hte

# THE HIGH THROUGHPUT EXPERIMENTATION COMPANY

A subsidiary of
BASF – We create chemistry

# SOLUTIONS FOR THE CHALLENGES OF OUR TIME

High Throughput Experimentation is a young research discipline in the field of catalysis which plays a key role in solving numerous challenges of our society. It can be used for cleaning of exhaust emissions, manufacturing chemical products from alternative raw materials instead of crude oil, or optimizing our power supply.

hte is a leading provider of high throughput technologies, and we have developed a unique technology platform. Our services enhance the productivity and efficiency of catalysis R&D.

We run the world's largest high throughput laboratory for catalysis R&D and we offer a broad spectrum of technologies and services.

In order to meet our own high standards, we combine four pillars of excellence: broad technical and scientific expertise, exceptional customer orientation, complete end-to-end solutions, and a superior data quality.

Theses pillars of excellence help us speed up the research of our customers and secure competitive advantages for them.

Our scientific work derives a long-term benefit from a **broad technical and scientific expertise** consisting of experts from different knowledge disciplines. These include chemists, engineers, and software technicians who specialize in high throughput research. They combine practical knowledge with pioneering technology and exceptional specialist expertise.

We have an **exceptional spirit** and we provide solutions that match the individual requirements of our customers. We offer **complete end-to-end solutions** in **catalysis research** with a **unique data quality.**

This makes us a driving force for efficiency and innovation in catalysis research and the market leader in our field.

Dr. Wolfram Stichert,
CEO, hte GmbH

## hte – THE HIGH THROUGHPUT EXPERIMENTATION COMPANY

| | |
|---|---|
| Location | Heidelberg |
| Founding | 1999 |
| Employees | > 300 |

**Business Offering**

**Research & Development Solutions**

- Scientific Consulting
- Catalyst Testing
- Catalyst and Process Development
- Technical Services
  - Independent Catalyst Testing
  - Quality Control
  - Production Support
  - Feed Studies
- Enabling R&D Services consisting of e.g.
  - Catalyst Synthesis Services
  - Reactor Loading
  - Analytical Services

**Technology Solutions**

- High Throughput Reactor Systems
- Bench Scale Systems
- Software Solutions
- Technical Consulting
  - Workflow Analyses
  - Design and Feasibility Studies
- After-Sales Service

**Business Areas**

Chemicals & Petrochemicals, Energy & Refining, Environmental, Renewables

# WELCOME TO THE WORLD'S LARGEST HIGH THROUGHPUT LABORATORY FOR CATALYSIS R&D

# CONNECTING TWO WORLDS: CONTRACT RESEARCH (RDS) MEETS PLANT ENGINEERING (TS)

### Catalyst Testing

We provide accelerated catalyst testing services, for example by delivering a ranking of catalysts with regard to activity and selectivity.

### Catalyst and Process Development

Together with our customers we plan, synthesize, and test new catalysts and bring these from laboratory to pilot scale.

### Technical Services

For catalyst manufacturers we offer benchmarking and performance tests in the production of catalysts in order to support their quality control processes. Furthermore, we perform independent competitive commercial catalyst evaluation for refineries including feed studies.

### Enabling R&D Services

hte also provides basic high throughput technology and methods for catalyst synthesis, reactor loading, and analytical services which optimize our research cooperations.

### High Throughput Reactor Systems

We offer high throughput technology for testing catalysts with a 16- to 48-fold degree of parallelization and a catalyst volume ranging from 0.1 ml to 10 ml per reactor.

### Bench Scale Systems

Our hardware offering for catalyst and process development comprises technology with a 1- to 8-fold degree of parallelization and a catalyst volume ranging from 10 to 300 ml per reactor.

