect critical assets.

By combining measurements at key process locations with systematic analysis of temperature trends, operators can improve sulfur recovery performance, reduce fouling and corrosion risks, optimise energy utilisation, support predictive maintenance initiatives, improve equipment reliability, and maintain stable long-term SRU operation.

Ultimately, effective temperature measurement provides the visibility required to balance process performance, equipment integrity, and operational reliability across the entire condenser-reheater train.

Improving energy efficiency in diesel hydrodesulfurisation

Optimising heat recovery across the reactor and fractionation sections can reduce fuel consumption, emissions, and pressure drop while helping refiners make better use of existing assets. **Marcos Matsufugi and Jay Jeong, Alfa Laval,** explain.

Diesel hydrodesulfurisation (HDS) has been central to North American fuel production for nearly two decades. The US began phasing ultra-low-sulfur diesel into the highway market in 2006, while Canada introduced closely aligned requirements. Today, on-road diesel across both countries is generally limited to 15 ppm sulfur, enabling advanced exhaust aftertreatment systems to control particulate matter and nitrogen oxides effectively.

Producing compliant fuel remains technically and economically demanding. Refineries must maintain sulfur conversion as feed composition and catalyst activity change, while managing hydrogen, heater, compressor, and utility constraints. Operators must also reduce energy use and direct emissions without compromising throughput or reliability.

This is especially relevant across North America's mature refining base. Improvements will often come from modernising and debottlenecking existing units. In HDS, optimising heat recovery in the high-pressure reactor loop and low-pressure fractionation section can reduce utility demand and preserve equipment capacity, with a positive impact in the refinery's margins.

Heat recovery in the reactor loop

HDS removes sulfur by reacting sulfur-bearing molecules with hydrogen over a catalyst at elevated temperature and pressure. Feed is mixed with hydrogen-rich gas, preheated, and passed through a fired heater before entering the reactor. The effluent is then cooled and separated, with treated liquid passing to a stripper or fractionator.

The combined reactor feed/effluent exchanger is central to this process. Hot effluent leaving the reactor contains energy that is transferred to the colder feed and hydrogen mixture. Every unit of heat recovered reduces the additional duty required from the fired heater and the cooling duty required downstream.



Many HDS units use shell-and-tube exchanger trains for this service. While proven, this arrangement is not thermally efficient and is constrained by surface area, pressure drop, fouling, and plot space. Additional shells can also increase the installation CAPEX.

Thermal performance is commonly assessed by monitoring the hot-end approach temperature (HAT), the difference between the hot reactor effluent entering the exchanger and the heated feed leaving it. A smaller approach indicates greater heat recovery and a higher feed temperature at the fired-heater inlet.

Alfa Laval's Packinox is a large, welded plate heat exchanger designed for this high-pressure feed/effluent duty in HDS units. According to application data, the heat exchanger can achieve a HAT as low as 5°C (9°F), compared with approximately 30°C (54°F) for a conventional shell-and-tube train in an illustrative design. Depending on the process, the additional heat recovery reduced reactor-preheater fuel consumption and release capacity in the heater and downstream cooler. Lower pressure drop can also preserve recycle-compressor capacity. Actual results depend on the feed, operating conditions, and existing equipment.

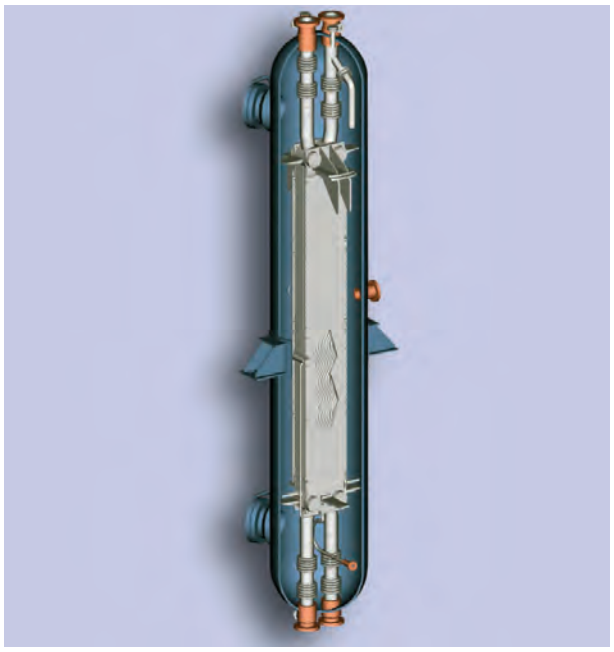


Figure 1. Packinox internal view.

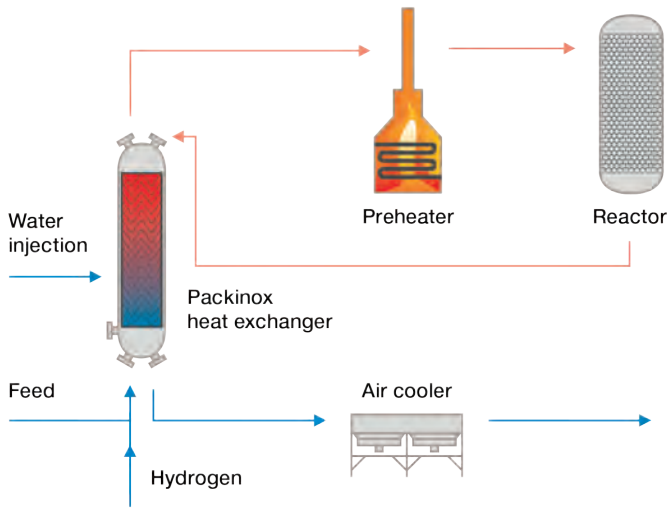


Figure 2. Packinox HDS diagram.

Fouling can affect that performance over time, particularly if ammonium salts accumulate on the effluent side of the exchanger at lower temperatures. Alfa Laval's PlateWash is an integrated cleaning system developed for Packinox in HDS services. By monitoring exchanger pressure drop, operators can identify when deposits begin to accumulate and initiate a water washing process during operation. This device allows the plates to be cleaned on-line, without stopping the unit, helping to maintain heat-transfer performance and avoid unplanned shutdowns.

Asian refinery case study

The refinery constructed two 63 000 bpd diesel hydrotreating units processing straight-run diesel blended with approximately 25 - 30% light cycle oil and light coker gas oil. Its objective was to limit CAPEX while maximising energy efficiency.

Instead of five shell-and-tube feed/effluent exchangers in each unit, the refinery installed one Packinox per train. This increased the fired-heater inlet temperature from 305°C to 350°C and reduced overall pressure drop from 18 bar to 11 bar. Furnace duty fell by approximately 80%, while compressor power consumption decreased by about 40%.

Across the two units, the reported energy saving was 15.5 MW. Using an assumed furnace efficiency of 85%, energy cost of €50/MWh and natural-gas firing, Alfa Laval calculated annual fuel and power savings of €6.8 million and avoided carbon dioxide emissions of 25 000 t.

Five years later, the refinery expanded sulfur-removal capacity by adding a second reactor to each train. With plot space restricted, it added another Packinox to each unit. Operating data showed a HAT generally between 5 - 15°C from 2007 to 2017, with limited fouling tendency and stable pressure-drop performance. The four units have accumulated between 16 and 22 years of operation.

Optimising the fractionation section

Further opportunities exist in the low-pressure stripper or fractionation section. Alfa Laval applies its Compabloc fully welded plate heat exchangers in duties including feed/bottoms interchanging, overhead condensation, product cooling, reboiling, and waste-heat recovery.

The feed/bottoms interchanger is often the first position to evaluate. Recovering heat from the hot fractionator bottoms to preheat the incoming feed reduces the load on both the final product cooler and fractionator reboiler. Maximising this duty with shell-and-tube technology may require several large exchangers, making the project costly or difficult to accommodate. A fully welded plate exchanger can accommodate temperature profile of seven to eight shell-and-tube exchangers in series configuration,

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Figure 3. Packinox installed.

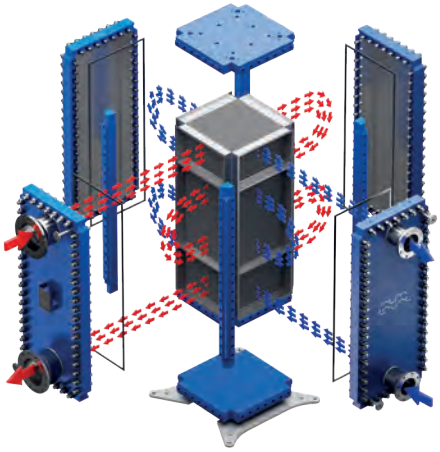


Figure 4. Compabloc ISO separated flow illustration.

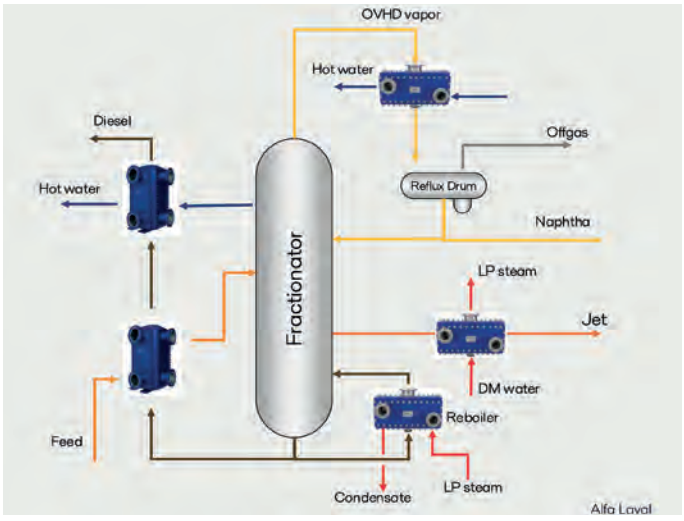


Figure 5. Optimised HDS fractionator design with Compabloc.

and achieve a temperature approach down to 3°C. This can often recover at least 25% more energy, reducing reboiler duty by an equivalent amount and potentially eliminating final product cooler.

