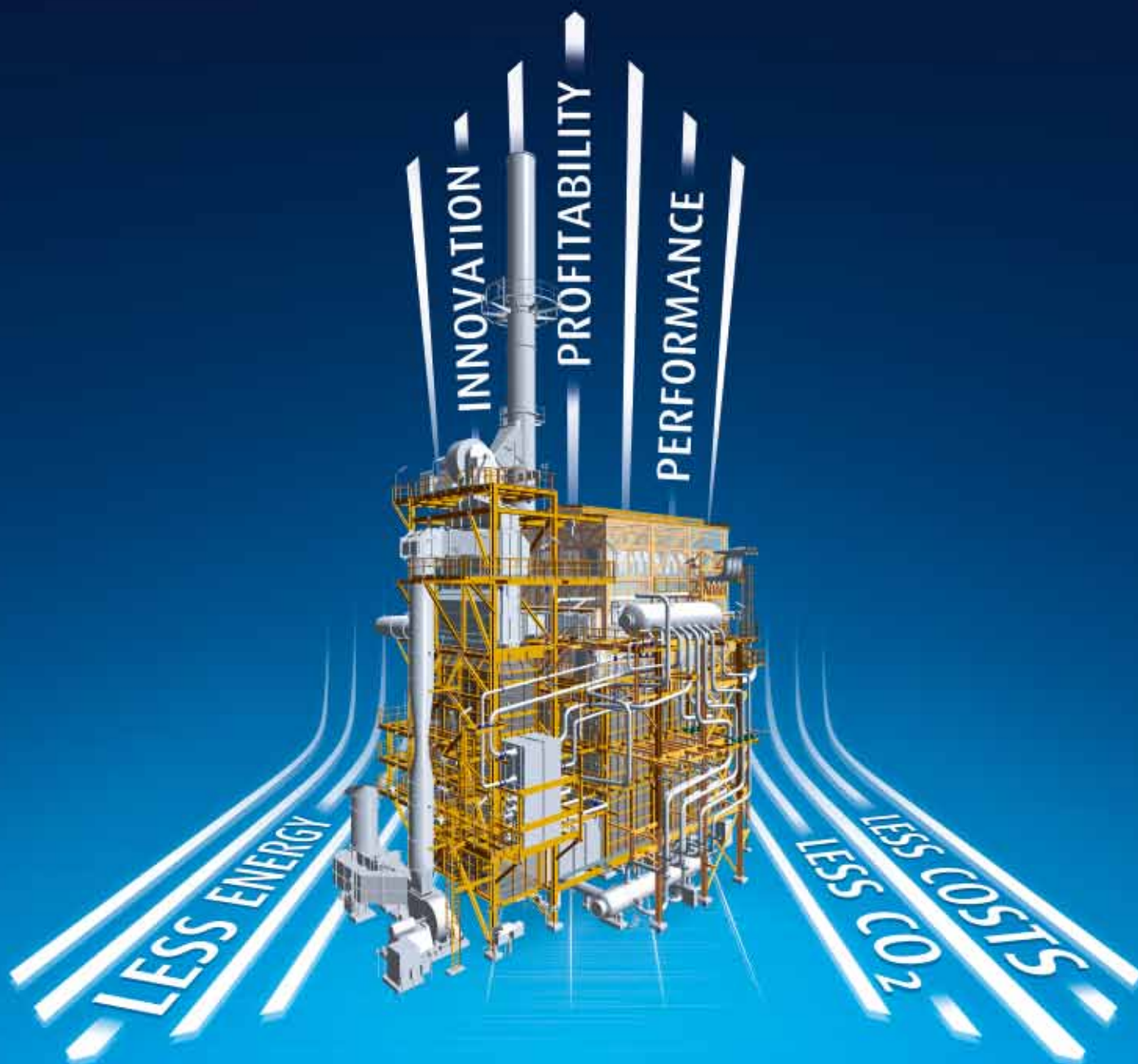


# Less energy consumption. More process efficiency.

Synergized benefits of Linde DRYREF™ and BASF SYNSPIRE™



In cooperation with:

**BASF**  
We create chemistry

*Linde*

# Strategic alliance to push the efficiency boundaries.

Syngas generation based on the conventional steam reforming process requires considerable amounts of process steam. Producing this steam has a major impact on the plant's energy bill. The industry is therefore looking for ways to reduce the steam-to-carbon (S/C) ratio of syngas generation. With conventional reforming catalysts, the reduction of steam can ultimately lead to or accelerate deactivation of the catalyst due to carbon accumulation and coke formation.