### Software Solutions

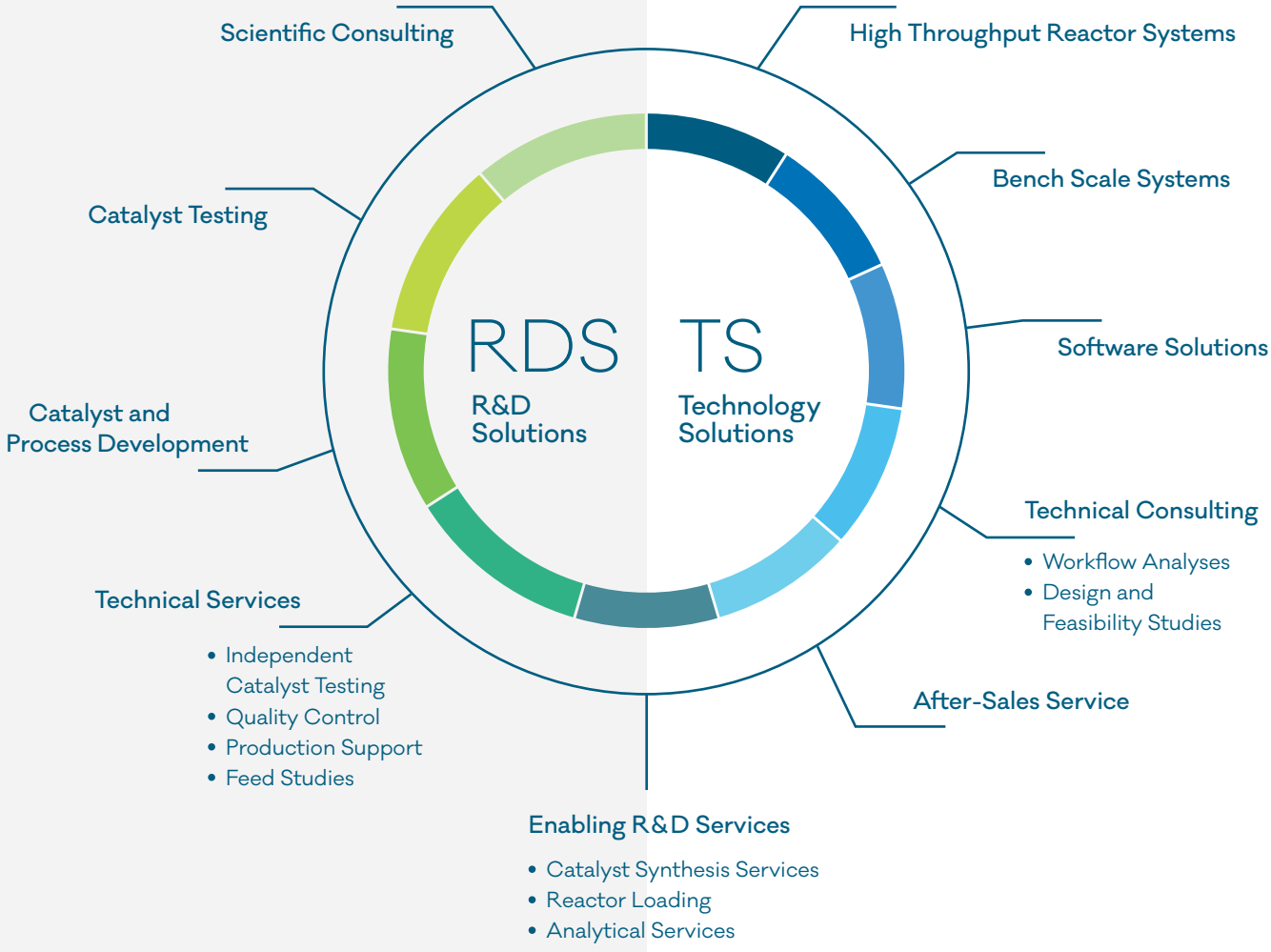
Solutions for test unit control, the design and execution of experiments, and complete data management of the catalyst development process.

### Technical Consulting

Workflow analyses, design and feasibility studies, as well as further detailed engineering services for evaluating plant engineering projects.

### After-Sales Service

With our global service we ensure that our customers' technology investment always delivers top performance.




**Business Offering hte**

## HIGH THROUGHPUT EXPERIMENTATION

The key principle of High Throughput Experimentation is parallelization. Experiments are no longer carried out on a typical serial basis but are conducted simultaneously. This makes R&D more efficient, as the experimental load grows without a corresponding increase in personnel costs or development time. This method allows the time to market of new products to be significantly shortened.