The overhead condenser presents another opportunity. Column pressure is influenced by the pressure drop across the condenser. Shell-and-tube or air-cooled exchangers generally require higher pressure drop and a larger approach to the cooling-medium supply temperature.
A high-efficiency Compabloc condenser can operate with significantly lower pressure drop, which is usually below 10 000 Pa. For fractionator, lower pressure drop at the condenser will make the column operating pressure lowered, and lower operating pressure will reduce the reboiler duty and improve separation dynamics in the column.

Low-grade heat from overhead vapour and rundown streams is often rejected through cooling water or air coolers because conventional recovery can be difficult or uneconomic. Compabloc units can instead recover this energy as low-pressure steam or hot water. These utilities may support wastewater evaporation, boiler-feed-water heating, tank or plant heating, electricity generation through an organic Rankine cycle, or a district-heating network where suitable infrastructure exists.

After waste-heat recovery has minimised the remaining cooling load, plate technology can also reduce cooling-water circulation in final product and vapour trim coolers. Conventional shell-and-tube designs may operate with less than a 10°C difference between cooling-water supply and return. By maximising the return temperature in a compact exchanger, cooling-water flow can be reduced by as much as 50%, lowering pumping energy and relieving an existing utility system.

A whole-unit approach

These opportunities should be assessed as an integrated system. Greater heat recovery can change heater and reboiler duties, column pressure, cooling-water temperatures, and downstream loads. An optimisation study should use reconciled data and model expected feed qualities, rates, catalyst ages, and seasonal utility conditions.

Engineers must also consider allowable pressure drop, metallurgy, corrosion risk, flow distribution, wash-water handling, installation access, and turnaround requirements. Economic assessments should distinguish measured savings from potential benefits, and emissions reductions should be calculated using actual fuel consumption and an accepted emissions factor.

For North American refiners, exchanger optimisation is not a substitute for catalyst management, hydrogen-system control, or mechanical-integrity programmes. It is one part of a broader strategy to extract more value from established assets. Evaluating the reactor and fractionation sections together can identify practical projects that reduce utility use and emissions while protecting the capacity and reliability required for ultra-low-sulfur diesel production.

Steam cracker cleaning

Scott Donson, IGS TubeTech, UK, discusses how operators can manage convection sector fouling to recover steam cracker efficiency.

Steam crackers are among the most energy-intensive assets in olefins production, where even small losses in thermal efficiency can have a significant impact on operating margin. As fuel costs, emissions targets, and competitive pressures continue to rise, avoidable energy losses are increasingly difficult to justify. One of the most common causes is fouling within the convection section, where deposits on the outside of finned tubes reduce heat recovery, raise stack temperature, and increase firing demand.

Because fouling develops gradually, declining performance is often accepted as a normal part of operation. However, across multiple furnaces and operating cycles, the associated fuel penalties and lost efficiency can be substantial. This article examines the measurable commercial impact of convection section fouling, explains how thermal performance data can be used to optimise cleaning schedules, and presents field examples demonstrating how robotic cleaning technology restores efficiency and reduces operating costs.

How fouling reduces heat recovery

Steam cracker furnaces contain three broad heat transfer areas: the radiant section, the convection section, and the transfer line exchanger. In the radiant section and transfer line exchanger, coke formation is an expected by-product of cracking reactions and is closely linked to run length, tube metal temperature, and decoking requirements.

The convection section has a particularly important role in furnace thermal performance because this is where useful heat is recovered from the flue gas. In the furnace convection section, ash, combustion-related deposits, and other particulate matter accumulate on the outside of finned tubes. As fouling builds, heat transfer declines. Less heat is recovered into the process, and the furnace must compensate to maintain operating conditions.

The consequences can include rising stack temperature, lower recovered duty, increased firing requirement, higher fuel consumption, reduced steam production or lower superheat, higher emissions, reduced operating flexibility, and greater pressure on maintenance and turnaround planning.

These inefficiencies make convection section heat transfer a performance issue. Cleaning should therefore be assessed by recovered duty and operating value, not visual cleanliness alone.

Quantifying the cost of lost efficiency

The commercial impact of fouling depends on furnace duty, fuel price, operating hours, plant configuration, and fouling severity.

The financial impact can be considered across four main areas:

- Maintenance costs: deposit build-up can increase planned and unplanned maintenance activity, adding cost and placing pressure on turnaround schedules.

- Energy costs: when heat transfer efficiency declines, the plant may require additional fuel firing to maintain operating conditions.
- Yield: thermal performance loss can affect feedstock conversion and reduce the value recovered from the process.
- Annual operating rate: fouling-related constraints, slowdowns, or unplanned downtime can cause the plant to fall behind its production target.

Each of these areas is connected. A fouled convection bank may cost more to operate, recover less useful duty, increase maintenance demand, and create avoidable constraints elsewhere in the plant.

Fuel is often the easiest loss to quantify, making it a clear starting point for assessing the commercial case for cleaning.

A typical case, as shown in Figure 1, is a six furnace steam cracker unit operating for 324 days per year. If each furnace has a fired duty of approximately 50 MW, a 2.0% efficiency loss equates to around 1 MW of additional fuel demand per furnace. At a fuel cost of US$40/MWh, this represents approximately US$311 000 per furnace per year.

Across six furnaces, the annual fuel cost associated with this level of efficiency loss is approximately US$1.87 million.



Figure 1. Cumulative fuel savings from robotic cleaning of a fouled convection bank. Basis: six steam cracker furnaces operating 324 days per year; furnace fired duty: approximately 50 MW per furnace; efficiency loss: 2.0%; fuel cost: US$40/MWh.

Efficiency recovery	$10/MWh	$20/MWh	$30/MWh	$40/MWh	$50/MWh
1.0%	$0.23m	$0.47m	$0.70m	$0.93m	$1.17m
1.5%	$0.35m	$0.70m	$1.05m	$1.40m	$1.75m
2.0%	$0.47m	$0.93m	$1.40m	$1.87m	$2.33m
2.5%	$0.58m	$1.17m	$1.75m	$2.33m	$2.92m

Figure 2. Sensitivity analysis showing estimated annual fuel cost associated with convection section fouling across different fuel price and efficiency loss scenarios. Figures are illustrative and based on six steam cracker furnaces operating 324 days per year.

Over three years, the cumulative saving from recovering this lost efficiency is estimated at approximately US$5.61 million.

The cost of fouling is also subject to external factors. The same level of thermal efficiency loss can have a very different financial impact depending on fuel price, production value, plant utilisation, and market conditions.

Again, fuel price is one of the clearest variables to give as an example. If reduced heat recovery forces an ethylene furnace to use additional fuel to maintain operating conditions, every MWh of avoidable fuel use becomes more expensive as fuel prices rise. Figure 2 illustrates how estimated annual fuel costs change across different fuel price and efficiency loss scenarios.

Operators may not be able to control regional feedstock advantages, ethylene pricing, or fuel price volatility, but they can identify where avoidable efficiency losses are increasing their cost base. Fouling-related fuel loss is therefore part of a wider margin conversation, particularly for assets under pressure to remain competitive.

As a result, the commercial case for cleaning can strengthen even when the underlying technical issue remains unchanged. Realising that value, however, depends on cleaning access, coverage, and the ability to verify recovered performance.

Limits of conventional cleaning

Convection section cleaning can be difficult because of the asset geometry. Horizontal convection banks may contain multiple tube rows, with fouling accumulating between square or triangular pitch tube arrangements. Deposits can sit deep within the bank, beyond areas that are easily reached by manual or line-of-sight cleaning.

Traditional cleaning methods can be effective in specific circumstances, but each has limitations. Manual hydroblasting may provide inconsistent contact and require high volumes of water. Chemical and cryogenic methods may be constrained by access, handling requirements, offline time, or cleaning verification, and if the fouling type is unknown, chemicals can compound the issue. Abrasive methods may not be suitable where there is concern over tube, insulation, or refractory damage.

The relevant measure is not only whether some deposit has been removed, but whether enough heat transfer surface has been restored to recover useful duty and justify the intervention. This places greater importance on access, cleaning coverage, and performance verification.

Robotic convection section cleaning

Remotely operated robotic cleaning systems provide a controlled method for removing fouling from convection section surfaces that are difficult to reach using manual or line-of-sight methods.

