

□ - BASF

We create chemistry

**The world's highest stability by the
inventor of styrene catalysts**



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BASF Catalysts Introduction

BASF – The Chemical Company

As the world's leading chemical company, BASF:

- Offers intelligent solutions and high-quality products for most industrial challenges
- Uses new technologies to optimize additional market opportunities
- Combines added value with environmental protection and social responsibility

BASF at a Glance

BASF creates chemistry for a sustainable future and combines economic success with environmental protection and social responsibility.

The approximately 122,000 employees in the BASF Group work on contributing to the success of our customers in nearly all sectors and almost every country in the world. Our 12 divisions are aggregated into six segments based on their business models. The divisions bear operational responsibility and are organized according to sectors or products. They manage our 54 global and regional business units and develop strategies for the 86 strategic business units.

BASF's Catalysts division, headquartered in Iselin, New Jersey, is the world's leading supplier of environmental and process catalysts. The group employs more than 5,000, with over 30 manufacturing sites worldwide.

As a global division of BASF SE, Ludwigshafen, Germany, Catalysts offers exceptional expertise in the development of technologies that protect the air we breathe, produce the fuels that power our world and ensure efficient production of a wide variety of chemicals, plastics and other products including advanced battery materials.

By leveraging its industry-leading research and development (R&D) platforms, passion for innovation and deep knowledge of precious metals, BASF's Catalysts division develops unique, proprietary catalyst and adsorbent solutions that drive customer success.

For styrene producers requiring highest operational stability & productivity, StyroStar® offers superior product stability from the original inventor of styrene industrial production and styrene catalysts (1929) as evidenced in the world's largest reference list including BASF's own styrene production.



BASF Quality and Reputation are Unmatched

BASF's Chemical Catalysts combine the strength of BASF – with the experience and expertise of our chemists and engineers. Our styrene catalysts are valued components of the dehydrogenation process for worldwide chemical manufacturing companies. BASF's commitment to the styrene monomer production process and ethylbenzene dehydrogenation catalysts results in products and services that meet and surpass customer expectations and requirements.

Important Facts about Styrene at BASF

- BASF has developed styrene catalysts for over 50 years (since 1965).
- Styrene production since 1965.
- BASF still runs a styrene plant in Ludwigshafen, Germany.

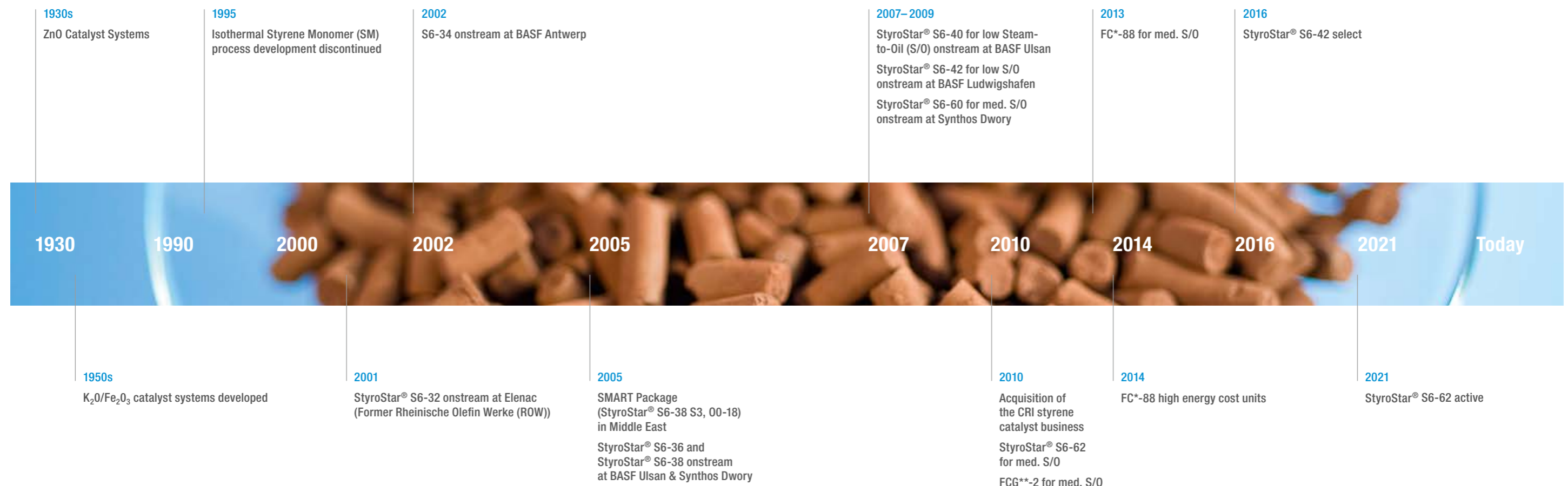
Applications for Styrene

Widely-used in the creation of plastics and rubber, styrene monomer is the largest petrochemical intermediate market. A significant quantity of styrene monomer is polymerized to polystyrene. Other products of styrene monomer are co-polymers such as acrylonitrile butadiene styrene (ABS), styrene-butadiene rubber (SBR), styrene-acrylonitrile resin (SAN) and unsaturated polyester resins.

The Main Uses of Styrene Include:

- Insulation
- Packaging
- Automotive Parts
- Fiberglass
- Food and Beverage Containers
- Plastic Pipes/Tubing

Milestones in Styrene Catalyst History



* FlexiCat ** FlexiCat Gold®
All BASF StyroStar® styrene catalysts are available as 3 mm.
Special geometries can be discussed individually.