## In environmental catalysis

Automobile manufacturers worldwide are confronted with ever stricter environmental regulations in order to reduce air pollution. The result is a growing need for research: a large number of new materials need to be tested under a range of process conditions when developing and optimizing catalysts. Our high throughput technology makes this all possible in a faster and more cost-efficient manner.

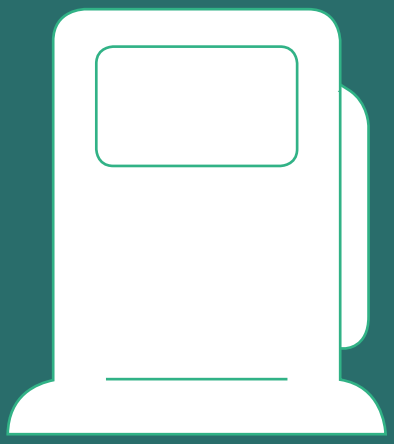
# SHORTER TIME TO MARKET

## For renewable raw materials

Biomass such as wood or vegetable oil is already being successfully used for the production of fuels and chemical products. Until now these have only been employed to a minor extent by the industry, as the transformation from biomass to valuable products must be economical and competitive in order to sustainably replace crude oil. This requires the development of new value chains. Our expertise and technology significantly shorten the development of these new processes.

## In the energy and refinery sector

The energy and refinery sector deals with a number of great challenges, from tapping of new energy sources and adhering to environmental regulations to utilizing unconventional raw materials including heavy crude oils and their complex processing. We support companies from the energy and oil industry in the research and development of catalytic processes for a more efficient utilization of raw materials in the manufacturing of clean fuels; we actually accelerate their R&D.



# FOR NEW PRODUCTS

## In the chemical and petrochemical sector

More than ninety percent of all chemical products are derived from crude oil. However, with the declining quality of oil and increasing energy prices, the chemical industry is required to seek alternatives. 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. The technologies and services of hte enable testing capacities to be expanded without increase of time and costs.

## CATALYSTS

More than ninety percent of chemical products manufactured worldwide are produced using catalysts – the chemical accelerators. Virtually everything that surrounds us in our day-to-day lives, such as plastics, paints, or fuels, came into contact with catalysts during their manufacture. Without catalysts, many reactions would simply not take place. This is also why the Chinese character for catalyst is derived from the character for the “marriage broker”. Catalysts make chemical reactions more efficient, or in some cases make them feasible in the first place. Many chemical reactions only take place at an exceptionally slow rate under normal conditions. To speed up this process, energy – for example heat – must be added. However, energy-intensive processes are inefficient and costly. A catalyst can change a chemical reaction in such a way that much less energy has to be added to the process. This makes the manufacturing of a product more cost-effective, resource-saving, and environmentally friendly.

# FROM NATURAL GAS TO VALUABLE CHEMICAL PRODUCTS

DR. NADINE BREM | TEAM LEADER R&D SOLUTIONS
TEAM: CHEMICALS & PETROCHEMICALS

I manage projects in which we test catalytic reactions for international customers and convert oil or natural gas components into commercially viable hydrocarbons. In the past, natural gas that was generated as a by-product when extracting crude oil was simply burned. Today, using suitable catalysts it is possible to use it for the manufacturing of products such as plastics, plasticizers, or colorants.

We generally work within the scope of "black box projects": a customer sends us proprietary or commercial catalysts, the composition of which we do not know. We test these materials on the basis of a jointly agreed testing program. Then we evaluate the results and provide an activity and selectivity ranking as well as the results for each individual catalyst.

However, there are also development projects in which we plan, synthesize, and test catalysts in agreement with the customer. These projects offer more creative freedom, allowing us to contribute our own ideas and expertise and be directly involved in development and test cycles. The results can be subsequently optimized by new synthesis steps. In such an arrangement, hte typically does not engage with other parties in the particular research field.

"The validation of a new application on a reactor system is a project highlight: Everyone wants to be there."