Providing access between finned tube rows, robotic systems can restore a high proportion of the original heat transfer surface area. This can improve recovered duty, reduce stack temperature, and support better steam

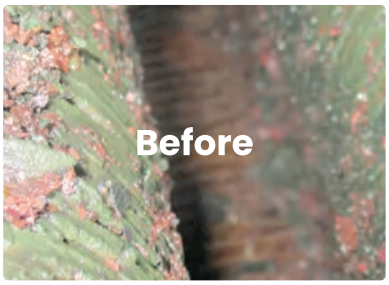
Convection Section Fouling Removal

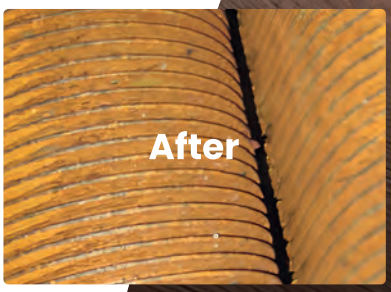
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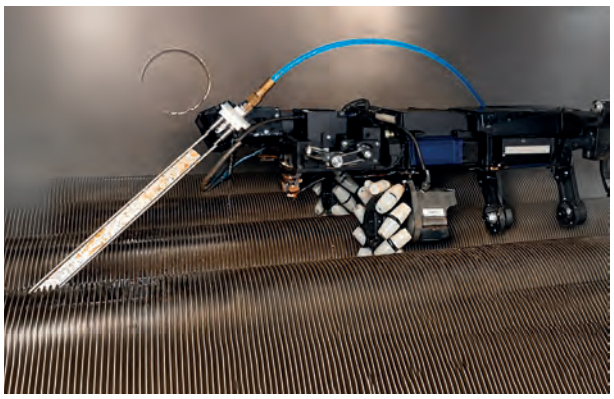


Figure 3. TubeTech's Rovex remotely operated robotic technology for fired heater convection section cleaning.

generation or superheat performance. The method can also allow cleaning to be carried out with greater control around tubes and refractory, helping to reduce the risk of damage during the cleaning process.

Robotic systems typically offer several technical advantages:

- Extended access: articulated equipment can navigate between tube banks and reach convection section surfaces that may be difficult to clean using conventional methods.
- Controlled cleaning: computer-controlled cleaning arms can adjust level and angle to maintain more consistent contact with fouled surfaces.
- Visual monitoring: onboard cameras can provide operators with real-time visibility during the cleaning operation.
- Performance verification: before-and-after imaging, combined with operating data, can be used to assess deposit removal, heat transfer recovery, and restored convection section duty.

In operational terms, robotic cleaning can reduce the need for personnel entry into confined spaces and limit reliance on chemicals, abrasives, or high volumes of water.

TubeTech's Rovex™ technology (Figure 3) is one example of this approach, with field applications showing restoration of up to 90 - 95% of original convection section duty compared with design specifications.

Case study one

Background

In 2020, a multinational operator of one of the world's largest industrial steam cracking facilities in the US contracted IGS TubeTech™ to clean a convection section furnace at its Texas site.

This single furnace produces around 150 000 tpy of ethylene. At this scale, lost heat recovery quickly translates into lost value. Fouling in the convection section was reducing heat transfer, limiting the furnace's ability to recover heat from the flue gas. The resulting increase in stack temperatures contributed to excessive fuel use, higher emissions, and concerns over reduced asset life.

Challenge

The convection section included fouling in areas that were difficult to clean effectively using conventional methods, including manual hydroblasting and chemical cleaning. Finned tube arrangements, restricted access, and deposits deep between tube rows would make full surface coverage difficult to achieve.

Solution

Robotic technology was selected for the task. Developed specifically for fired heater convection section cleaning, the remotely operated system was deployed to navigate the convection bank and access affected tube surfaces without the need for personnel entry during cleaning.

Its articulated cleaning lance allowed the system to adjust cleaning angle and position as it moved through the bank, improving contact with fouled surfaces and supporting more consistent deposit removal. Real-time visual monitoring gave the cleaning team visibility of progress during operation, while the controlled cleaning method helped reduce risk to tubes, insulation, and refractory.

Results

The robotic cleaning removed fouling from more than 90% of the tube area and restored convection section performance to design operating parameters. The work was completed safely and ahead of schedule, using very low volumes of water and without the need for chemicals or abrasives during cleaning.

The first-year return from the cleaned furnace was reported at approximately US$3 million. This result prompted the operator to contract TubeTech across multiple furnaces and build robotic convection section cleaning into its standard procedures each time the site carries out a recoil.

The method has since been deployed year-on-year across the facility's 34 steam crackers.

Technical significance

The defining outcome from this case was not only the first-year return from one furnace, but the operator's decision to adopt the method as part of standard procedure across a much wider furnace population.

This shows how convection section cleaning can shift from an individual maintenance intervention to a regular performance recovery practice given the proven value.

Reliability-centred cleaning strategy

Across multiple furnaces, cleaning can be prioritised by asset criticality, fouling rate, and recoverable value. Indicators such as rising stack temperature, reduced steam generation, and increasing fuel penalty help identify where intervention will have the greatest operational and financial impact.

Thermal efficiency evaluation and ROI modelling can then confirm whether the expected performance recovery justifies the cleaning cost, downtime, and likely rate of re-fouling. This is particularly valuable at large steam-cracking sites, where resources must be prioritised across the furnace population.

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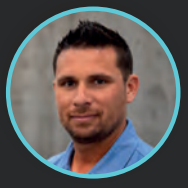
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Thermal efficiency evaluations and ROI modelling

Cleaning strategies should be supported by thermal efficiency evaluations that compare current performance with design expectations and translate losses into operational and financial terms.

A typical evaluation may consider:

- Stack temperature vs design.
- Estimated efficiency loss.
- Fuel cost impact.
- Production or feed recovery potential.
- Cleaning cost and payback period.
- Recommended cleaning interval.
- Post-clean performance.

This helps operators determine what value is being lost, what can be recovered, and when cleaning makes financial sense.

Post-clean evaluation verifies performance recovery and tracks the rate of re-fouling, creating a data-led basis for planning future interventions. Before-and-after imagery (Figure 4) can demonstrate deposit removal, but should be assessed alongside operating data.

Case study two

Background

An SRT-IV pyrolysis furnace at a large South American ethylene facility had experienced a sustained increase in stack temperature over several years. The furnace convection section comprises four tube coils, each approximately 10.3 m (33 ft) long, recovering heat from flue gas before it exits the furnace.

Ahead of a planned turnaround in 2025, operating data showed that stack temperature had been increasing by approximately 20°C per year, reaching 416°C before the outage. The trend indicated declining heat recovery and increasing fuel demand.

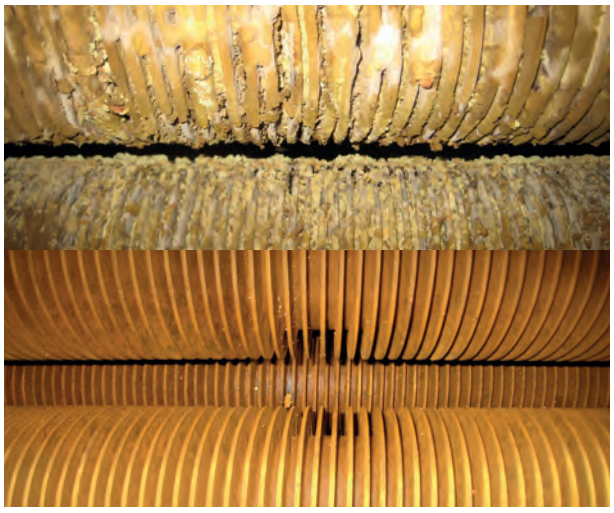


Figure 4. Before (top) and after (bottom) robotic convection section cleaning, showing deposit removal from finned tube surfaces.

Table 1. Thermal efficiency evaluation results for a South American ethylene furnace

Metric	Result
Stack temperature reduction	130°C/234°F
Fuel savings/steam gain	2.2 MW (7.2%)
Estimated annual savings	US$900 000
CO_2 emissions reduction	3500 tpy
Payback period (fuel gas savings/steam gain scenario)	40 days

Challenge

An inspection completed by IGS TubeTech confirmed deposits embedded between finned tubes, hard scale on bare tubes, and fouling across all four convection coils, with the heaviest accumulation in the lower tube banks. Convection section fouling had become the primary cause of reduced heat transfer and declining furnace efficiency. However, the operator needed to confirm whether cleaning would deliver sufficient operational and financial return.

Solution

Using plant operating data, IGS technicians completed a thermal efficiency evaluation to predict the benefits of convection section cleaning, including fuel savings, efficiency improvement, ROI, and payback. The study showed that the project would deliver a strong operational and financial return.

Robotic high-pressure water jetting was then deployed to access the affected tube banks and remove deposits from areas that had been difficult to treat effectively using previous methods. The remotely operated technology delivered 95% cleaning coverage, with no personnel entry into the convection section. Real-time cleaning verification was used during the work, and the system achieved multi-level access to all accessible tube banks. Cleaning was completed in four shifts with zero incidents.

Results

Following cleaning, stack temperature reduced from 416°C before the turnaround to 286°C, a reduction of 130°C. The project delivered a fuel savings/steam gain of 2.2 MW, equivalent to a 7.2% efficiency improvement, and estimated annual savings of US$900 000.

CO_2 emissions were reduced by 3500 tpy, and the payback period for the fuel gas savings/steam gain scenario was 40 days.

The remotely operated system achieved greater fouling removal than previous cleaning methods used on the furnace. The stack temperature reduction was also reported as the largest efficiency improvement recorded on the furnace in more than 30 years.

Conclusion

Fouling losses in steam cracker convection sections can be measured, valued, and recovered through performance-led cleaning. Where deposits are difficult to reach, robotic systems can restore heat transfer and provide verifiable results.

By quantifying the loss, recovery potential, and ROI, operators can prioritise cleaning based on asset criticality and recoverable value rather than fixed maintenance schedules.

BUILT FOR WHAT'S NEXT

Tony Sardella and Todd Doherty, Atlas Copco Comptec, explain the importance of expanding manufacturing capacity to facilitate future gas compression projects.

