hte

CHRONICLE
CELEBRATING 20 YEARS

A subsidiary of
BASF – We create chemistry

20 YEARS hte

Enhancing innovation by use of high throughput technology in catalysis research

Wolfram Stichert
CEO, hte GmbH

FROM AN UNUSUAL IDEA

20 years high throughput research – a good opportunity to look back. Within two decades, hte was able to take a remarkably successful path: From an empty laboratory in 1999 to a company with more than 300 employees today. From an unusual idea to a world-leading technology for fast and productive research and development in catalysis.

Our customers value our precision and speed – our technology platform is widely considered as the leading concept for digitalization of R&D in the field of catalysis. An integral part of this platform is our software. High throughput experiments produce enormous amounts of data – tailor-made software solutions are necessary to support scientists in experiment control, evaluation, structuring, analysis, and visualization of data.

Our employees are the basis and reason for our successes – our greatest asset. The pleasure they take in their work and their agile can-do and customer-first mentality, their passion, and expertise have taken us to the top and will be the basis for the next chapters of our success story.

THE IDEA BECOMES A VISION

Catalysts get chemical reactions moving. The Chinese ideogram for catalyst means "marriage broker". These marriage brokers reduce the energy required to kick off almost every chemical transformation. Without them, some chemical transformations would simply be impossible.

There are many different areas of application. Catalysts help to reduce harmful emissions in automotive exhaust gases, extract base substances for medicine, or find new value chains to use alternative resource materials instead of crude oil. They contribute to saving energy, using fossil raw materials more effectively – more diesel per barrel – or tapping new energy sources. They also make an important contribution to climate protection.

The big question in catalyst research is: How do I find the right catalyst – quickly and efficiently – to optimally support a chemical reaction? This challenge was the foundation on which hte was built. The team of researchers and founders at hte was searching for a way to test the suitability of a variety of different substances as catalysts at the same time – and thus accurately identify the most effective reaction accelerator.

ENERGY EFFICIENCY

MOBILITY

CLIMATE PROTECTION

ENVIRONMENTAL PROTECTION

At the top Armin Brenner, Wolfgang Strehlau, Stephan A. Schunk, Wolfram Stichert, Dirk Demuth

On the right John M. Newsam, Ferdi Schüth

THE VISION BECOMES REALITY

The company's actual birth location was the Johann Wolfgang Goethe University in Frankfurt, Germany, and the Max-Planck-Institut für Kohlenforschung, where Professor Ferdi Schüth, one of the seven founders, has been actively involved in R&D programs within the field of heterogeneous catalysis. He identified very early on the potential to make industrial research and development in the area of heterogeneous catalysis more efficient using high throughput methods. His idea was to develop technologies for accelerating synthesis, screening, and evaluation of catalysts using combinatorial methods.

Ferdi Schüth convinced several colleagues of his idea to introduce high throughput experimentation into catalyst development. Just a few months later, the team – including Armin Brenner, Stephan A. Schunk, and Wolfram Stichert – had built a prototype of a parallel reactor and validated the technology. The data quality was excellent and the potential to accelerate catalytic experiments by a factor of 50-100 was established. The only thing missing was proof of its economic and industrial benefit. The group decided to contact the R&D department for catalysts at BASF Aktiengesellschaft with the plan to set up a joint research and development project.

BASF had already worked actively on evaluating the potential of combinatorial methods for a broad range of R&D applications in catalysis. From then on, Professor Schüth's group was involved in the discussion on further evaluating the potential of this novel technology and a possible research assignment.

At this time Dirk Demuth joined Professor Schüth's team. First plans for founding a company took shape. The sixth member to join the team was Professor John M. Newsam in mid-1998. At the end of that year, the business plan for hte was completed and Wolfgang Strehlau became the seventh founding member. **hte – the high throughput experimentation company** was born on March 26, 1999.

hte began its operation in June 1999. One month later the first industrial research project began: BASF commissioned hte to establish suitable processes for accelerating the development of new catalysts.