For both types of projects – testing and development projects – we make use of our internal testing technology comprising various high throughput and bench scale systems. A milestone of every project is the validation of the testing system, that is the point at which we start it up and receive the first results of the target chemical reaction. Many customers from Asia or the USA travel to Heidelberg because they want to experience it live. The first results can then be discussed and examined on site. It is a project highlight: Everyone wants to be there.

My job is highly varied and has many different aspects: a scientific side, the cooperation with the customer, and also a technical side. In the latter I am involved in the further development of our reactor system.

When I started at hte I operated one of our testing units myself for six months. This gave me an idea for how long individual steps take and which problems can arise during catalyst testing. That experience has helped me to this day in coordinating my team and advising our customers.

DR. FLORIAN HUBER | TEAM LEADER R&D SOLUTIONS
TEAM: HYDROPROCESSING

In my team, everything evolves around crude oil processing. Our customers are large oil companies and refineries. We offer them two types of projects: the testing of commercial catalysts and the development of new catalysts and processes.

Testing is about finding out which catalyst is best suited to the existing refinery process and whether the catalyst delivers the promised performance.

> "The application of high throughput research with very heavy, complex feeds is one of our unique features."

In development projects, however, our customer needs a completely new catalyst, for example in order to convert heavy feeds into valuable products such as diesel and gasoline. Today we handle very heavy oils. The residue that is left over after distillation of the crude oil, which is also known as resid, is of low value. But if you can use it to create valuable products such as fuel, significant profit margins for the industry are possible. To convert these residues, new catalytic processes are needed. The difficult part of it is that you never know how heavy feeds are going to behave under different reaction conditions. So hte can make a valuable contribution here. The combination of high throughput research and these complex feeds is one of our unique features.

Here we deliver detailed and conclusive results within a short period of time. In principle, our flexible reactor systems make this possible: each can be used for a wide range of applications – from naphtha to resid refinement.

What makes us special is that we at hte have the courage to tackle new fields. Our customers know that we are not afraid of challenges and that we are prepared to push boundaries and break new ground.

I personally greatly appreciate the cooperative and trusting manner in which we work with our customers. Teamwork is a major priority internally, too. In all projects, we chemists work with colleagues from the Engineering, Automation, Synthesis, or Software departments. Everyone can utilize experience and competence from various areas in his daily work. This is one of the big advantages of working at hte.

> "Our customers receive guaranteed quality at a guaranteed price within a guaranteed time frame."

As a team leader and contact person for our customers, I place great emphasis on excellence and commitment. Many people are good at what they do. However, we deliver guaranteed quality at a guaranteed price within a guaranteed time frame.

# MORE DIESEL PER BARREL

## PRODUCTS MADE FROM CRUDE OIL

| Finished products | and share |
|---|---|
| Liquid gases, e.g. propane, butane | ~5 % |
| Naphtha | ~12 % |
| Gasoline | ~26 % |
| Jet fuel (kerosene) | ~6 % |
| Diesel fuel, light heating oil | <24 % |
| Heavy heating oil | ~13 % |
| Bitumen, heavy heating oil | ~5,5 % |
| Lubricants | ~3,5 % |
| Other products, waste, etc. | ~5 % |


CLEANER
AIR


In the Environmental Catalysis team we investigate new materials for more efficient catalytic converters. Optimized catalytic converters eliminate particles, nitrogen oxides, hydrocarbons, and carbon monoxide from exhaust emissions and ensure cleaner air. Moreover, they also contribute to the reduction of greenhouse gases.

"Our technology allows us to screen a large number of materials in a short space of time."

A research project at hte runs through many phases. At the start of the catalyst development process we investigate many new materials and analyze their different compositions. The most important contribution to efficient testing is made by our high throughput testing units, which we develop in-house with 48 parallel test reactors. This technology allows us to screen a large number of materials in a short space of time. Often, they are only available in small quantities. However, these are sufficient for analyses in our reactor system with regard to their suitability.

Every day we generate large quantities of data, which we evaluate quickly using our in-house developed software solutions. This enables us to determine the optimum catalyst composition and formulation within a short period of time.

"We place great emphasis on realistic conditions in our research."