A decade ago, many compression projects across North America could be manufactured, transported, and installed within the constraints of existing, conventional facilities. Today, the landscape looks very different. LNG export terminals are growing larger, gas processing infrastructure is expanding, and emerging applications such as carbon capture, industrial gases, and industrial heat pumps are creating demand for increasingly sophisticated compression systems. These changing market requirements are driving not only advancements in compressor technology but also the manufacturing environments required to build, test, and deliver them.

The expansion of Atlas Copco Comptec's production facility at Voorheesville in New York, US, was completed against the backdrop of this market evolution, and it will be the focus of this article. Among other things, the expansion includes the installation of the considerably enlarged manufacturing and assembly 'high-bay' area that can now accommodate larger compressor packages and heavier components than the previous facility allowed for. It has additionally created a more connected and efficient production environment across the entire site with improved warehousing, material handling, and digital manufacturing systems.

The challenge of scale

As customer compression requirements evolve, so too must the capabilities needed to engineer, manufacture, test, and deliver these solutions. That evolution extends beyond product innovation. It includes strategic investments in manufacturing infrastructure that enables larger, more complex projects to be delivered efficiently while maintaining the quality and reliability customers expect.

Atlas Copco Comptec, which is part of Atlas Copco's turbomachinery division/business, delivers integrally geared centrifugal compressor solutions to customers around the world. The expansion of the Voorheesville production facility not only reflects the growing demand in North America but that projects are also growing in scale and complexity. Specialist manufacturing companies need to evolve alongside them. Clearly, over the past decade there has been a fundamental shift in project requirements: systems are larger, schedules are tighter, and customers want more work completed before equipment leaves the factory. In short, customer expectations are very different from what they were just a decade ago. Manufacturing capability is now equally as important as engineering capability to ensure successful project execution.

Today's manufacturing demands mean larger footprints, higher pressures, more flow, and much more complexity in





Figure 1. High Bay Expansion Facility, Atlas Copco Comptec LLC, Voorheesville, New York, US.



Figure 2. Atlas Copco Comptec LLC, Voorheesville, NY.

testing and logistics. At the same time, project developers are seeking higher levels of factory assembly and testing to help reduce complexity at site and accelerate commissioning activities. Customers want larger, more integrated systems delivered with greater certainty and shorter schedules. That is why having the right manufacturing infrastructure is becoming just as important as having the right compressor technology. As a result, manufacturers require facilities capable of handling larger modules, heavier components, and more comprehensive testing before equipment leaves the factory.

The solution: expansion and increased capabilities

Additional floor space is the obvious feature of the Voorheesville expansion. But the investment was always about much more than that. The project adds approximately 5840 m^2 (63 000 ft^2) of manufacturing space and increases the site's footprint by around 75%, creating additional capacity for the assembly and manufacture of larger engineered compressor packages. Moreover, it has also provided engineers with the infrastructure and flexibility needed to support larger compression packages while maintaining quality, reliability, and performance.

The investment is designed to enhance manufacturing capabilities, improve production flow, strengthen logistics and testing infrastructure, and support a growing range of applications, such as LNG, gas processing, industrial gases, carbon capture, hydrogen, and emerging energy technologies. While a larger warehouse area measuring 875 m^2 (9400 ft^2) is important, the key to the expansion is the new high-bay production area, as explained in this article.

A purpose-built high-bay facility

The new 4960 m^2 (53 300 ft^2) high-bay has been designed specifically to support larger engineered compressor systems while improving manufacturing efficiency across the site. Unlike conventional facility expansions that primarily focus on increasing floor space, the project incorporates infrastructure tailored to the assembly of large process gas compression packages.

The previous facility had physical limitations that restricted the size and complexity of equipment that could be assembled. Existing crane capacity was limited to 20 t, hook height was approximately 4.8 m (15 ft 7 in.), and the available assembly space was not designed for the larger compressor systems now requested by customers.

Capabilities have been transformed, and key enhancements now include: lifting capacities of up to 120 t, approximately 11.3 m (37 ft) of hook height, dedicated assembly bays, enhanced material handling routes, improved logistics capability, and space to assemble up to four large packages simultaneously.

One of the most significant benefits of the expansion, therefore, is the ability to manufacture larger and more complex compressor systems than was previously possible. The facility now supports compressor systems containing up to eight stages, power levels approaching 40 MW, coupling power up to 50 000 hp, flow rates approaching 280 000 ft^3/min. (480 000 m^3/hr), and pressures up to 205 bar.

What does such an expansion mean on a practical level? Simply, as projects continue to increase in scale, greater factory completion (as opposed to on-site completion) becomes increasingly valuable and achievable. Larger assembly areas, higher lifting capacities, and improved workflow enable more integration work to be completed in a controlled manufacturing environment before shipment, contributing to improved quality and more predictable project execution.

Long-term benefits, locally and globally

The investment typifies the growing importance of regional manufacturing capability throughout the hydrocarbon industry, plus other current and emerging process industries. As projects from these sectors continue to expand across North America, customers increasingly value suppliers that can provide local engineering, manufacturing, testing, and aftermarket support from within the region, across the whole project lifecycle, from the design stage, throughout building and testing, and long-term operation.

While the Voorheesville expansion strengthens Atlas Copco Comptec's ability to support these requirements locally, it also remains connected to the expertise, resources, and manufacturing network of Atlas Copco Gas and Process globally. By combining regional responsiveness with this wider geographical experience, customers get support wherever projects are developed. And as production volumes grow, additional engineering and manufacturing resources can be added over time to support future market demand.

However, manufacturing capability alone does not determine project success. Efficient logistics, transportation planning, and workflow optimisation also play critical roles when delivering large scale process equipment. This is why the new facility incorporates dedicated assembly and logistics areas designed to support modularisation strategies,

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Figure 3. East side of the High Bay Expansion Facility, Atlas Copco Comptec LLC, Voorheesville, NY.

minimise unnecessary handling activities, and improve overall workflow. The objective is not simply to ship larger packages, but to optimise the balance between factory assembly and field installation, reducing risk during transportation, installation, and commissioning.

The project also includes enhancements to warehousing, material handling, and digital manufacturing systems, helping create a more connected and efficient production environment. Planned technologies include synchronised crane controls, integrated warehouse solutions, and expanded connectivity with enterprise systems.

Maintaining quality and testing excellence

Maintaining quality and testing rigour remains essential, especially with growing and more complex compressor packages. The Voorheesville operation already has extensive testing capabilities, including multiple test beds and the ability to conduct mechanical testing in accordance with API requirements.

Existing testing infrastructure will continue to play an important role as the facility evolves, supported by the new process flows mentioned previously which are designed to improve efficiency and integration between manufacturing and testing activities. Together with deep engineering expertise and machining capabilities, these resources help ensure compressor systems are thoroughly validated before shipment.

Looking ahead

Manufacturing capability has become a strategic differentiator in the compression industry. As projects grow larger and schedules become more demanding, manufacturers must be able to scale alongside their customers. Changing market requirements are driving both advancements in compressor technology and the manufacturing environments required to build, test, and deliver them.

Through the expansion of its Voorheesville facility, this project demonstrates how manufacturing infrastructure can evolve alongside market requirements, ensuring that customers have access to the expertise, capacity, and technology needed to support the next generation of process gas compression applications.

Across the US, Atlas Copco Group operates more than 160 locations, including 25 production, remanufacturing, and distribution facilities, and employs more than 7000 people.



Enabling circularity



José Miguel González, Tecam, Spain, provides an overview of various chemical recycling technologies and how they can be best integrated into hydrocarbon and petrochemical infrastructure.

The global hydrocarbon and petrochemical industries are facing increasing pressure to decarbonise operations, reduce waste generation, and transition towards more circular production models. Plastic waste, end-of-life petrochemical products, and complex polymer-based residues represent a significant challenge, as conventional mechanical recycling routes are often limited by material contamination, degradation, and quality loss. In this context, chemical recycling has emerged as a complementary and increasingly strategic pathway to recover value from waste streams that cannot be effectively managed through traditional recycling methods.

Chemical recycling refers to a family of technologies capable of converting plastic waste and other polymer-based materials back into their chemical building blocks, fuels, or feedstocks. These outputs can be reintegrated into existing refinery and petrochemical processes, closing the carbon loop and reducing dependence on virgin fossil resources. For hydrocarbon engineering professionals, chemical recycling presents both an opportunity and a technical challenge, requiring robust process design, emissions control, and integration with established industrial infrastructures.

This article provides an overview of the main chemical recycling technologies, their role within the hydrocarbon value chain, key technical considerations, and how specialised engineering solutions can support their safe, efficient, and environmentally compliant deployment.

Limitations of mechanical recycling

Mechanical recycling has long been the dominant route for plastic waste recovery. However, its applicability is constrained by several technical and economic factors. Mixed plastics, multi-layer materials, contaminated waste streams, and polymers with additives or fillers are often unsuitable for mechanical recycling. Repeated processing also degrades polymer chains, resulting in downcycling and limited end-use applications.

As regulatory targets for recycled content increase and brand owners seek higher-quality recycled materials, the limitations of mechanical recycling have become more evident. Chemical recycling addresses these gaps by enabling the processing of heterogeneous and contaminated waste streams, while producing outputs with properties comparable to virgin materials.

Overview of chemical recycling technologies

Chemical recycling encompasses several technology pathways, each with specific feedstock requirements, operating conditions, and end products. The most relevant routes for the hydrocarbon and petrochemical sectors include pyrolysis, gasification, depolymerisation, and solvolysis.