In April 2000, hte founded hte North America with leadership of John M. Newsam. The primary technological focus was molecular catalysis. Two years later, all catalysis programs were relocated to Heidelberg, Germany. hte North America was hived off as a new, independent company called fqubed Inc. and sold to the pharmaceutical company Nuvo Research Inc. in 2005.

RISE TO GLOBAL MARKET LEADER

In 1999, it was a start-up with an unusual idea – today hte has over 300 employees and is global market leader in the field of high throughput catalysis research. hte technologies have now become benchmarks and are routinely used in many companies within the chemical, petrochemical, and oil industries.

Following years of development, it succeeded in breaking onto the market with the new technology in 2004 to 2006. In addition to its first customers BASF and Chevron, hte succeeded in winning further important partners with Shell, BP, and Albemarle.

This development phase reached its peak in 2008 with the majority acquisition by BASF, which had held a smaller stake in the company since 2003. The takeover involved no changes to hte's business model of offering technologies and services on the worldwide market.

The size and stability of BASF were a huge advantage in the financial crisis of 2009/2010 – work on the technology platform was able to continue during this period and hte participated fully in the economic upturn that followed in 2011. Since then, hte has held onto its leadership of the market, continuously expanding upon it. Today, many of the major global players in the fields of oil & gas, chemicals, and refining place their trust in the efficiency and high quality of hte's catalyst testing methods.

Ferdi Schüth
Founder and chairman of the supervisory board until 2003

"The founding years of hte were the most exciting and unique ones in my professional life: getting ideas started, convincing customers, and creating the appropriate structure for a customer-oriented technology company. Now, after 20 years, I just feel extremely proud of hte and the people working there – especially when customers of hte tell me what a great company it is!"

Wolfram Stichert
Founder and CEO since 2013

"In 20 years, one thing has never changed for me: the special spirit of hte. No matter how tough the challenge is, our team is able to handle it. We are motivated, act fast, flexible and goal-oriented. You feel it when walking through the corridors here. It is also something our customers genuinely appreciate."

Dirk Demuth
Founder and CEO until 2012

"It is the corporate culture that makes hte special. The desire to tackle new challenges. This is unique. Despite the growth of the company, one can still feel it even after many years."

Armin Brenner
Founder and Project Manager & Patent Auditor at hte

"How can I supply multiple reactors with gases and liquids at the same time to run them in parallel and test them simultaneously? This question was the challenge on which hte was built. Today, we do not have only one answer to this question, we have several, which help to meet our customers' needs for faster and more precise catalysts. I am very proud of this."

Detlef Kratz
President, Process Research & Chemical Engineering, BASF SE

The foundation of a start-up in the field of high throughput research was a bold decision 20 years ago. Since then hte has gone from strength to strength: The former start-up has blossomed into a mature company that is a global leader and sets standards.

hte has even been instrumental in advancing BASF research: High throughput technologies and methods are now a standard tool for BASF research and play a role in numerous successful research projects. hte also provides digitalized workflows – a modern research technology with appropriate software environment – to many BASF research locations around the world. Not least, BASF benefits from hte's creative power. A BASF-exclusive research team and a team of international post-doctorates are developing new ideas and approaches for our project pipeline together with the colleagues from BASF. It was an important strategic decision not to integrate hte as another research department, but to keep it as an independent entity. This preserved the company's start-up culture and freedom to operate. My wish for hte's future is for the company to retain its technical, scientific, and creative power and for its portfolio to be expanded with further important research topics.

Wolfgang Strehlau
Founder and responsible for environmental catalysis and business development until 2007

"Personally, hte stands for innovation, entrepreneurship, independence, good cooperation, and many "smart" people with different backgrounds. The company also stands for a common will to achieve something great, as well as for tasty Thai food."