When preparing catalysts in our laboratories, we employ procedures that replicate the production processes of our customer. We also precisely simulate real conditions in our test systems. For example, we can dynamically imitate the composition of exhaust gases that are produced by a car while it is running in various operating states. This means that we are very close to how a car behaves while it is being driven on the road. This type of experiments helps the customer reduce the number of its own engine and vehicle tests and thereby save time and development costs.

"We accompany the product from powder to the finished catalytic converter."

The cooperation with our customers is very close and we are fully involved in their catalyst development process. I find it exciting that we are so close to the market and can accompany the product from powder to the finished catalytic converter in the car.

DR. CLAUDIA LIEBOLD | PROJECT MANAGER R&D SOLUTIONS
TEAM: HYDROPROCESSING

I work together with our customers in converting biomass to fuels and other basic chemicals. These can be generated from many raw materials, for instance wood, rapeseed, or algae. I think that the utilization of waste is particularly interesting as this could potentially transform the piles of garbage of today into the raw material sources of tomorrow.

> "The customer brings their knowledge of raw materials to the table while we contribute our expertise in chemical processes."

Compared to crude oil-based processes, the procedures for converting biomass into fuels and chemicals are relatively new. This is an aspect that I like a lot, because in the context of being the provider of research services, we are strongly involved in the design of experiments. I often have customers that have little or even no experience in the field of heterogeneous catalysis or hydroprocessing – a key petroleum refining process. They come to us and say: "We want to turn this raw material into a fuel." This is a productive kind of cooperation, as you complement each other. The customer brings their knowledge of raw materials to the table while we contribute our expertise in chemical processes. In these projects, communication is very open and cooperation close and personal. I enjoy this very much as I can then contribute a lot.

> "My projects in this area are varied: they include catalyst synthesis, process development, and feasibility studies for batch to continuous and scale-up."

For the different research projects we have access to the entire research portfolio of hte's testing technology. We can carry out proof of concept studies, for example in our autoclaves. In these autoclaves, the feed is mixed with the catalyst, and the reaction is analyzed. This is then transferred to a continuous process in the next stage of research. Here we can identify the ideal process conditions in our testing units. In scale-up projects we then expand processes from laboratory to pilot scale.

# UTILIZATION OF BIOMASS

## hte's REACTOR SYSTEMS FOR CATALYST TESTING

| | High Throughput Systems | Bench Scale Systems |
|---|---|---|
| Application | • Catalyst screening<br>• Kinetic modeling | • Catalyst optimization<br>• Process development |
| Number of reactors | • Up to 48 reactors | • Up to 8 reactors |
| Catalyst volume of reactor<br>Catalyst form | • 0.5 – 10 ml<br>• Powder<br>• Shaped materials (extrudates, spheres, tablets) | • 10 – 300 ml<br>• Shaped materials (extrudates, spheres, tablets) |
| Feed in the reactors | • One feed for all reactors | • Different feeds for each reactor |

**Xiaoyan Wang**
**Specialist Sales Controlling**
**Business Development & Marketing**

Xiaoyan optimizes the sales process and provides the management with important information for strategic orientation. She also supports marketing in China.

**Dr.-Ing. Alfred Haas**
**Principal Scientist**
**R&D Solutions**

Alfred has been reseaching in the field of heterogeneous catalysis for over 30 years. He is particularly inspired by the quality of the data delivered by hte's high throughput systems, as a researcher he does not compromise on quality.

**Volker Mathes**
**Team Leader Project Management**
**Technology Solutions**

For ten years Volker has been successfully implementing large-scale plant engineering projects, in which he coordinates project teams consisting of engineers, programmers, workshop employees, chemists, and analysts.

**Sally Glad**
**Technical Expert Analytics**
**Offline Analytics**

Sally works on the development of new methods and techniques for offline analysis.