Organization of the Styrene Catalyst Business

AMERICAS

Iselin, New Jersey

- Headquarters
- Regional Marketing & Sales

Elyria, USA

- Catalyst Production

Houston, USA

- Sales Office

Sao Paulo, Brazil

- Sales Office

EMEA

Ludwigshafen, Germany

- Catalyst Production
- Catalyst Research
- Regional Sales
- Technical Service

De Meern, Netherlands

- Sales Office

Moscow, Russia

- Sales Office

Abu Dhabi, UAE

- Sales Office

ASIA

Shanghai, China

- Oxidation and Dehydrogenation Catalysts Global Business Management
- Catalyst Production
- Regional Sales
- Technical Service

Seoul, South Korea

- Sales Office

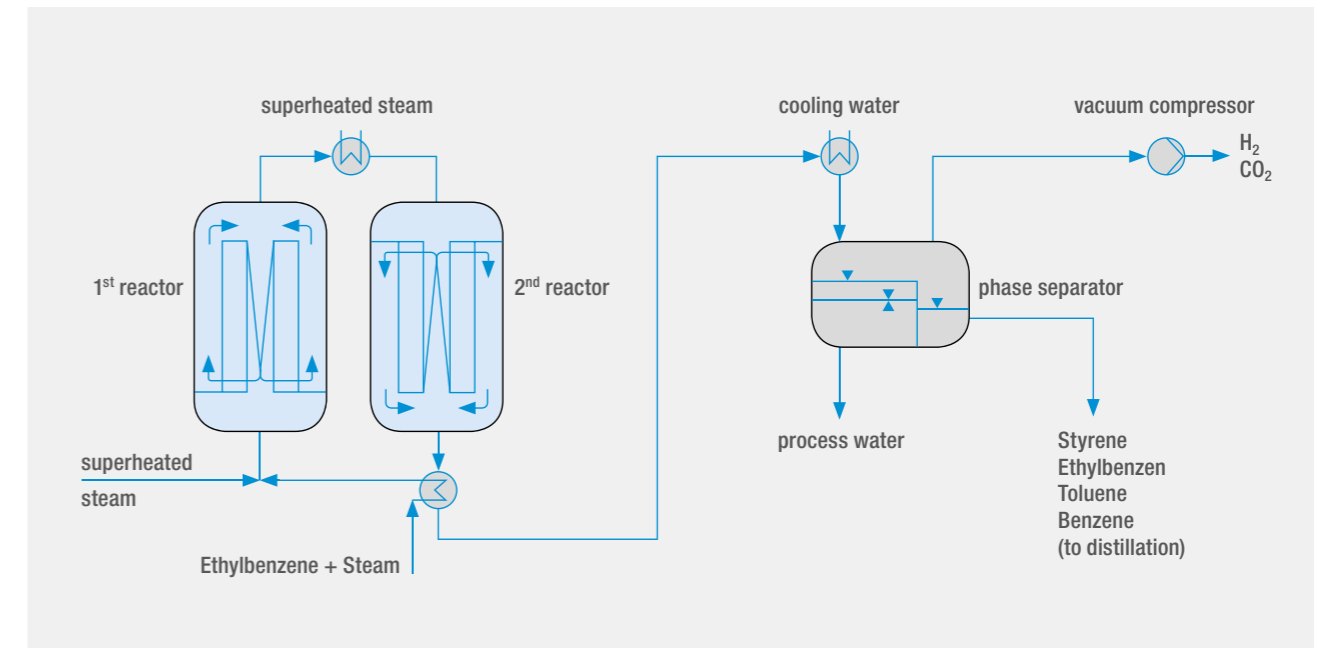
Tokyo, Japan

- Sales Office

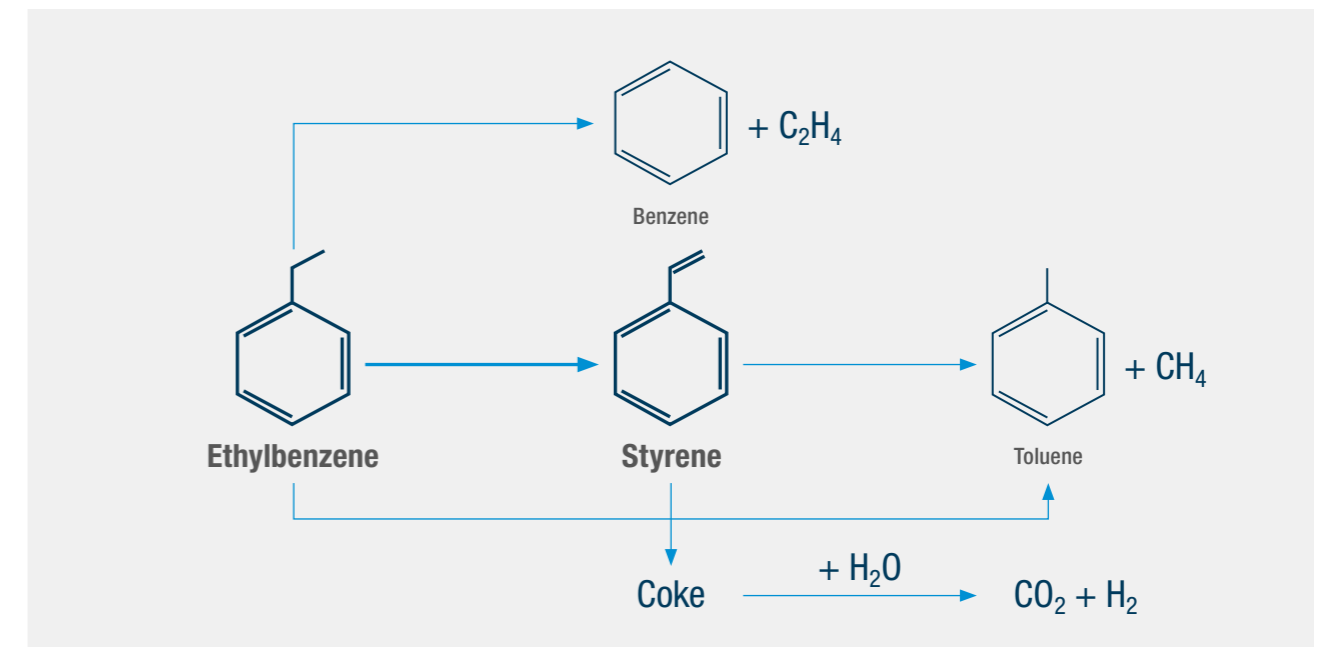


Styrene Adiabatic Dehydrogenation Process

In most cases, the styrene process consists of two or three adiabatic reactor systems that combine superheated steam with ethylbenzene to produce styrene with minimal by-products. A simplified process schematic with two reactor systems is shown below.