To advance process technologies in this area and improve process efficiency overall, industry leaders Linde Engineering and BASF – building on the catalyst screening capabilities of BASF affiliate hte – joined forces with renowned academic partners Karlsruhe Institute of Technology, the Technical University of Munich, the University of Leipzig and DECHEMA Forschungsinstitut.

The aim of the partnership was to optimize the steam reforming process by reducing surplus process steam and hence energy consumption, while simultaneously importing and utilizing carbon dioxide (CO<sub>2</sub>) from the battery limit.

Developed by Linde in collaboration with the alliance partners, the DRYREF™ syngas generation plant not only achieves these objectives but also generates additional CAPEX savings.

Supported by:

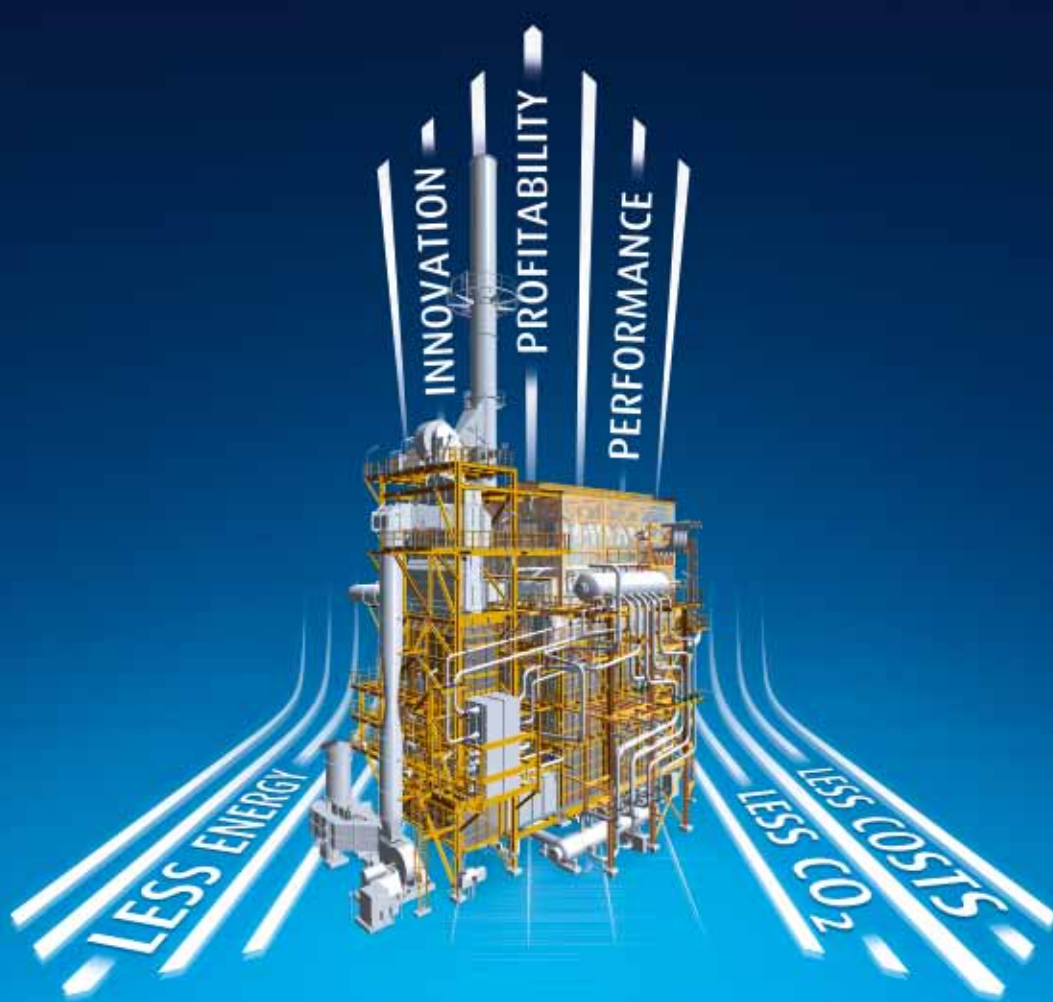


on the basis of a decision  
by the German Bundestag



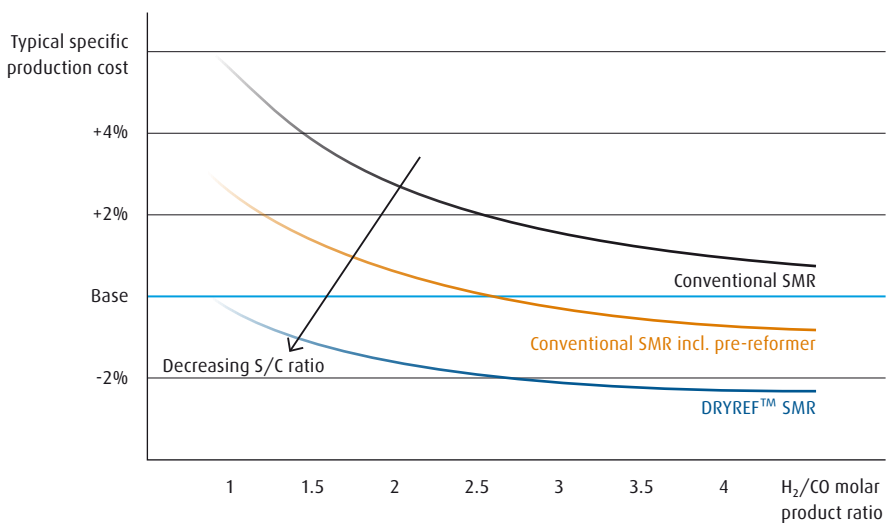
## Leveraging synergies

This alliance builds on Linde Engineering's strengths and proven track record in the design and delivery of turnkey industrial plants, with a particular focus on our experience and application know-how in CO<sub>2</sub> capture, compression, drying and purification. It bundles Linde's capabilities with BASF's leading role in the development of high-performance catalysts and, more specifically, BASF innovations to increase catalyst activity and coking resistance.



## Lower investment. Higher return.

Linde's DRYREF™ syngas generation plant in combination with the SYNSPIRE™ catalyst from BASF offers a number of compelling benefits beyond the prospect of clean energy and a contribution to climate mitigation. These benefits make the DRYREF technology an attractive and competitive alternative to partial oxidation plants with low  $H_2/CO$  ratios – effectively extending the  $H_2/CO$  reach of steam reforming.



DRYREF technology offers the lowest syngas production cost (depending on utility costs)



### Benefits at a glance

- New catalyst enables coke-free operation
- Low OPEX – energy savings and lower costs
- CAPEX savings thanks to more compact equipment
- CO<sub>2</sub> utilization as feedstock
- Smaller carbon footprint

### Potential applications:

- All processes with a CO<sub>2</sub> source that require a  $H_2/CO$  ratio < 3
- Various processes in the chemical industry
- Downstream processes in oil and gas (refining)

# Reduced catalyst deactivation. Extended syngas envelope.

One of the highlights of the DRYREF™ syngas generation plant – powered by BASF's SYNSPIRE™ G1-110 catalyst – is the fact that these technologies not only dramatically reduce energy consumption, but also consume carbon dioxide.