Stephan A. Schunk
Founder and Research Director /Vice President at BASF

"hte stands for innovative power, finding solutions, and focusing on what customers want and when they want it – in short: being on the pulse of market. To me, hte has always been a place where I could put science into action, realize highly ambitious technological concepts and turn them into reality."

John M. Newsam
Founder and General Manager of hte North America until 2002

"hte established itself quickly as a leader in high throughput experimentation. We were able to differentiate our company early on, to approaches and offerings from others in the field. The capabilities of hte are impressive and the company now has a successful track record. But fundamentally, people do business with people. The potential for making business happen is greatest when there is mutual respect, mutual trust, and personal resonance."

Testing technology for the dry reforming project

hte STORIES

Our service portfolio comprises research collaborations and integrated hardware and software solutions that enable customers to establish high throughput workflows in their own laboratories. We contribute to overcoming the global challenges of our time. Here is a small selection of success stories.

In the **chemical sector** new value chains are in demand in order to use alternative resource materials such as natural gas or renewable raw materials in a cost-efficient way. These challenges are addressed by new chemical processes or the improvement of existing processes for which the optimization of catalysts plays a key role.

hte was involved in a German research cooperation that developed an innovative technology for the environmentally friendly production of synthesis gas (a mixture of H_2 and CO). Production of synthesis gas through **dry reforming** of natural gas means that carbon dioxide (CO_2) can be used on an industrial scale as an economical feedstock. The process is also significantly more energy efficient than the conventional method of reforming. The synthesis gas can be used to produce valuable downstream products such as base chemicals or fuels. hte was responsible for searching and developing the active mass and for testing the catalysts.

Within a short time, it was possible to identify two new catalyst candidates. They were then developed, tested on an industrial scale, and launched to market. The pilot project was funded by the German Ministry for Economic Affairs and Energy (BMWi).

hte supported BP in accelerating the **commercialization of the Fischer-Tropsch process.** This process is used to convert syngas into synthetic fuels and lubricants. During the collaboration, hte's technology platform has been continuously refined and advanced for the Fischer-Tropsch synthesis reaction. This allowed BP to perform a large number of rapid and precise data for the scale-up of catalysts and processes. In this scope, strict laboratory protocols were developed for catalyst development (screening), process development (kinetics), catalyst scale-up (quality control), and process scale-up (e.g. start-up). Ultimately, hte was able to test Fischer-Tropsch catalysts on all scale of process development – from powders to extrudates, from 3 mm to 21 mm tube reactors.

BIOMASS CONVERSION

NEW ENERGY SOURCES

EFFICIENT UTILIZATION OF RAW MATERIALS

Testing technology for energy and refining projects

CLEAN FUELS

ENERGY SAVINGS

REDUCTION OF CO_2

hte supports companies from the energy and refining sector in R&D of catalytic processes for a more efficient utilization of raw materials and in the manufacturing of clean fuels: from tapping of new energy sources and adhering to environmental regulations to utilizing unconventional raw materials.

In developing a new styrene catalyst for CRI/Criterion, hte enabled a significant increase in the number of catalysts tested through the use of a 48-fold reactor system. Ultimately, CRI was able to present a product to the market that allowed customers to further optimize costs and performance in their styrene production. Prior to this, hte supported CRI with the market launch of two new catalysts: AstraCat Gold and AstraCat Select.

Numerous refineries commissioned hte as an **independent service provider** for testing and benchmarking of commercial refining catalysts: naphtha reforming for Axens, isomerization of commercial light cut naphtha for OMV, and naphtha reforming and hydrocracking for BP. With MOL we developed an aging protocol for hydrotreatment applications. Aside from research collaborations, we support our customers in equipping their own laboratories. We supply reactor technology and implement complete high throughput workflows for testing catalysts. Here are a few examples:

- BASF operates a **laboratory for testing FCC catalysts** at our site.
- For Saudi Aramco we equipped a **high-end laboratory for high throughput research in Dhahran, Saudi Arabia.**
- Together with Instituto de Tecnología Química (ITQ) we further developed the **Micro Downflow Unit for FCC catalyst testing** and tap new applications within high-temperature process development.
- For **SABIC** we operate a dedicated **high throughput laboratory** at our site in Heidelberg, Germany.