Styrene Simplified Reaction Scheme



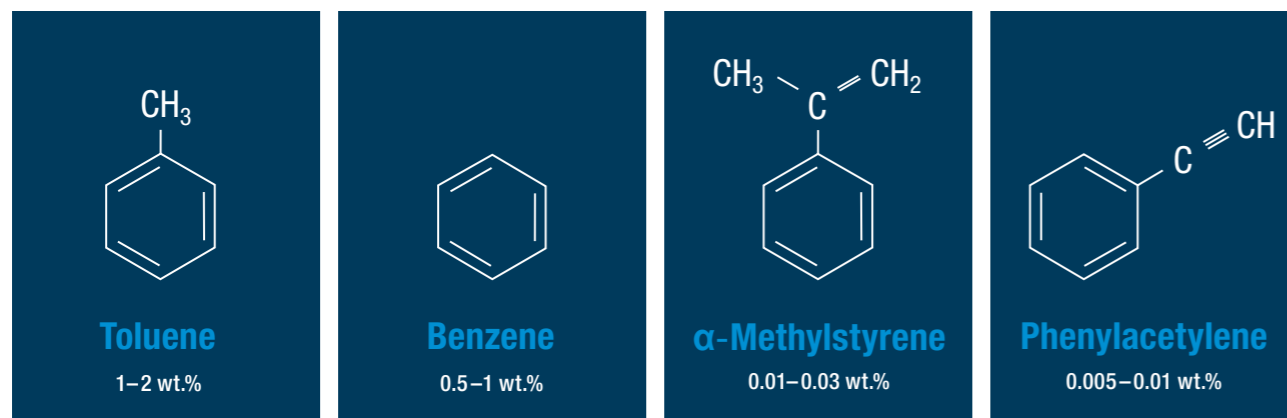
Advantages as a Styrene Catalyst Supplier

- BASF offers over 90 years experience in styrene production and more than 100 years in catalyst research. This legacy forms a strong foundation for continuous innovation and product improvement.
- Our constant improvement of styrene catalysts results in the introduction of a new catalyst constantly. For example, we introduced StyroStar® S6-42 in 2009 and StyroStar® S6-62 in 2010. We introduced StyroStar® S6-42 Select to the market in 2016. In 2021 StyroStar® S6-62 Active is launched.
- BASF experts provide:
 - Catalyst filling supervision
 - Start-up assistance
 - Regular detailed performance reviews and optimization of current operations
 - Routine customer visits
 - Global Styrene Customer Forum meetings

Delivering our products to the customer site is just the beginning of our offerings. BASF stands behind its products and, through our global technical service representatives, ensures that our products perform and deliver value (for more information, please see our Technical Services section on page 27). Our innovations make our customers more successful.

Main By-Products in Organic Phase

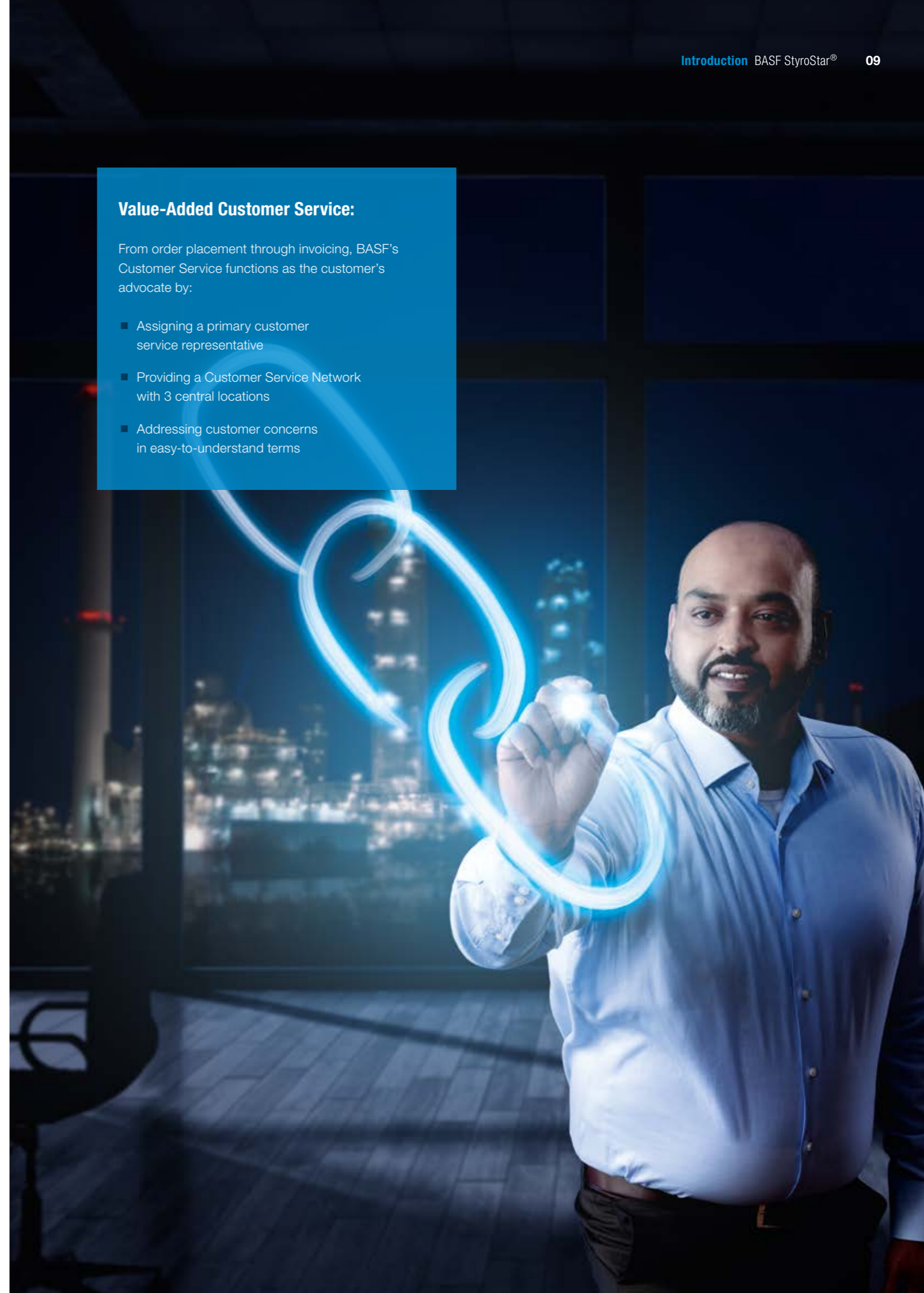
Molecules of Benzene, Toluene, Phenylacetylene and α -Methylstyrene with approximate formation in weight percentages (wt.%) in standard conditions.