Figure 1. Plastic pellets for chemical recycling via pyrolysis.

Pyrolysis

Pyrolysis involves the thermal decomposition of plastic waste in the absence of oxygen, typically at temperatures between 400 - 800°C. The process produces a mixture of pyrolysis oil, non-condensable gases, and solid residues (char). Pyrolysis oil can be further refined and used as a feedstock in steam crackers or refineries to produce new polymers or fuels.

Pyrolysis is particularly suitable for polyolefin-rich waste streams, such as polyethylene (PE) and polypropylene (PP). From an engineering perspective, controlling reaction conditions, managing contaminants (e.g. chlorine from PVC), and ensuring stable product quality are key challenges.

Gasification

Gasification operates at higher temperatures (typically above 800°C) and in the presence of controlled amounts of oxygen or steam. Plastic waste is converted into synthesis gas (syngas), composed mainly of hydrogen and carbon monoxide. Syngas can be used for power generation, hydrogen production, or as a feedstock for chemical synthesis, including methanol and Fischer-Tropsch fuels.

Gasification offers flexibility in feedstock composition and can handle highly contaminated waste. However, it requires complex gas cleaning systems and robust emissions control due to the high operating temperatures and potential formation of pollutants.

Depolymerisation and solvolysis

Depolymerisation processes aim to chemically break polymers back into their monomers or oligomers using heat, pressure, catalysts, or solvents. Examples include glycolysis, methanolysis, and hydrolysis, particularly for polymers such as PET, polyamides, and polyurethanes.

These technologies produce high-purity outputs that can be directly reused in polymer manufacturing. While depolymerisation typically requires more homogeneous feedstocks, it offers significant advantages in terms of material circularity and product quality.

Integration into existing hydrocarbon infrastructure

One of the key advantages of chemical recycling is its potential integration into existing refinery and petrochemical assets. Pyrolysis oils and depolymerised outputs can be processed using conventional upgrading units, reducing the need for entirely new downstream infrastructures.

However, successful integration requires careful consideration of feedstock variability, impurities, and compatibility with existing process units. Chlorine, sulfur, nitrogen compounds, and metals present in waste-derived feedstocks can negatively impact catalysts and equipment if not properly managed.

From an engineering standpoint, front-end waste preparation, advanced separation systems, and robust gas and liquid treatment technologies are essential to ensure stable and compliant operation.

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Figure 2. Pyrolysis pilot plant for a Scandinavian customer.

Environmental and regulatory considerations

Chemical recycling plants must comply with increasingly stringent environmental regulations, particularly regarding atmospheric emissions, wastewater discharge, and solid residues. Depending on the technology, potential emissions include acid gases, volatile organic compounds (VOCs), particulate matter, and trace pollutants such as dioxins or furans.

Best available techniques (BAT) for emissions control typically involve a combination of thermal oxidation, wet and dry scrubbing, filtration systems, and continuous emissions monitoring. Life-cycle assessments (LCA) are also increasingly required to demonstrate the environmental benefits of chemical recycling compared to incineration or landfilling.

In Europe and other regions, regulatory frameworks are evolving to clarify the status of chemically recycled materials and their eligibility to count towards recycled content targets. Engineering solutions must therefore be designed with flexibility to adapt to future regulatory developments.

Key engineering challenges

While chemical recycling offers significant potential, it also presents complex technical challenges that must be addressed during project development and operation such as the following:

- Feedstock variability: waste composition can fluctuate significantly, affecting process stability and product quality.
- Emissions management: high-temperature processes and contaminated feedstocks require advanced emissions abatement systems.
- Energy efficiency: optimising heat integration and energy recovery is critical to improving overall process sustainability.
- Operational reliability: continuous operation demands robust materials selection, corrosion management, and process control.

Addressing these challenges requires multidisciplinary engineering expertise and a deep understanding of both waste-derived feedstocks and conventional hydrocarbon processes.

Supporting chemical recycling projects

Tecam brings experience in environmental technologies for emissions abatement and waste valorisation across the hydrocarbon, petrochemical, and chemical industries. In the field of chemical recycling, the company supports project developers, EPC contractors, and operators through specialised engineering services and tailor-made solutions.

Tecam's capabilities include the design and integration of advanced gas and air treatment systems to control acid gases, VOCs, particulate matter, and other regulated pollutants generated during chemical recycling processes. These solutions are engineered to comply with local and international environmental standards while ensuring high availability and operational safety.

In addition, the company provides process integration support to optimise heat recovery, energy efficiency, and the interface between chemical recycling units and existing refinery or petrochemical infrastructures. This includes front-end engineering, technology selection support, and feasibility studies focused on environmental performance and long-term operability.

By working closely with clients to adapt emissions control and waste treatment solutions to the specific requirements of pyrolysis, gasification, and depolymerisation technologies, the company helps chemical recycling projects to achieve both environmental compliance and industrial robustness.

Outlook

Chemical recycling is expected to play a growing role in the transition towards a more circular and low-carbon hydrocarbon economy. While it is not a standalone solution, it complements mechanical recycling and renewable feedstocks by addressing difficult-to-recycle waste streams and enabling higher-quality material recovery.

For hydrocarbon engineers and decision-makers, the successful deployment of chemical recycling depends on sound process design, effective integration with existing assets, and rigorous environmental control. As technologies mature and regulatory frameworks evolve, engineering partners with expertise in emissions abatement and waste valorisation will be essential.

By combining advanced process technologies with robust environmental engineering, chemical recycling can become a viable and scalable pathway to reduce waste, lower emissions, and support the long-term sustainability of the hydrocarbon and petrochemical industries.

IMPROVING PERFORMANCE AMID PRESSURE



Yong Tat Lee, Emerson, Singapore, considers how continuous monitoring accessories can help operators detect pressure relief valve lift, leakage, and failure before they affect safety, emissions, or uptime.

Process manufacturers worldwide rely on pressure relief valves (PRVs) for reliable overpressure protection of equipment and personnel. PRVs are mechanical devices by design, allowing them to operate fully independently of the process control system. As a result, PRVs inherently give no feedback or indication of their status.

Fortunately, a host of PRV accessories are now available that empower plant personnel to monitor both PRV operation and status. This article discusses this equipment and highlights several use cases where PRV monitoring installations have created significant improvements in plant operations, safety, and emission reductions.

PRV monitoring challenges

A typical operating site has hundreds of PRVs protecting tanks and process equipment from catastrophic overpressure. Each of these valves employs mechanical features, such as springs or pressure pilots, to sense process conditions and open the valve as necessary to vent excess process fluids and keep internal pressure from exceeding equipment limits.

The mechanical nature of a PRV allows it to operate as an independent protection layer against overpressure, but that design results in a device that has no visibility to plant personnel. A lifting PRV might be heard or noticed from abrupt changes in process pressure, but in a closed application, such as a flare or blowdown header, it may not be noticed at all.

Venting PRVs can create lost product, environmental emissions, or cause process control problems. If hazardous chemicals are released as a result, the release quantity usually must be reported, but accurately determining that release quantity may be difficult or even impossible without an ability to monitor the PRV.

Leaking or failed PRVs might not be discovered for weeks or months, often creating environmental releases and potentially compromising the ability of the PRV to perform its overpressure protection role should a PRV bellows develop a crack.

In response, several PRV monitoring accessories have been developed to overcome these challenges and limitations. These solutions span a broad range of price points, and they provide varying degrees of feedback and information. Each of these devices offers excellent PRV performance and operational insight that was not available previously.



Figure 1. This monitoring solution uses proximity switches to detect the open/close status of vacuum breakers on LNG storage tanks (Emerson Anderson Greenwood™ 96A series with the Emerson TopWorx™ GO™ Switch shown).

PRV monitoring alternatives

There are a number of methods to detect when a PRV is lifting, and in some cases the exact amount of lift. The simplest and least costly option is adding a limit switch on the bonnet of the PRV to indicate when the PRV rises off the disc (Figure 1).

Installation is usually straightforward and typically involves replacing and/or modifying the bonnet to incorporate the switch. There are several different styles and options that use mechanical or proximity switches to sense PRV stem movement.

This solution provides an immediate and accurate indication of when the PRV lifts and returns to seat, alerting plant personnel of the overpressure condition, and helping them determine the quantity of release if monitoring is necessary. For many applications, that information is all that is required, but the limit switch monitoring option does have limitations.

It cannot detect a leaking PRV disc or a failed PRV bellows. It also tends to lead to emission overreporting since it assumes that the PRV is fully lifted during the length of the lift event. This is often not accurate because most PRVs only lift to approximately 60% unless the process pressure is well over setpoint.

An improved PRV monitoring option replaces the limit switch with a position transmitter. This device uses a linkageless sensor to identify the spindle position, and it sends a 4 - 20 mA signal proportional to the amount of lift to a host control or monitoring system.

Like the limit switch technology, this device indicates when the PRV lifts and reseats, but it also reveals the extent of lift, allowing the site to determine the quantity of released vapour. In addition, the data from the position transmitter can help plant personnel identify simmering and chattering events.

More advanced PRV monitoring offerings may have higher price points, but the data they deliver can offset the expense. For example, a wireless acoustic level/temperature transmitter can be installed on the discharge of the PRV. This device can determine when the PRV opens and closes, as well as low-level-seat leakage (Figure 2). For bellows PRV applications, a pressure transmitter can be installed on the PRV so it can measure the pressure of the space inside the bellows.