INSIGHTS

Testing and optimizing catalysts correctly is not an issue everybody can handle. It takes know-how, experience, and appropriate technical facilities. hte combines all of these things at its site in Heidelberg, Germany. Twenty years ago, we operated laboratories covering an area of 500 square meters; today our laboratories, workshops, and offices extend more than 9,000 square meters: the optimum research environment for our customers.

Employees

We employ the most experienced and qualified scientists, engineers, and software specialists. Their knowledge and skills are the key to our success, as they combine specialist abilities with creativity and enthusiasm.

Laboratories

The heart of the company. hte has the world's largest high throughput laboratory for catalysis R&D. In Heidelberg we operate over 50 systems for catalyst testing and development. This is where we conduct experiments from customer projects and validate systems before they get delivered – chemically and physically. hte offers the broadest range of technologies and applications: in chemicals and petrochemicals, in the energy and refinery sector, and in environmental catalysis.

Workshops

Our strong arm. Our internal electronic and mechanical workshops build robust systems that run in a fully automatic 24/7 mode. We offer service, maintenance, and safety consulting – on site and from single source. We are fast and flexible when it comes to providing solutions. Delivery takes place in less than 12 months from placing an order.

Synthesis laboratory

Our synthesis team has many years of experience in a wide range of catalyst synthesis processes. They know what effect formulation and preparation have on the properties of catalysts. More than 35,000 samples are produced per year, more than 16,000 samples prepared for testing.

Software

All steps of the catalyst testing workflow are supported and enabled by our software solutions – from experiment planning, through synthesis, to reactor filling, testing, and analytics. hteControl™ is a dedicated process control suite for the systems, myhte™ generates and manages vast amounts of data. This creates a fully digitalized workflow. The time saved in data evaluation is immense. This combination of technology and software integration makes our solutions unique.

Laboratory for reactor filling

This team's work is what enables the catalysts to be tested at all. They load the reactor and remove the catalysts again. They take care of cleaning, maintenance, and quality control. The smallest changes in filling can have major impacts on the test result. Reactors for more than 50 high throughput systems are filled here; there are over 70 different reactor properties that need to be taken into account. All activity in the world's largest laboratory for reactor filling is completely digitally recorded and is integrated into our myhte™ software solution.

Analytics laboratory

Making science visible. Our analytics team manages the huge number of samples from catalyst tests and provides reliable results from online and offline analyses. On a next-day delivery basis, this team characterizes gases, fluids, and solids in a broad field of parameters. They use the latest chemical and physical methods of analysis and further develop them for our customers.

MORE THAN 300 REASONS

responsible for our success: our employees

hte INSIDE

- > 300 employees
- 16 nationalities
- We speak 28 languages
- 22 % female and 78 % male colleagues
- Average age 39 years
- Highly skilled scientists, engineers, and software specialist

hte stands for the best and strongest high throughput catalyst research team in the world. Our employees are our most valuable asset. Despite the size of our company, we have retained the can-do mentality of a dynamic start-up. And we love tackling new challenges. With team spirit, the will to think outside the box, and new solutions. In a positive working atmosphere, we are at the forefront when it comes to handling highly relevant topics and shaping something that moves us forward. That's what motivates us.

Tamara Gabriel
Technical Expert Analytics

What do you like about hte?
I like seeing how hte has developed itself over the past years – from a small start-up to a major player. At the same time, I can still identify with the company and I can see the development in my field of work.

What do you wish hte for the future?
THE COURAGE TO FURTHER PROGRESS.

Marike Meier
Office Manager

What do you think is special about hte?
What's special about hte for me is that no day is like any other. hte stands for FLEXIBILITY, SPONTANEITY, GREAT SOLIDARITY, and short decision-making channels. Teamwork plays a key role and EVERY SINGLE PERSON contributes to our success.