Value-Added Customer Service:

From order placement through invoicing, BASF's Customer Service functions as the customer's advocate by:

- Assigning a primary customer service representative
- Providing a Customer Service Network with 3 central locations
- Addressing customer concerns in easy-to-understand terms



BASF Research & Development

With research and development, we shape the future and develop profitable growth. In 2018, we generated sales of around € 9 billion with products launched on the market in the past five years that stemmed from research and development activities. Optimized processes and intelligent system solutions, along with new and innovative products, make key contributions to the long-term success of our customers as well as ourselves. At BASF, more than 11,000 employees are working worldwide in research and development at approximately 70 locations.

BASF's Research Verbund covers the central technology platforms, the research and development units in our operating divisions worldwide and at group companies, as well as affiliated companies. In addition, we are currently involved in more than 1,900 collaborative partnerships worldwide with leading universities, research institutes, startup companies, and industrial partners, which add momentum to our research activities around the world.

- BASF leads the world's chemical industry in expenditures for R&D with approximately € 2.028 billion in investments.
- As the strongest innovation power in the chemical industry, BASF is ranked first in the Patent Asset Index™.
- BASF filed 900 new patents in 2018.



Isothermal Reactor for Screening



Adiabatic Reactor for Catalyst Testing

BASF Styrene Catalyst Research



Experience in a Commercial Plant

Advantages of Collaborating with BASF R&D

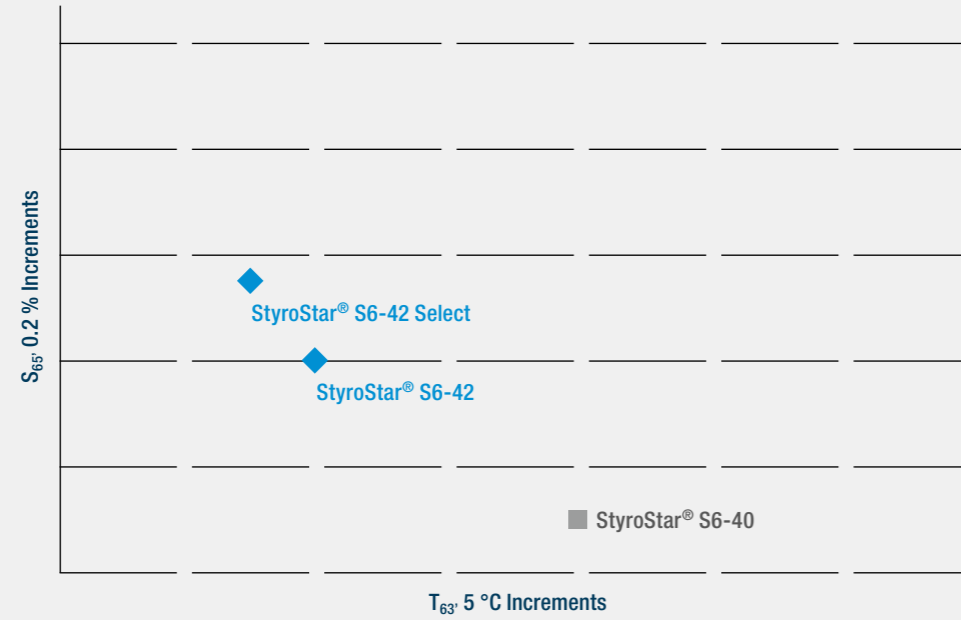
- Projects benefit from BASF's close cooperation between production, marketing, technical services, and R&D.
- Our own pilot plant uses the reactants from styrene production plants to create realistic scenarios for catalyst screening and long-term testing.
- Customers have direct access to BASF's R&D facilities.

Catalyst Research is the backbone of the BASF styrene catalyst business. By constantly improving our portfolio, we make sure our customers are always provided with the best product available on the market!

Styrene Catalysts Comparison at Standard Isothermal Conditions

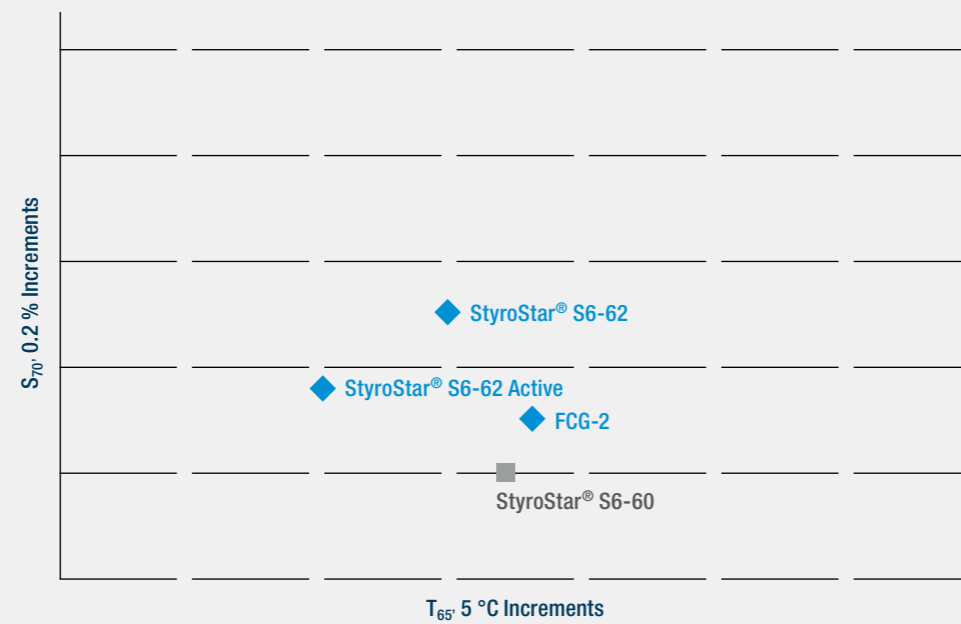
Low S/O

S/O = 1.0 wt./wt.; Pressure = 350 mbar
 Liquid Hourly Space Velocity (LHSV) = 0.40/hr;
 Conversion = 63%



Medium S/O

S/O = 1.25 wt./wt.; Pressure = 400 mbar
 LHSV = 0.40 /hr; Conversion = 65%



◆ Present BASF products
 ■ Previous generation BASF products



Styrene catalyst research is one of the most intense topics for BASF R&D's catalyst development with dedicated isothermal and adiabatic pilot plant units. Our R&D scientists and technicians develop catalysts with the focus on the future needs of our customers. We provide fast solutions to customer requirements based on our in-depth knowledge of styrene catalysts as well as process testing performed in our dedicated pilot plant facilities. Close cooperation with the styrene production unit in BASF SE enables us to continuously improve styrene catalysts for our customers."