This information can help determine if there is a bellows crack or failure, either of which will compromise the PRV's operation if the discharge header is subject to variable backpressure. The transmitter pressure data can also be used to determine the extent of bellows damage, as well as the rate of fugitive emission through the bonnet.

In pilot-operated PRV applications, a differential pressure transmitter provides a very accurate indication of valve lift, allowing plant personnel to accurately calculate the release quantity.

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Figure 2. This acetic acid application uses a combination of monitoring solutions, including proximity switches to detect open/close status of a direct spring-operated PRV, and a pressure transmitter to detect bellow rupture (Emerson Crosby™ J series with the Emerson Topworx GO Switch and Emerson Rosemount™ 3051 Pressure Transmitter shown).

PRV monitoring case studies

Avoiding steam system trips

A steam plant was struggling with PRV operations on its boilers. When a PRV lifted, it dramatically impacted boiler level control, requiring immediate operator intervention to avoid a boiler trip. However, there was no indication in the control room when the PRV lifted, so the operators would discover the problem only after the boiler level was in an alarm state and on the verge of tripping.

The answer was to add a limit switch to the steam PRV spindle. The control system only had 120VAC inputs available, so a mechanical limit switch and relay was added to the PRV bonnet, allowing plant personnel to instantly know the moment the PRV lifted. This empowered the operators to immediately intervene before the boiler levels were upset and out of operational range, avoiding costly trips and outages.

LNG solution protects tanks

An LNG storage facility uses multiple, large vacuum relief devices on their tanks to protect against vacuum conditions which could implode the vessels. A vacuum relief device lift event in this application indicates there could be an interspace pressure imbalance, potentially creating a purging gas control issue or other hazard. As a result, it is imperative that the operators know when a vacuum relief device lifts and how long it remains open.

The original design used cheap switches that were prone to failure, creating false alarms in this challenging operating environment. The sensors were replaced with fully sealed proximity switches that were better suited for the operating conditions. The new switches were much more reliable and provided an accurate indication of PRV events as they occurred, with no false alerts. Ultimately all the LNG vacuum PRVs were retrofitted with the revised design, significantly improving operations, while eliminating many maintenance manhours that had been expended on the original faulty switch design.

Chemical plant improves bellows operation

A chemical plant was struggling with PRV bellows failures on a high temperature, corrosive process. The site needed a way to reduce the number of bellows failures, and to immediately know when a PRV bellows was damaged. The solution incorporated a high temperature-rated Monel bellows PRV combined with a pressure transmitter mounted on the PRV. The Monel bellows offered extended service life in this difficult application, and the integrally mounted transmitter gave an immediate indication of the presence and extent of any bellows damage. It also empowered plant personnel to accurately calculate the quantity of fugitive emissions that resulted when a bellows did fail.

PRV monitoring advances improve operations

The mechanical nature of PRVs ensures an independent layer of overpressure protection, but the design offers no feedback to indicate when they lift, leak, or fail. Fortunately, a host of new PRV accessories address this gap, providing data on PRV operation, condition, and emission data.

PRV monitoring solutions have varying price points and capabilities, so each application must be evaluated to determine the best option for a particular installation. In many cases, a simple limit switch may provide enough data to solve the problem. In other situations, position or differential pressure transmitters may be necessary to gather the critical operational PRV feedback needed to address the problem.

With this broad collection of continuous monitoring accessories, PRV monitoring can now supply real-time operational data not previously available. Process manufacturers are using this information to respond more quickly to PRV lift events, better understand their causes, and eliminate future PRV lift events entirely. The resulting improvements in plant performance and emission reduction have been significant, easily justifying the initial capital cost.

AN UNCHARTED DIGITAL WORLD



John Nixon, Siemens Digital Industries, explains that industrial AI requires integrated and trusted context to deliver real value for downstream operations.

For years, industry leaders have described data as 'the new oil.' The phrase is useful because it captures a truth: data has value. In the age of industrial artificial intelligence (AI), the comprehensive digital twin, and digitalisation technologies, data helps teams uncover insights once locked inside engineering documents, laboratory records, process models, maintenance logs, legacy systems, and operating experience.

But from an industrial leader's perspective, the metaphor is incomplete and sometimes misleading.

Oil is valuable because humans can extract, refine, and transform it into useful products through well-understood physical processes. Industrial data is different. It does not become valuable simply because it exists. It becomes valuable when people and systems understand what it means, where it comes from, how it relates to other information, and if it is trustworthy in the context of real operational decisions.

That is why data is not the new oil. It is an uncharted digital world.

In energy, chemicals, and other asset-intensive industries, every facility has its own digital terrain. Product definitions, process recipes, engineering requirements, quality parameters, simulation models, equipment specifications, maintenance records, field inspections, and production history all describe pieces of the same reality. Yet, those pieces often live in different systems, use various languages, and evolve at different speeds.

Industrial AI cannot unlock the hidden insights within that landscape by guessing its topography. It needs a map.

The complexity of an unmapped digital world

Consider a downstream energy company that operates a refinery and produces specialty chemical additives for fuels, lubricants, or industrial applications. On the surface, this seems like a familiar environment: feedstocks enter the site, processes transform them, quality teams validate outputs, and operational teams keep assets running.

But beneath that physical process is a much more complex digital world.

The company may manage product and process definitions using an integrated lifecycle management system. It may also host formulation and recipe data that

originated in the lab, evolved through pilot production, and was later adapted for commercial scale manufacturing, alongside engineering requirements tied to equipment, control logic, inspection plans, and safety constraints. The company may equally utilise simulation models to understand reaction behaviour, flow dynamics, material properties, heat transfer, fouling risk, or scale-up constraints. It may also have field service workflows that dispatch specialists to inspect equipment, verify asset condition, review service history, or confirm that physical installation matches the governed digital record.

Individually, these data sources may be accurate on their own. The difficulty is that they are not isolated: they have relationships.

The formulation is related to product specification. The product specification is related to a recipe. The recipe is related to process conditions. Process conditions are related to equipment capabilities. Equipment capabilities are related to inspection, maintenance, safety requirements, and field observations. Field observations are related back to asset history, engineering assumptions, and future design improvements.

An operator may understand these relationships intuitively whilst a process engineer may know that a change in viscosity affects pump selection. A maintenance planner may know that a recurring seal issue is related to operating conditions rather than the pump itself and a field technician may recognise that the 'as-maintained' asset no longer perfectly reflects the 'as-designed' documentation. A quality leader may know that a small formulation change in the lab could create a large variation at production scale.

But unless humans define, connect, and govern those relationships, industrial AI must infer them from incomplete context clues within the data.

That is where risk enters the system.

Imagine that an operator asks an AI assistant why a specialty chemical batch has drifted outside performance limits. The relevant answer may require data from product lifecycle management (PLM), formulation development, process simulation, manufacturing execution, asset maintenance, quality records, and recent field inspections. If the AI can see a maintenance record but not the formulation change, it may overemphasise equipment failure. If it can see the formulation but not the inspection history, it may miss a degraded heat exchanger. If it can see operating data but not the governed process intent, it may recommend a change that improves throughput but introduces quality, compliance, or safety risks.

The problem is not that the AI is weak. The problem is that the digital landscape is unmapped.

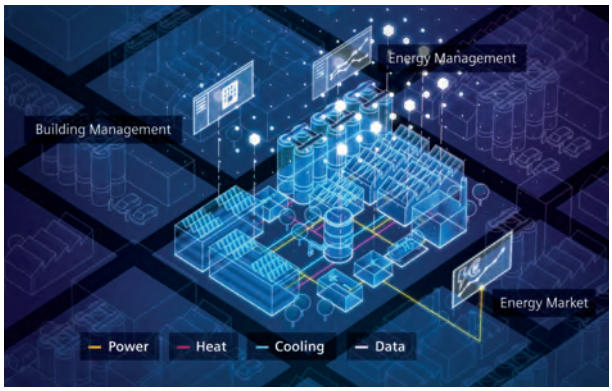


Figure 1. Data is not the new oil. It is an uncharted digital world. (Source: Siemens).

Integrated lifecycle management provides the organising backbone

This is why integrated lifecycle management matters so deeply in process industries. It is not simply about creating another system of record. It is about building the organising backbone that connects product, process, plant, and operational context across the lifecycle.

In specialty chemicals, the 'product' is not only a physical material. It is also a formulation, process definition, quality expectation, regulatory commitment, manufacturing strategy, and set of operational constraints. The lifecycle begins long before full scale production. It starts in research, moves into formulation, passes through pilot scale validation, expands into manufacturing definition, and continues through operations, service, optimisation, and future product improvements.

If the digital thread breaks anywhere along that journey, the organisation loses context. The handoff from lab to plant becomes a translation exercise. The relationship between intended process conditions and observed operating performance weakens. Maintenance and inspection activities disconnect from the product and process decisions that create the asset requirements in the first place.

An integrated lifecycle approach changes that posture. It helps create continuity from concept to commercialisation, from product intent to process execution, and from operating reality back to engineering knowledge. It enables teams to understand not just what data exists, but why it exists and how to use it.

That distinction matters.

A refinery or specialty chemical plant is not a spreadsheet: it is a living system. Equipment ages, feedstocks vary, environmental targets shift, production priorities change, and customer requirements evolve. Field technicians discover deviations that were never visible in design documents, while new materials and chemistries introduce new behaviours. Every change adds complexity to the digital world that surrounds the physical plant.

Without lifecycle context, each new data point adds noise. With lifecycle context, each new data point can add knowledge.