What do you wish hte for the future?
My wish for hte is for the company to remain successful and full of MOTIVATION and for it to hold on to its SPIRIT OF SOLIDARITY, OPEN COMMUNICATION, and LATERAL THINKING.

Stefan Kallus
Senior Counsel – European Patent Attorney

What do you wish hte for the future?
It would be great if we could retain the uniqueness and character of hte in cooperation with BASF. And if we, being a technology company, could continue to generate ideas for SUSTAINABILITY, optimized ENERGY EFFICIENCY, and PROFITABILITY. I also wish hte and every single member of staff much success and enjoyment for the upcoming years.

Alexandra Hess
Chemical Engineer

What do you like about hte?
hte is young, DYNAMIC, and offers an OPEN ENVIRONMENT to me. Here, everyone has enough space to contribute their knowledge and skills across interfaces – and to contribute to the COMPANY'S SUCCESS.

What do you wish hte for the future?
For the future I wish for hte to retain its DIVERSE CHARACTER, RESEARCH SPIRIT, and TEAM PHILOSOPHY.

Jean-Claude Adelbrecht
Business Development Manager

How do you see the company today?
hte thrived to become the market leader of high throughput in the competitive field of catalyst testing primarily because the company values innovation. More innovative integrated solutions are the only path to growth.

What do you wish hte for the future?
My wish would be that it remains this INTELLECTUALLY STIMULATING COMPANY while keeping this AMAZING FAMILY SPIRIT that makes it so special.

Can Cengiz
Electrical Engineer

What do you wish hte for the future?
I hope that in the future we will be able to stay as PROACTIVE and CREATIVE as we are today.

People & Site

Reactor Technology & Applications

1999–2003

- In 1996, the idea to create technology to accelerate synthesis, screening, and evaluation of catalysts was developed by Prof. Ferdi Schüth. The first prototype of a catalyst test unit was built.
- In 1998, the first patent was filed.
- hte was founded on March 26, 1999 and started its operation in June.
- The first site expansion was completed in 2001 (building A2).
- In 2003, BASF Venture Capital GmbH made capital investments in hte allowing hte to further develop its technology.

Primary Screening
Used for new discoveries

- **Reactor system** Bead reactors, 48-fold tube reactors
- **Volume** < 1 ml
- **Shape** Powders (100 – 500 µm)
- **Reaction type** Gas-phase reactions

- Emissions control
- Selective oxidation
- Syngas conversion
- Methanol-to-hydrocarbons

2004 –2008

- Second site expansion in 2007 (building A3).
- In February 2007, hte had 100 employees.
- BASF increased its stake in hte in 2008.
- Broad range of industrial experts in catalysis.

Secondary Screening & Catalyst Testing
Used for continuous improvements

- **Reactor system** 16-fold tube reactors
- **Volume** Up to 10 ml
- **Shape** Shaped materials
- **Reaction type** Gas and liquid products, trickle-bed applications

- Gas-to-alcohols
- Gas-to-acetic acid
- Hydroprocessing

2009–2013

- 200 employees working at hte in July 2012.
- hte nominated for the German Future Prize 2010.
- hte won the STEP Award 2011.
- hte reached the final of the German Industry's Innovation Award in 2013.
- Further expansion of hte's facilities in 2012 (building D2) and 2013 (building B4).

Parallel Extrudate Testing
Used for kinetic modeling & process development

- **Reactor system** 1-fold to 16-fold parallel tube reactors
- **Volume** Up to 300 ml
- **Shape** Commercial extrudates & others
- **Reaction type** Gas and liquid products, trickle-bed applications

- Hydrocracking / Resid upgrade
- Light cut naphtha cracking, methanol-to-olefins, others
- Naphtha reforming, transalkylation, others

2014–2018

- BASF opened a new testing and research laboratory for FCC catalysts in 2014 at hte's facilities.
- hte and SABIC signed an MoU to fast-track R&D.
- In 2016, the HetCatLab, an early phase material science lab for BASF, was established at hte employing postdocs.
- More than 300 employees working at hte since 2018.