With conventional reforming catalysts, coking is initiated through deposition and insertion of a carbon species from the vapor phase into the metallic nickel (Ni) particles. Carbon accumulates at these weak points, forming carbon “whiskers” and soft coke. This ultimately leads to deactivation of the catalyst.

The stabilized crystal structure and tuned catalyst composition of BASF's SYNSPIRE G1-110 catalyst improves gasification activity and paves the way for coke-free operation under conditions with a low S/C ratio.

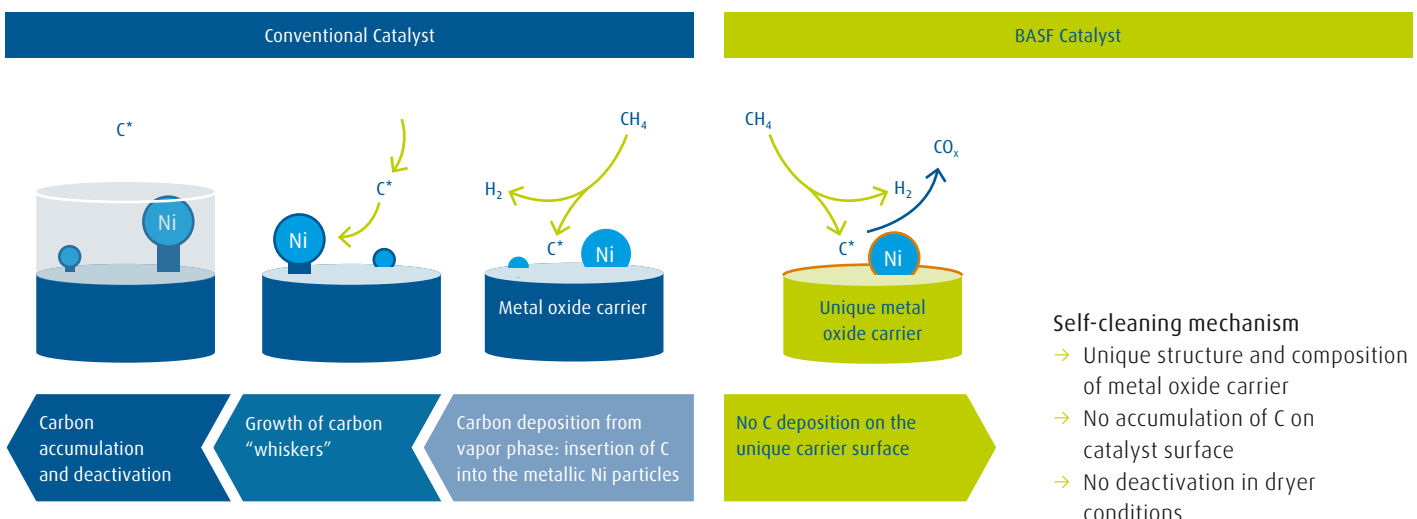
## BASF's SYNSPIRE™ catalyst – designed to withstand coke formation

Catalysts	SYNSPIRE G1-110
Main active component	Ni-oxides
Shape and size	Green tablets, 4-hole quadrilobes, 15 mm x 8 mm
Tapped density	0.9–1.1 kg/l
Packaging	200 l steel drums
Expected lifetime	5–8 years
Typical operating conditions	S/C < 1.8 [mol]/[mol] H <sub>2</sub> /CO: 1–3 [mol]/[mol]
Typical operating temperature (outlet gas temp)	800–950°C
Typical operating pressure	20–40 bara