FAIR data helps make the landscape usable

It is intuitive that teams cannot simply connect siloed systems to industrial AI and expect reliable outcomes. Without context, how can operators or algorithms know whether the data is correct? How can they know whether two data points describe the same asset, the same formulation, the same process condition, or the same version of a specification?

These challenges grow over time. Data complexity behaves like entropy: it does not naturally become more ordered. It increases as organisations add new facilities, equipment, products, partners, regulations, suppliers, digital tools, and operational models.

A practical response is to make data findable, accessible, interoperable, and reusable (FAIR). FAIR data is not an abstract

data-science ideal. In process industries, it is what enables engineering, manufacturing, operations, quality, and service teams to work from a common understanding of the industrial system.

Findable data is detectable by people and systems. Accessible data is usable by the right stakeholders and applications. Interoperable data can move across systems without losing meaning. Reusable data carries enough structure, context, and governance to support future decisions.

The value of FAIR data becomes especially clear when field service enters the picture. A specialist dispatched to inspect equipment in a refinery needs more than isolated fragments of information. They need the asset record, engineering context, service history, process conditions, inspection procedure, and safety constraints. They may also need to capture what they observe in the field, so the digital record reflects the current physical reality.

That inspection should not live as a disconnected service note. It should become part of the lifecycle history of the asset, tied back to process performance, maintenance planning, engineering assumptions, and future operating decisions.

That is the difference between data capture and lifecycle intelligence.

Ontologies map data relationships

Even with FAIR data practices, industrial AI still needs a way to understand relationships. This is where ontologies become important.



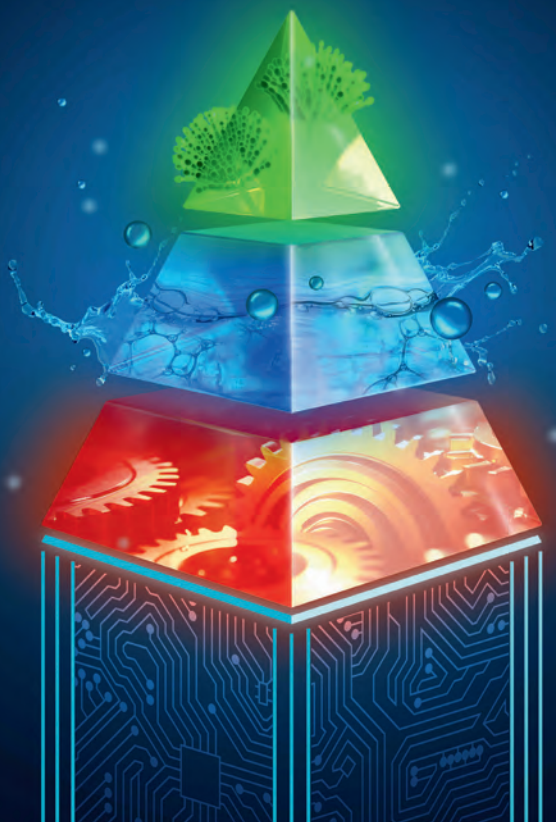
Figure 2. Individual data sources are not truly isolated. They have relationships within the real world. (Source: Siemens).

An ontology is a way of describing the meaning of data and the relationships between data in a specific domain. In a specialty chemical plant, the ontology can help define how materials, products, recipes, batches, equipment, process parameters, inspections, maintenance events, quality outcomes, and engineering requirements relate to each other.

Although humans often understand these relationships through experience, AI needs that context spelled out explicitly. Without an ontology, data can look deceptively similar. For example, a temperature value may describe a lab experiment, a simulation boundary condition, a process setpoint, an actual historic reading, or an inspection observation.

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To a human expert, the differences are obvious, but for an AI system, they need value definitions.

Ontologies act like maps of the digital world. They help show not only where information sits, but how it connects. They identify which relationships are directional, conditional, historical, and authoritative. Just as a physical map helps an explorer avoid treating a river, a road, and a pipeline as interchangeable paths, digital ontologies help industrial AI avoid treating unrelated data points as equivalent.

This is how organisations move from data accumulation to data understanding.

The comprehensive digital twin shows where the map is incomplete

The digital twin is not a new concept. At its simplest, it is a virtual representation of a physical object, process, or system. In industrial environments, a digital twin can connect engineering data, simulation logic, operating data, and lifecycle history to help teams understand and improve real-world performance.

A comprehensive digital twin takes this further. It can represent larger systems, facilities, and lifecycle relationships. For a refinery or specialty chemical plant, its digital twin may include process units, equipment, control systems, material flows, operating constraints, inspection records, service histories, and simulation models.

This comprehensive system is powerful because it exposes gaps.

If the digital twin cannot reconcile the process model with the current operating history, the organisation learns where context is missing. If it shows that a field inspection contradicts the engineering record, the organisation learns where its physical and digital realities have drifted apart. If AI-generated recommendations vary depending on which system supplies the data, the organisation learns that its data relationships are not sufficiently governed.

In this way, the comprehensive digital twin is not only a tool for prediction or optimisation. It is also a test of data maturity. It shows whether the digital world maps well enough to support decisions in the physical world.

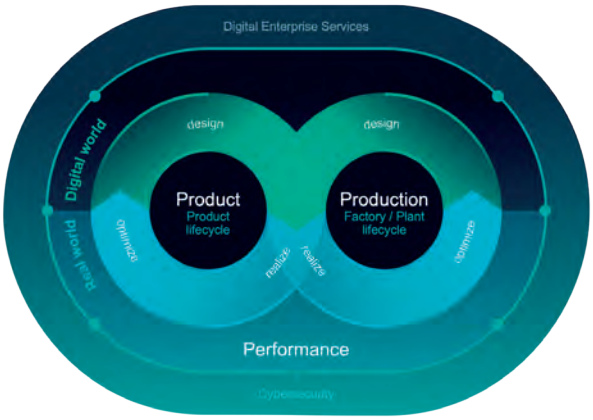


Figure 3. Integrated lifecycle approaches create continuity from product intent and concepts to process execution and operations. (Source: Siemens).

What connected, contextualised data makes possible

When industrial organisations connect, contextualise, and govern their data, they expand the value of industrial AI, the digital twin, and other digitalisation technologies. They improve troubleshooting, optimise yield, accelerate scale-up, reduce downtime, strengthen quality consistency, and support safer field operations.

For specialty chemical producers, this can improve the transition from lab success to production reliability. For refinery operators, it can strengthen the link between asset performance and process outcomes. For maintenance and field-service teams, it can provide better guidance before, during and after inspection work. For engineering teams, it can create a closed loop where operational insights inform future design and process improvements.

The larger value is organisational. When data silos begin to dissolve, teams stop working from competing versions of reality. They instead make decisions from a shared lifecycle context. Industrial AI can then operate less like a guessing engine and more like a trusted decision-support layer grounded in domain knowledge and operational reality.

This is the real lesson behind the 'data is the new oil' metaphor.



Figure 4. Reference architecture for industrial AI and advanced analytics via Databricks and Siemens technology. (Source: Siemens).

Oil gains value when it moves through a refinery. Data gains value when it moves through context that connects, governs, and ensures its meaning across the lifecycle.

Industrial companies do not need more disconnected data silos. They need a mapped digital landscape – where products, processes, plants, assets, and field-service information connect across the lifecycle with the structure and trust to support real-world decisions.

Data is not the new oil. It is the terrain industrial organisations must learn to navigate. The companies that map it well are most likely to unlock the next era of industrial intelligence.



PROVING AI IN THE PLANT

As AI moves from pilot to plant floor, the measure of success in downstream operations has shifted from what the technology can do to what it can deliver. **Gino Hernandez, ABB Energy Industries,** explains.

A couple of years ago, the conversation in the industry began with two questions: what can AI do, and where do we already have it running? Today it is a different question entirely: what did it do to margins last quarter?

That shift, from a technology conversation to a profit and loss conversation, tells you most of what you need to know about where downstream operators are with AI right now. There is a straightforward expectation of return.

AI earns its place on the OPEX line

A few things have pushed AI from an interesting experiment to something everyone is familiar with. The generative AI wave of the last three years accelerated that shift, but the technologies being discussed are not all doing the same job.

Predictive AI identifies patterns and anticipates outcomes, while generative AI can synthesise information and make complex knowledge easier to access. Then there is agentic AI, which introduces the potential for systems to reason across tasks and coordinate actions.

The conversation has moved on from what AI is, to where each form of AI can be applied against a specific operational outcome.

Several pressures have converged on downstream operators: compressed margins that show no sign of easing, transformation of an energy system that is balancing resilience and decarbonisation, and the great crew change, where decades worth of tribal knowledge are leaving the plant as experienced operators retire. No hiring plan solves any of those on its own. That is what has moved AI from a discretionary project to something plants now need in place.

The technology underneath has matured to meet that need. Advances in data infrastructure, edge computing, and AI models make industrial deployment increasingly practical. But model capability alone is not enough. Industrial AI

needs trusted operational data and enough process context to understand the relationships among assets, operating states, alarms, and constraints.

That is what turns AI output into useful industrial intelligence. Maybe the clearest signal of maturity is where the budget now sits, which is increasingly on the operating plan rather than in an innovation fund.

From AI insight to operational value

With that shift comes higher expectation. Producing a useful prediction is only part of the challenge. The real test is whether that insight improves the way the operation performs. In industry, that means embedding intelligence into the workflows and control environments where decisions are made so AI contributes to measurable outcomes rather than becoming another isolated dashboard.