Dr. Florina Patcas, Senior Principal Scientist
 Catalysis Research, BASF SE

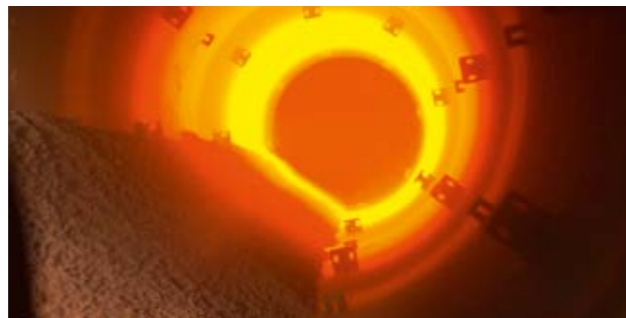
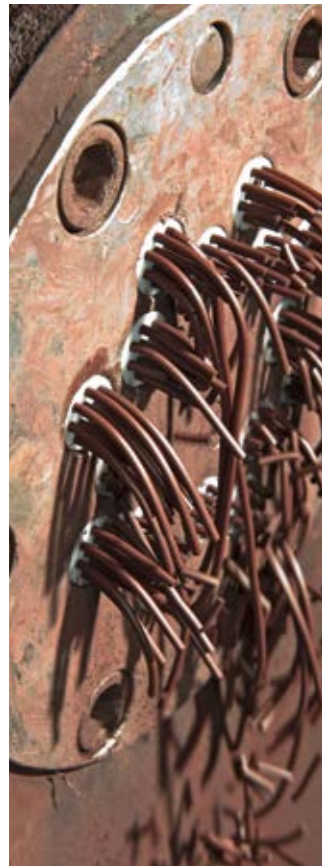


Catalysts Manufacturing

BASF has a great deal of experience in producing styrene catalysts as well as other catalysts in its manufacturing facility at Ludwigshafen, Germany. This Verbund Site is a state-of-the-art manufacturing facility that complies with internationally recognized standards to ensure that our high quality products are safe and effective. BASF continuously invests in its production facilities to improve productivity and energy efficiency.

The highly-trained and qualified manufacturing teams provide a wealth of experience to ensure that high quality standards are maintained throughout the operational process.

BASF's first production plant for chemical catalysts in Asia officially opened in November 2017. It produces base metal catalysts, mainly SM catalysts and adsorbents, to serve the region's growing chemical industry. Production in China provides shorter delivery times & higher flexibility.



There three styrene catalysts manufacture sites worldwide: Ludwigshafen, Germany; Elyria, US; Shanghai, China.

One Source, Three Plants, One Quality!

Quality Control and Assurance

BASF has a quality assurance system which strictly adheres to the specifications defined by R&D and safety guidelines. Each step in manufacturing, documentation and testing at BASF is reviewed and controlled by the highly qualified Quality Assurance team.

The quality control team performs stability studies as well as testing of raw materials, intermediates, and finished products in accordance with international standard operating procedures. This allows for successful execution of quality control testing.

The quality control laboratory ensures that our raw materials to finished products fulfill the required specifications to achieve maximum performance. BASF has the requisite analytical instruments and equipment to meet the needs of quality control. Due to these extensive quality control and assurance measures, our quality management system continuously earns ISO 9001 certification.



BASF Styrene Catalysts Portfolio

BASF has been serving the styrene catalyst market for decades. Our catalyst portfolio includes catalysts for low and ultra-low S/O processes, as well as for medium and high S/O ratio applications. Our styrene catalysts are valued components of the dehydrogenation process for worldwide operating chemical companies. Our aim is to develop a catalyst that best serves the needs of our customers.

StyroStar® S6-42 is designed especially for the dehydrogenation of ethylbenzene to styrene at ultra-low (0.85 wt./wt.) and low S/O ratios (<1.2 wt./wt.). This catalyst provides very low deactivation rate and very low Phenylacetylene (PA) formation.

Compare with StyroStar® S6-42, BASF's newly developed StyroStar® S6-42 Select gives additional 0.3–0.4% selectively with the same outstanding stability.

StyroStar® S6-62, FlexiCat Gold®-2 (FCG-2) are designed for medium S/O applications. All these medium S/O catalysts are developed to meet the needs of our customers.

StyroStar® S6-62 operates in the S/O range between 1.2–2.0 wt./wt. and provides the highest styrene selectivity.

The merger of BASF and CRI technical assets resulted in the development of FCG-2 for medium to very high S/O ratio (1.2–2.5 wt./wt.) operations.

Launched in 2021, StyroStar® S6-62 Active has an improved activity of 4–6 K depending on operation conditions and 7% low density, compared to its proven predecessor StyroStar® S6-62.

Catalyst Portfolio

Properties	StyroStar® S6-42	StyroStar® S6-42 Select	StyroStar® S6-62	StyroStar® S6-62 Active	FlexiCat Gold®-2
Average Bulk Density, kg/m ³	1,400	1,400	1,400	1,300	1,400
Tapped Density, kg/m ³	1,300–1,650	1,300–1,650	1,300–1,650	1,200–1,500	1,300–1,650
Max. Loss On Ignition (L.O.I.) 900°C, wt.%	3	3	3	3	3
Min. Knife Edge Hardness, N	50	50	50	50	90
Max. Attrition Loss, wt.%	1.5	1.5	1.5	1.5	1.5
Min. K ₂ O, wt.%	10	10	10	10	10
Min. Promoters, wt.%	10	10	10	10	8
Fe ₂ O ₃	matrix	matrix	matrix	matrix	matrix
Introduced in	2008	2016	2010	2021	2010

Catalyst Segmentation

	S/O Ratio (wt./wt.)	Catalysts offered
very high	> 2.0	StyroStar® S6-62, StyroStar® S6-62 Active, FlexiCat Gold®-2
high	1.5–2.0	StyroStar® S6-62, StyroStar® S6-62 Active, FlexiCat Gold®-2
medium	1.2–1.5	StyroStar® S6-62, StyroStar® S6-62 Active, FlexiCat Gold®-2
low	1.0–1.2	StyroStar® S6-42, StyroStar® S6-42 Select
ultra-low	0.85–1.0	StyroStar® S6-42, StyroStar® S6-42 Select

Styrene Catalysts for Low S/O

StyroStar® S6-42, StyroStar® S6-42 Select

StyroStar® S6-42 is designed for the dehydrogenation of ethylbenzene to styrene at very low S/O ratios. Its outstanding features include excellent activity, selectivity, and mechanical strength. Like its proven predecessor, catalyst StyroStar® S6-40, the new StyroStar® S6-42 is a robust and durable catalyst, combining excellent mechanical properties with an exceptionally low monthly decline rate.