Pilot Plant Testing
Used for commercial production at industrially relevant conditions

- **Reactor system** 1-fold pilot plant reactors and recycle reactors
- **Volume** 100 – 10,000 ml
- **Shape** Extrudates
- **Reaction type** Gas and liquid products, trickle-bed applications; catalyst and process scale-up

- FCC
- Fine chemicals starting from biomass-based intermediates through selective oxidation or selective hydrogenation
- Integration of refining & petrochemical processes

2019 → **Worldwide leading provider of technologies and services for enhanced catalysis R&D**

2014 → COMPETITIVE COMMERCIAL CATALYST TESTING

2009 → PROCESS-ORIENTED R&D

2004 → CATALYST DEVELOPMENT

1999 → CATALYST DISCOVERY

Portfolio & Partners

- Parallelization of fixed-bed reactors
- Catalyst screening & testing
- Setting up of the technology platform with BASF and Chevron.

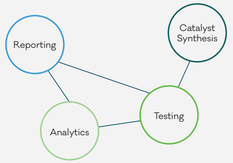
- hte and BP Chemicals announced a successful research collaboration in the field of gas-to-products.
- hte applied its technology to CRI's strategic catalyst development programs (styrene catalysts).
- First high throughput reactor systems delivered to customers.

- hte jointly developed new catalyst formulations and process options for dry reforming within a national consortium.
- Start of co-development of new FCC lab testing technology (micro downflow technology).
- First bench scale systems supplied to customers.

- Independent catalyst testing at industrial level and technical service support for refineries and petrochemical companies.
- Processing of heavy feedstocks and accelerated catalyst aging protocols added to hte's portfolio.
- hte has now the world's largest high throughput laboratory for catalysis R&D with a broad range of international clients from the energy & refining, chemical & petrochemical, and environmental industries.

DIGITILIZATION

First automatization software for test units and data evaluation program connecting the key steps of the catalyst testing workflow



Laboratory automation was considered for greater efficiency in laboratories

Enhancements in hte's software solutions

due to higher complexity and modularization of reactor units and the integration of further analytical tools:

- hteControl™ – One common system for all reactor technologies at hte
- myhte™ – New web-based front-end and Oracle as relational database

Sophisticated automatization and data management software solutions

hteControl Experiment Automation

- User-friendly process control suite
- Fully automated experiment control ensuring 24/7 operation
- Flexible concept for setting up and monitoring experiments with the job editor, convenient trend charting, and reliable GC control.

myhte Scientific Data Warehouse

- Powerful data management software that retrieves, integrates, stores, analyzes, and visualizes data generated within the catalyst testing workflow.
- Connecting huge amounts of online and offline analytical data with synthesis parameters in one database.

Lab 4.0 – Advanced analytics & software solutions enabling fully digitalized workflow solutions

- Example of successful implementation: Closed feedback loop for constant RON-operation in naphtha reforming

LAB 4.0 FULLY DIGITALIZED WORKFLOW in catalyst testing

With integrated laboratory automation and intelligent software solutions we make R&D faster and more efficient for our customers. Our experimental data are evaluated in such a way that our test systems take over process control for optimizing the experiments.

From the very beginning digitalization played an important role in research at hte. Experiments in parallelized multiple systems generate enormous amounts of data that need to be linked and evaluated. These data are the engine that drives our customers' research – which is why integrated, accelerated data analysis is critical in catalyst synthesis, characterization, and testing. Our software solutions connect all steps of the catalyst testing workflow and enable an efficient data management. The constant availability of data via cloud services, high data quality, as well as access to historical data allow our customers to accelerate their R&D.

Today, after 20 years, we offer a digitalization industry solution for chemical catalysis and process research and are the global market leader in this field.