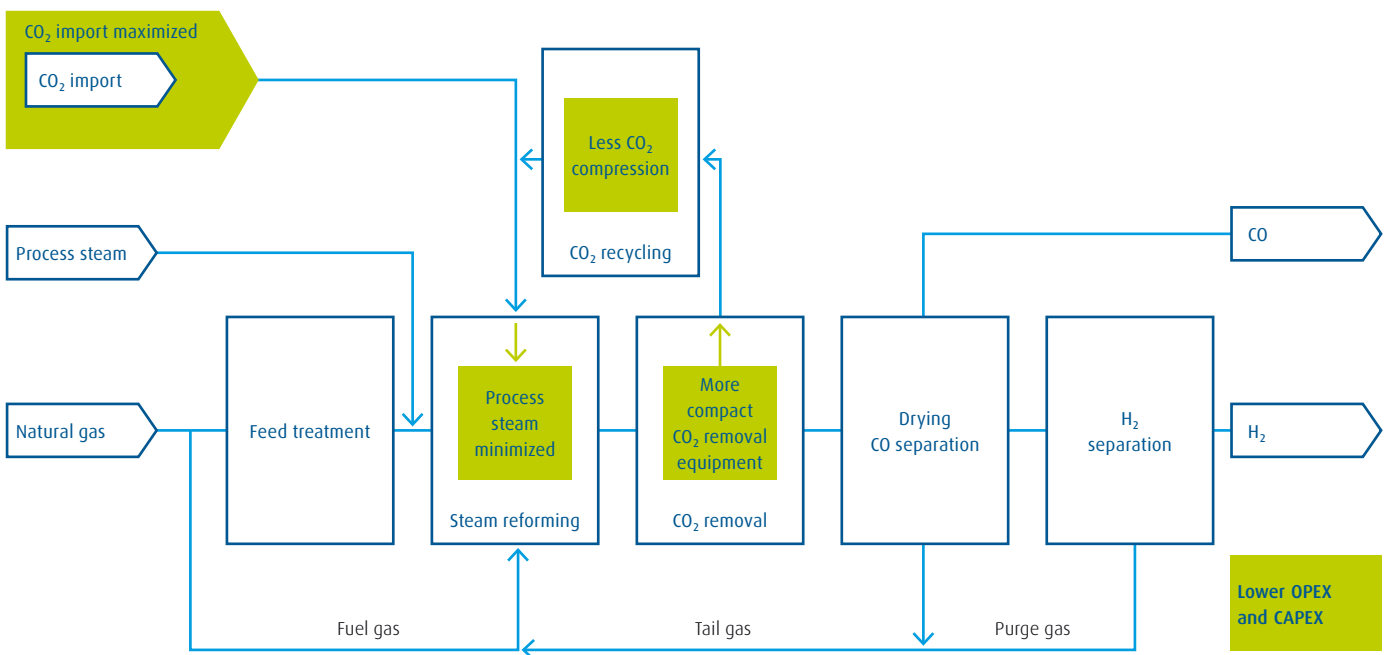
BASF's SYNSPIRE™ G1-110 catalyst – designed to withstand coke formation

## The unique structure of BASF's SYNSPIRE™ G1-110 catalyst enables coking resistance in low S/C conditions



Linde's DRYREF™ syngas generation plant capitalizes on the features of this new catalyst based on a tailored set of steam reforming parameters.

## DRYREF™ process for hydrogen and carbon monoxide production



■ Conventional process    ■ Innovation in the process

The reduced surplus process steam lowers the flow through the plant and enables the syngas composition to be adjusted over a wider envelope. The better thermodynamic equilibrium results in less net CO<sub>2</sub> that needs to be removed. This shrinks the CO<sub>2</sub> removal equipment footprint with less regeneration and recompression energy required.

The utilization of CO<sub>2</sub> imported from the battery limit instead of a substantial fraction of natural gas and steam also has a positive impact

on process economics. The S/C ratio can be significantly reduced, depending on the product composition, thus obviously reducing the boiler and steam equipment in size or enabling additional steam to be exported. This translates into significant CAPEX and OPEX gains.

The benefits of DRYREF™ technology can also be leveraged by replacing catalysts in existing steam reformers with the SYNSPIRE™ G1-110 catalyst.

# Milestones to commercial maturity.

## 2010–2014 (Phase I) Catalyst screening tests

The catalyst concept and process flow of the DRYREF™ plant was established during a government-funded project in cooperation with our academic partners. In addition to mechanical studies and kinetic investigations, this included extensive catalyst screening in the highly efficient, high-throughput hte experiment facility in order to identify and fine-tune BASF's SYNSPIRE™ G1-110 catalyst.