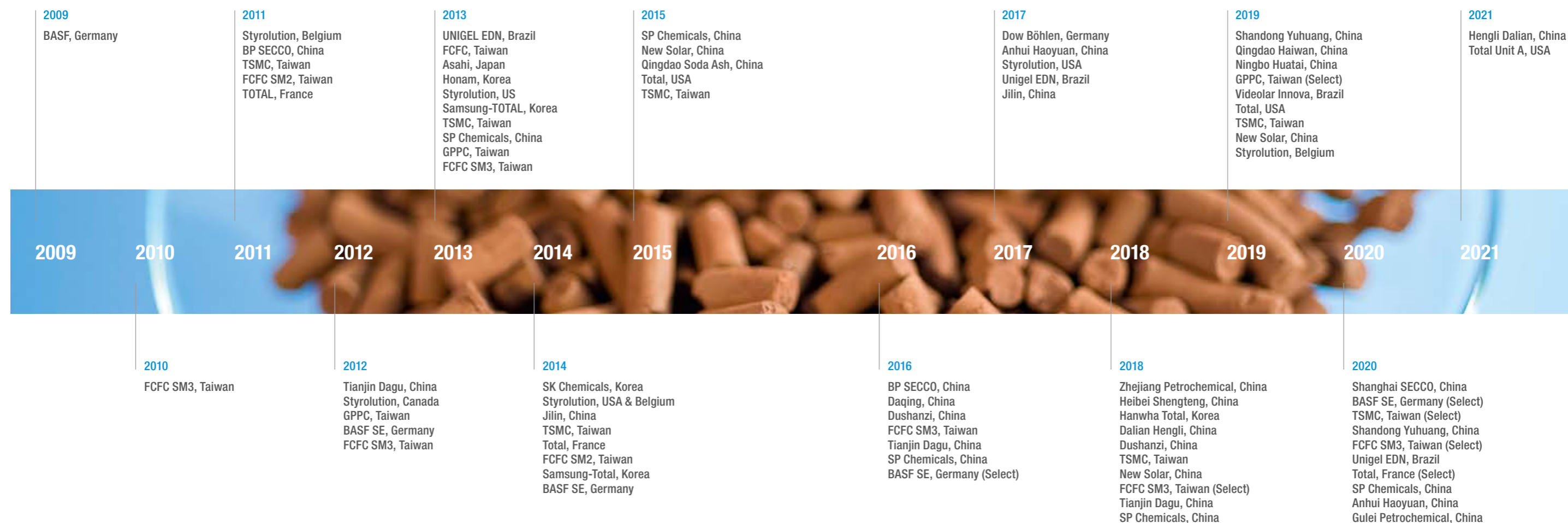
In particular, StyroStar® S6-42 exhibits improved performance in terms of activity (approx. 5°C) and selectivity (0.2–0.3 wt.%) depending on the conditions. Also, like StyroStar® S6-40, the formation of by-products is very low. Compare with StyroStar® S6-42, BASF's newly developed StyroStar® S6-42 Select gives additional 0.3–0.4% selectivity with same outstanding stability.

The Market Leader in Low Steam-To-Oil (S/O)

- Designed for operation at low and ultra-low S/O ratios
- Outstanding activity and selectivity
- Exceptionally low monthly decline rate
- Highest stability for low and ultra-low S/O ratios
- Robust and durable mechanical strength
- Low PA formation