Most of the value being generated today is still in advisory and operator augmentation, not closed-loop autonomy. That is the right place to start in a safety-critical environment. ABB can augment the operator today through the process control environment, helping people understand what is happening, why it may be happening, and what actions they should consider. The human remains accountable for the decision, while the technology improves the quality, speed, and consistency of that decision.

Where the returns are real

Ask where AI is delivering the clearest operational value in downstream right now, and a handful of areas consistently come up. Predictive maintenance remains at the top of the list, because the return is easy to point to – an avoided shutdown or a block of unplanned downtime hours, for example. Energy and process optimisation is another, balancing margin and emissions at the same time. Both are established enough now that customers are not asking whether they work, only how quickly they can be rolled out across more of the site.

Operator augmentation is a third area, and it is where this becomes tangible. ABB's Augmented Operator approach brings relevant operational information and decision support into the environment where the operator already works. Picture a process beginning to drift towards an excursion. Rather than waiting for an alarm to force a reaction, the operator can be presented with the developing condition, relevant process context, and prior operational knowledge. The objective is to help the operator recognise the issue earlier and make a better-informed decision.

The same underlying approach extends to keeping a process within its normal operating envelope, nudging it back in line before it drifts too far, and to alarm management, where thresholds get rebalanced continuously rather than reviewed manually every couple of years. In each case, the pattern is the same: catch the problem earlier, give the operator context instead of just an alert, and let judgement, not automation alone, make the final call.

What connects all three of the strongest use cases is a bounded scope and clear KPIs, such as number of operator interventions, avoided downtime hours, or energy saved against a baseline. That is what makes them measurable, and measurable is what makes them scalable.

Getting past the pilot stage

Plenty of organisations have already proven value through pilots. What is harder is turning that early success into something running at scale, and this is where many pilots stall, rather than the technology itself.

A pilot proves technical feasibility, but scaling requires organisational adoption and economic viability. If an AI output sits on a separate dashboard and adds another step to the operator's workflow, even a technically strong model can struggle to create sustained value. The solutions that scale are the ones that fit how the plant operates and have clear ownership for the business outcome.

Three factors consistently show up in organisations getting this right. First, a repeatable foundation that can be deployed beyond a single pilot. Second, it is creating governance that defines how AI is used and who remains accountable. The third factor is executive sponsorship tied to measurable value. These combine to turn a successful experiment into an operating capability.

IRPC's cogeneration plants in Thailand are a good illustration of what this looks like once it is working. ABB's Advanced Process Control Steam and Energy Optimization software was implemented to improve efficiency and stability across the site's steam network. The result was a reduction of up to 50% in pressure variability on the high-pressure steam header, along with reduced steam consumption, translating into fewer disturbances to the refinery's process units and more responsive steam distribution to meet changing internal demand. It is a downstream petrochemical operation getting a measurable, quantified return from a live AI-driven optimisation system.

The alarm management side of this is worth its own mention. At Saras' refinery in Sardinia, Italy, a recent control system modernisation included a structured approach to alarm management alongside the core upgrade, addressing exactly the kind of alert fatigue that the product AlarmInsight is designed to solve. Alarm strategy is an unglamorous problem, but it is one of the clearest, most measurable ways AI is changing daily operations for control room teams.

Between the two, the same underlying signal holds. Whether it is optimising steam flow or refining an alarm strategy, AI's most convincing downstream wins right now are specific, bounded problems that are solved well, not a sweeping transformation.

When agents start taking action

Agentic AI changes the shape of the conversation because it introduces systems that can pursue goals, reason across multiple steps, and coordinate tasks rather than simply produce a prediction or response. In an enterprise setting, an incorrect action may be inconvenient. In a refinery, it can become a safety event. That difference makes human oversight, bounded authority, and safety constraints fundamental to industrial agentic AI.

As these capabilities mature, the question will not simply be whether an agent can recommend an action, but under what conditions it should be allowed to act. Any progression towards autonomous execution will require clear authority, operating limits, and safeguards appropriate to the process. That is how the industry can move responsibly from augmented decision-making toward higher levels of autonomy.

The barrier to building agents is low right now. In an industrial setting, the crucial question is whether an agent can act safely inside a live process.

The control room of the future

The control room of the future will evolve over time. Today, technologies such as ABB's Augmented Operator can bring together operational data, process context, and decision support to help operators understand what is happening, why it is happening, and what actions they should consider. As AI capabilities mature, that augmentation can become increasingly intelligent, combining predictive AI, generative AI, and eventually agentic AI to help operators manage greater complexity and make faster, more consistent decisions.

Over time, the relationship between the operator and the automation system will continue to change. Routine and well-understood activities can progressively move from human decision-making to AI-supported recommendations, to operator-approved actions and, where the risk and operating boundaries are sufficiently understood, to bounded autonomous action. The operator does not simply disappear from the process. Instead, the role moves higher in the decision hierarchy, from monitoring individual loops and responding to alarms towards supervising, orchestrating, and managing exceptions across increasingly intelligent operations.

This is also where AI can help address the loss of institutional knowledge as experienced operators retire. Operational experience that has historically existed in procedures, maintenance records, alarm histories, and the knowledge of individual operators can increasingly be contextualised and made accessible at the point of decision. Generative AI can make that knowledge easier to retrieve and interpret, while agentic AI may eventually allow systems to reason across multiple sources of information and coordinate increasingly complex operational tasks.

Autonomous operations should therefore not be viewed as a binary choice between people running the plant and a completely unmanned facility. Autonomy is a spectrum. Different processes and decisions will progress along that spectrum at different rates depending on safety, process maturity, economics, regulatory requirements, and the level of trust that has been established.

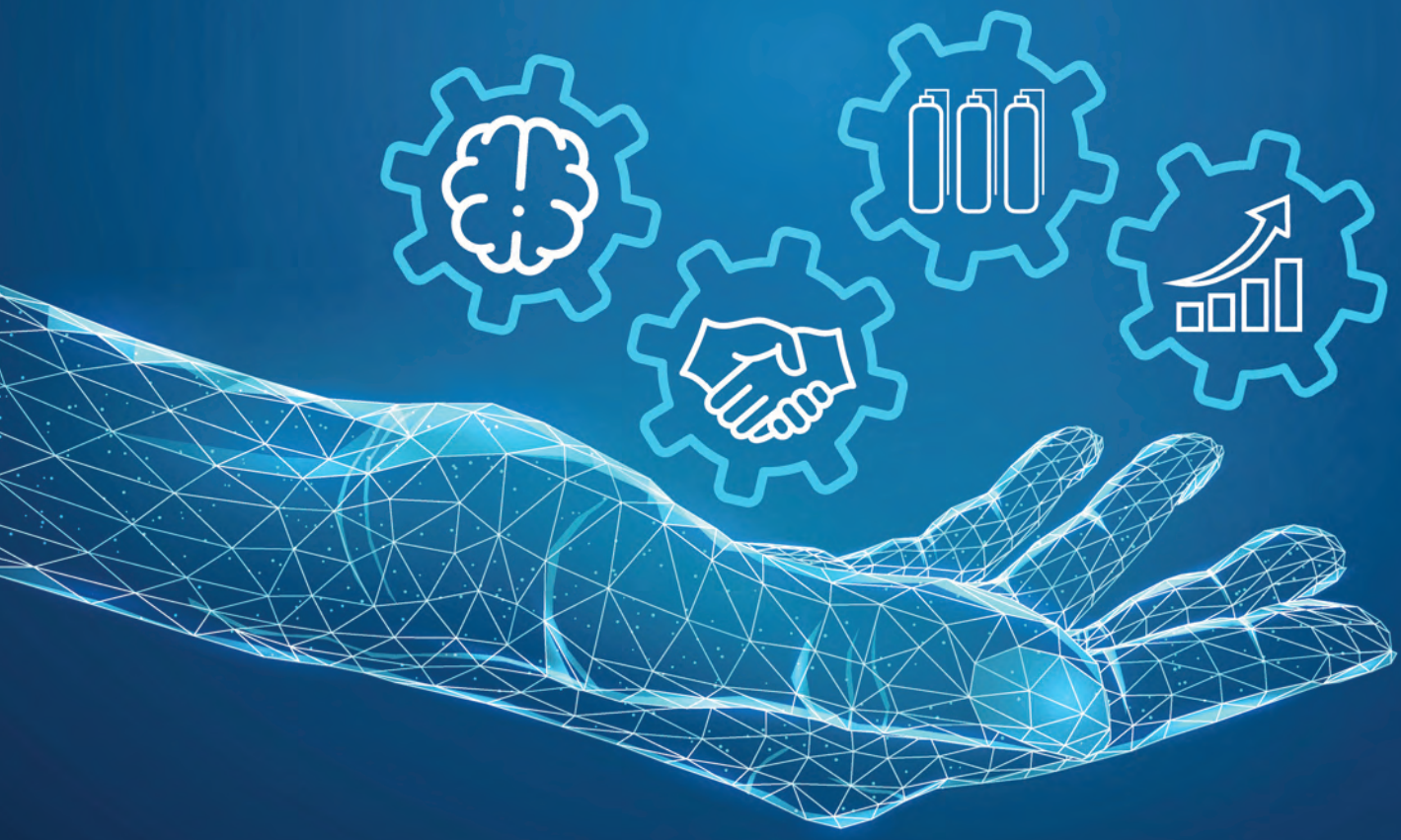
The objective is not autonomy for its own sake. It is to determine the appropriate balance between human judgement and machine intelligence to improve safety, reliability, efficiency, and business performance. Accountability remains fundamental throughout that journey.



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