## 2014–2016 (Phase II) Catalyst development and laboratory tests

The SYNSPIRE™ G1-110 catalyst was upscaled from a few grams to a few hundred kilograms and transferred to production by BASF. Extensive performance testing was performed in lab equipment and in miniplants by Linde and BASF, enabling the partners to confirm that the SYNSPIRE G1-110 catalyst offers unique resistance to coking in low S/C reforming conditions.

## 2016–2017 (Phase III) Pilot testing

The Linde Pilot Reformer (LPR) installed at Linde's site in Pullach enables new process technologies to be tested under real-life conditions.

LPR is a monotube-fired steam reformer equipped with additional instrumentation to support accurate analysis of catalyst performance. The commercial-scale SYNSPIRE G1-110 catalyst pellets and the optimized DRYREF process parameters were tested under actual reformer tube conditions. This step helped to transition catalyst development from the lab to industry much more quickly and at significantly lower risk.

## 2017–2018 (Phase IV) Commercial demonstration

Commercial readiness was demonstrated at Linde's industrial-scale HyCo plant with full product utilization.

# Your partner for the production and processing of gases

## Delivering reliable process plants for maximum capital efficiency

Linde has been optimizing gas processing technologies for 140 years, successfully delivering more than 4,000 plant engineering projects around the globe. Favoring trusted, lasting business relationships, the company collaborates closely with customers to enhance plant lifecycle productivity and innovate process flows. The company's proven gas processing expertise plays an indispensable role in the success of customers across multiple industries – from natural gas and oil refining through petrochemicals and fertilizers to electronics and metal processing.

## Operational excellence along the entire plant lifecycle

We work closely with our customers to gain an in-depth understanding of individual needs. Building on the unique synergies of Linde as an integrated plant operator and engineering company, Linde offers innovative process technologies and services to exceed our customers' reliability and profitability expectations. This commitment to innovation extends along the entire plant lifecycle. The LINDE PLANTSERV® service team supports customers every step of the way – from maintenance and repairs to full revamps. Leveraging the latest digital technologies to offer on-site and remote operational and support services, we consistently take asset performance to the next level.

## Making the impossible possible

From the desert to the Arctic, from small- to world-scale, from standardized to customized designs, Linde's engineering specialists develop solutions that operate under all conditions. The company covers every step in the design, project management and construction of gas processing plants and components. Customers can always rely on Linde to deliver the plants, components and services that fit their needs best – anywhere in the world.

Discover how we can contribute to your success at [www.linde-engineering.com](http://www.linde-engineering.com)

Get in touch with our hydrogen and synthesis gas plants:  
[www.linde-engineering.com/contact](http://www.linde-engineering.com/contact)

## Core competencies at a glance

### Plant engineering

- Air separation plants
- LNG and natural gas processing plants
- Petrochemical plants
- Hydrogen and synthesis gas plants
- Adsorption plants
- Cryogenic plants
- Carbon capture and utilization plants
- Furnaces, fired heaters, incinerators

### Component manufacturing

- Coldboxes and modules
- Coil-wound heat exchangers
- Plate-fin heat exchangers
- Cryogenic columns
- Cryogenic storage tanks
- Liquefied helium tanks and containers
- Air-heated vaporizers
- Water bath vaporizers
- Spiral-welded aluminum pipes

### Services

- Revamps and plant modifications
- Plant relocations
- Spare parts
- Operational support, troubleshooting and immediate repairs
- Long-term service contracts
- Expert reviews for plants, operations and spare part inventory
- Operator training

## BASF contacts

For catalyst information, please get in contact with our catalyst team in your region: [catalysts-america@basf.com](mailto:catalysts-america@basf.com); [catalysts-asia@basf.com](mailto:catalysts-asia@basf.com); [catalysts-europe@basf.com](mailto:catalysts-europe@basf.com)