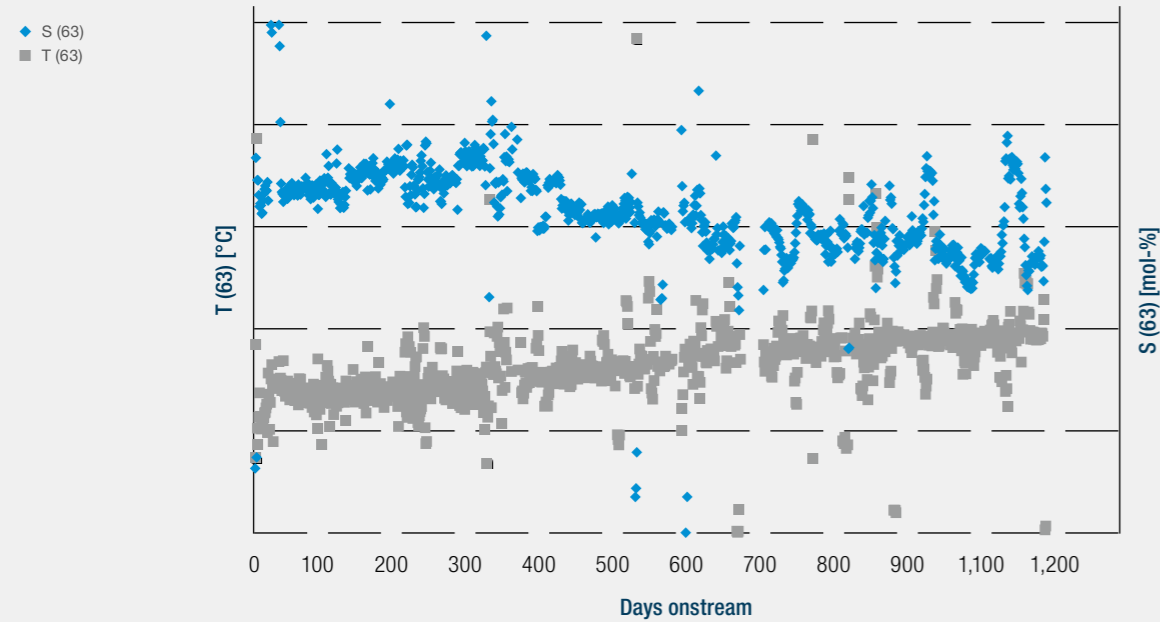


StyroStar® S6-42 and Select References



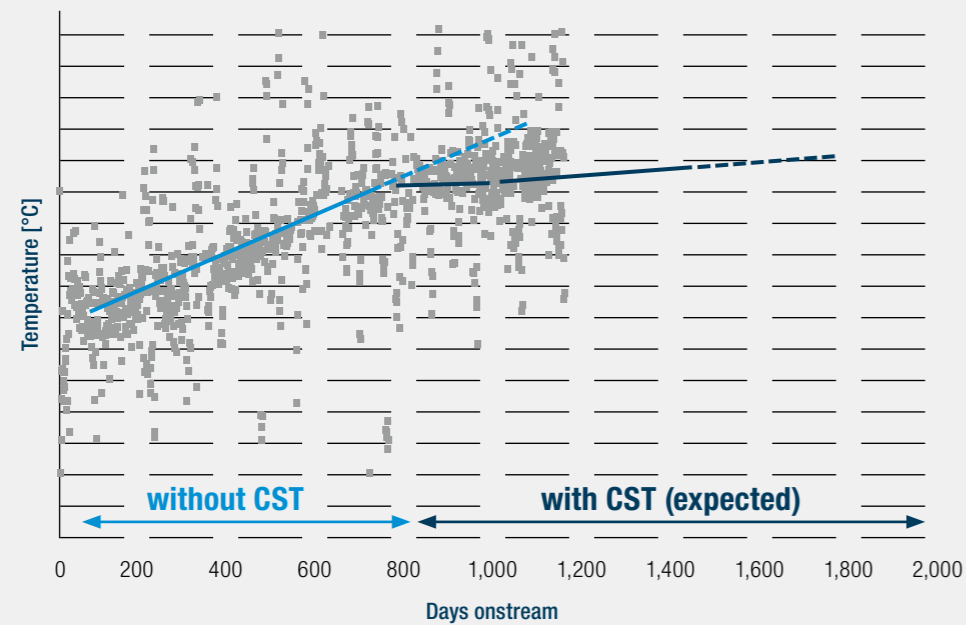
Commercial Reference

Stability of StyroStar® S6-42 Catalyst



Commercial experience more than 3 years. StyroStar® S6-42 keeps excellent selectivity and shows a very low deactivation rate.

Experience with CST



Catalyst Stabilization Technology (CST)*

- StyroStar® S6-42 and StyroStar® S6-42 Select can be used with CST.

Product and Packaging

StyroStar® S6-42 and StyroStar® S6-42 Select is especially developed for very low S/O ratio (0.85 – 1.2 wt./wt.) operations.

Packaging

- 1,150 L super sack (IBC flexible) with liner

Weight (include both metric and US measures)

- 1,100 kg net

Shipping Point

- BASF SE, Ludwigshafen, Germany; Shanghai, China; Elyria, US

The typical physical form is 3 mm extrudates that are red-brown in color. The chemical composition refers to the catalyst in its calcined state.

* Styrene Catalyst Stabilization Technology has been patented by Badger Licensing.

Typical Properties

Average bulk density, kg/m ³	1,400
Tapped Density, kg/m ³	1,300 – 1,650
L.O.I. at 900°C, wt.%	3 maximum
Knife Edge Hardness, N	50 minimum
Attrition Loss, wt.%	1.5 maximum
K ₂ O, wt.%	10 minimum
Promoters, wt.%	10 minimum
Fe ₂ O ₃	matrix

These typical properties do not represent process capabilities or specifications.



Styrene Catalysts for Medium and High S/O

StyroStar® S6-62 / StyroStar® S6-62 Active

StyroStar® S6-62 is designed for the dehydrogenation of ethylbenzene to styrene for medium and high S/O ratio (1.2–2.0 wt./wt.) conditions. Its outstanding features include good activity, excellent selectivity and mechanical strength. Like its proven predecessor, Catalyst StyroStar® S6-60, StyroStar® S6-62 is a robust and durable catalyst. Compared to FlexiCat Gold®-2 and StyroStar® S6-60, StyroStar® S6-62 has a higher catalyst activity and is the catalyst of choice for long runs with excellent selectivity. StyroStar® S6-62 Active is a newly developed medium and high S/O ratio catalyst, it has an additional 4–6 K activity and 7% low density, compared to StyroStar® S6-62.

Features

- Highest selectivity in the medium S/O catalyst portfolio
- Very good activity
- Excellent mechanical strength

FlexiCat Gold®-2

FlexiCat Gold®-2 is designed for the dehydrogenation of ethylbenzene to styrene. Outstanding features include excellent activity, selectivity and mechanical strength. FCG-2 is based on the proven technology of FlexiCat Gold® (FCG) catalysts.

Like its predecessor FlexiCat Gold®, FlexiCat Gold®-2 is a robust and durable catalyst, combining outstanding mechanical properties with an exceptionally low monthly decline rate and very stable selectivity during its lifecycle. In particular, FlexiCat Gold®-2 demonstrates improved performance in terms of activity (up to approximately 3°C) and selectivity (up to 0.8 mol-%) depending on the conditions.

Features

- Applicable for medium to very high S/O ratios
- Good selectivity and activity
- Low PA formation
- Excellent mechanical strength

StyroStar® S6-62 References



* Undisclosed customer

Product and Packaging

StyroStar® S6-62 / StyroStar® S6-62 Active

StyroStar® S6-62 and StyroStar® S6-62 Active are suitable for a wide range (S/O ratio 1.2–2.0 wt./wt.) of plant designs and operating conditions, including 3-stage applications such as UOP/Lummus Smart™ Technology.

Packaging

- 1,150 L super sack (IBC flexible) with liner

Weight (include both metric and US measures)

- 1,100 kg net

Shipping Point

- BASF SE, Ludwigshafen, Germany; Shanghai, China; Elyria, US

The typical physical form is 3 mm extrudates that are red-brown in color. The chemical composition refers to the catalyst in its calcined state.

Typical Properties

	StyroStar® S6-62	StyroStar® S6-62 Active
Average bulk density, kg/m ³	1,400	1,300
Tapped Density, kg/m ³	1,400	1,200–1500
L.O.I. at 900°C, wt.%	3 maximum	3 maximum
Knife Edge Hardness, N	50 minimum	50 minimum
Attrition Loss, wt.%	1.5 maximum	1.5 maximum
K ₂ O, wt.%	10 minimum	10 minimum
Promoters, wt.%	10 minimum	10 minimum
Fe ₂ O ₃	matrix	matrix

These typical properties do not represent process capabilities or specifications.

FlexiCat Gold®-2

FCG-2 is especially developed for medium to very high S/O ratio (1.2–2.5 wt./wt.) operations.

Packaging

- 1,150 L super sack (IBC flexible) with liner

Weight (include both metric and US measures)

- 1,100 kg net

Shipping Point

- BASF SE, Ludwigshafen, Germany; Shanghai, China; Elyria, US

The typical physical form is 3 mm extrudates that are red-brown in color. Star-shaped 6 mm extrudates are available on request. The chemical composition refers to the catalyst in its calcined state.

Typical Properties

Average bulk density, kg/m ³	1,400
Tapped Density, kg/m ³	1,300–1,650
L.O.I. at 900°C, wt.%	3 maximum
Knife Edge Hardness, N	90 minimum
Attrition Loss, wt.%	1.5 maximum
K ₂ O, wt.%	10 minimum
Promoters, wt.%	8 minimum
Fe ₂ O ₃	matrix

These typical properties do not represent process capabilities or specifications.

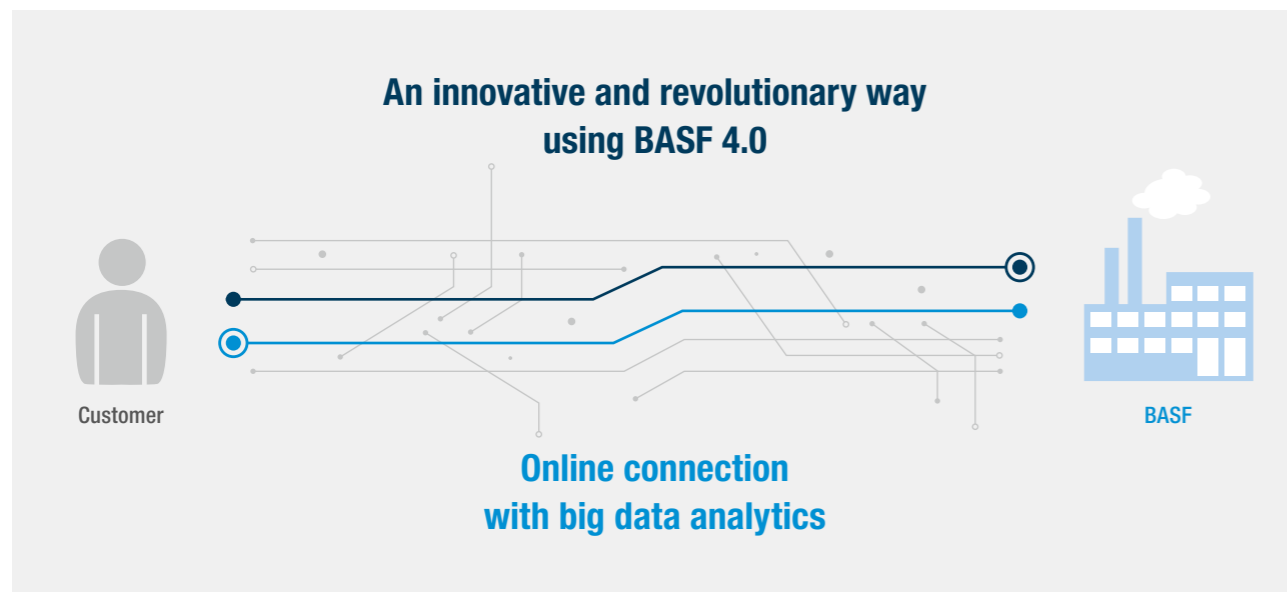


Innovative Solutions Styrene 4.0

Benefits for Styrene 4.0 Customer

- Access to BASF's **expertise** with a click of a button
- More **efficient interaction** between BASF and Customer
- **Online access** for quick detailed technical reviews and recommendations
- Increases **efficiency** and **data accuracy** through system automation
- **Accurate predictions** with advanced modeling and data analytics
- Simulate **new operating conditions** online to meet market changes
- Catalyst life prediction for **better planning** and **maximizing economic benefits** in a dynamic market

BASF Customer Interaction and Support Model



Support customer in maximizing styrene production output over the catalyst's lifetime

Support Technical Services

Customers who utilize our catalysts are offered individualized service agreements for a wide range of technical services. BASF's dedicated technical service team has extensive experience in oxidation and dehydrogenation catalytic behavior under a variety of operating conditions. This technical team is equipped with a full range of resources to analyze the most complex problems, and has full access to our R&D facility and dedicated R&D personnel. This comprehensive service approach provides the best possible assistance to our customers anytime and anywhere in the world.

Each region in the world is assigned a dedicated BASF technical team.

Asia Pacific

through our Styrene catalyst global business management in Shanghai

Europe, the Middle East, and Africa (EMEA)

through our technical service team in Ludwigshafen

Americas

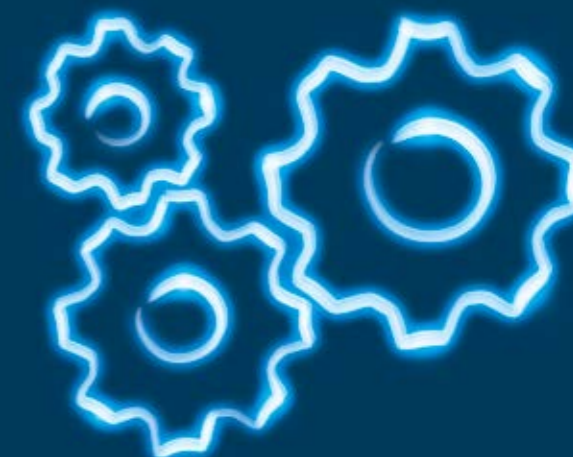
through our technical service team in Ludwigshafen

Features

- Catalyst selection and performance forecasting
- Loading and start-up support
- Performance evaluation and optimization of current run
- Analysis of aged catalyst
- Troubleshooting
- Lifetime calculations
- Training of production staff

Customer Support: BASF Styrene catalyst package

BASF provides not only the fitting styrene catalyst. In addition, we provide top class technological expertise by our experts as well as guidelines for the catalyst's use. We support our customers even by conducting dedicated experiments in our R&D department, in case that is necessary. Last but not least, we offer in-depth catalyst training covering the whole theoretical background of this technology.





We create chemistry

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About Us

BASF's Catalysts division is the world's leading supplier of environmental and process catalysts. The group offers exceptional expertise in the development of technologies that protect the air we breathe, produce the fuels that power our world and ensure efficient production of a wide variety of chemicals, plastics and other products, including advanced battery materials. By leveraging our industry-leading R&D platforms, passion for innovation and deep knowledge of precious and base metals, BASF's Catalysts division develops unique, proprietary solutions that drive customer success.

BASF – We create chemistry

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www.catalysts.basf.com/styrene