# THE POOL FROM WHICH INNOVATIONS EMERGE

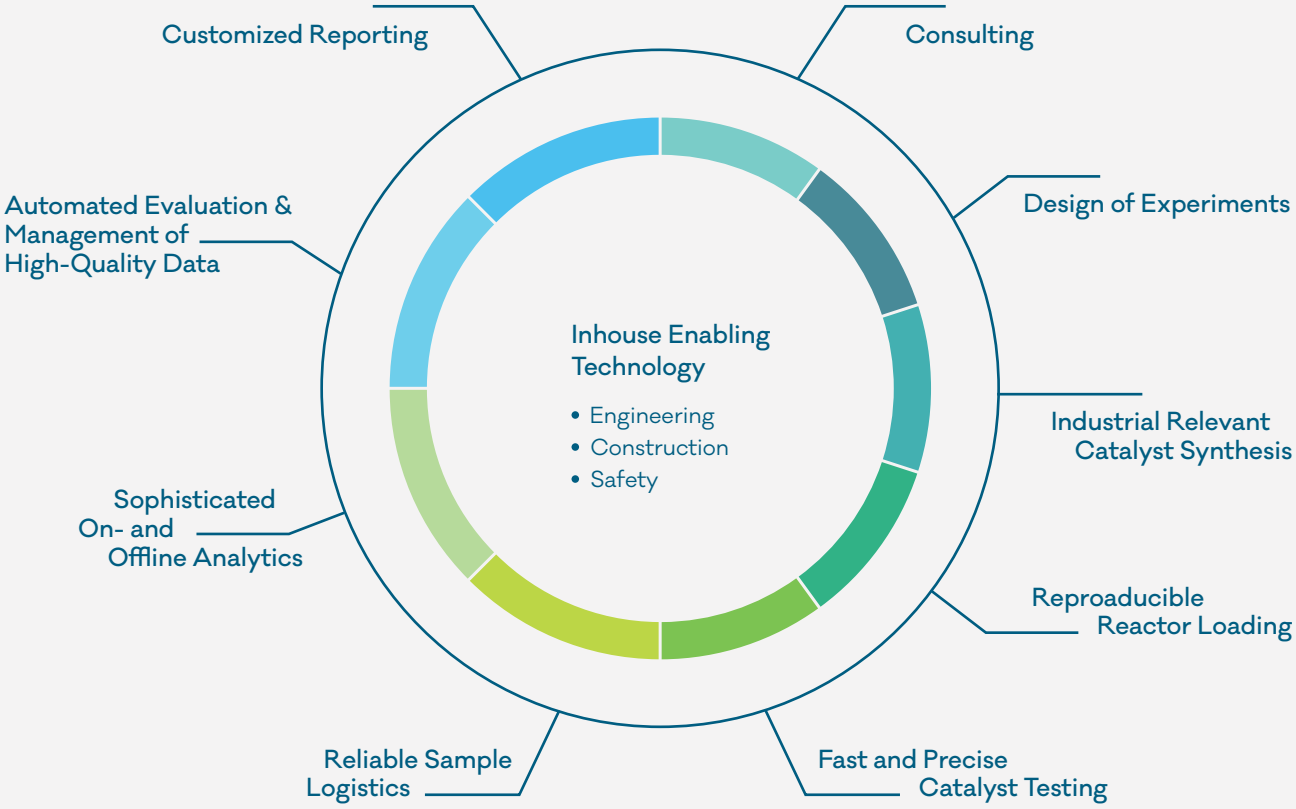
**Dr. Sascha Vukojevic**
**Senior Business Development Manager**
**Business Development & Marketing**

Sascha represents hte worldwide. Together with the departments of RDS and TS, he transforms customer needs into sucessful projects.

We offer the broadest spectrum of high throughput catalysis testing equipment and our success is predominantly shaped by our talent pool: the employees. These come from a wide range of scientific disciplines and cultures.

Some of the world's most experienced engineers and software specialists work at hte in the field of high throughput research. We deliver state-of-the-art technology and are able to provide successful research for our customers because our employees have a unique blend of specialist knowledge and passion. This makes us a leading interdisciplinary specialist!

# INTERDISCIPLINARY POOL OF EXPERTISE




**www.hte-company.com/en/company/competencies.html**
Visit our website and find out more about our competencies.

**Dr. Simone Sieg**
**Head of Experiment Automation Software Solutions**

Simone leads the development team of hteControl™, the software solution for automated experiment process control, and always strives for improvement with regard to robustness, user-friendliness, and performance.

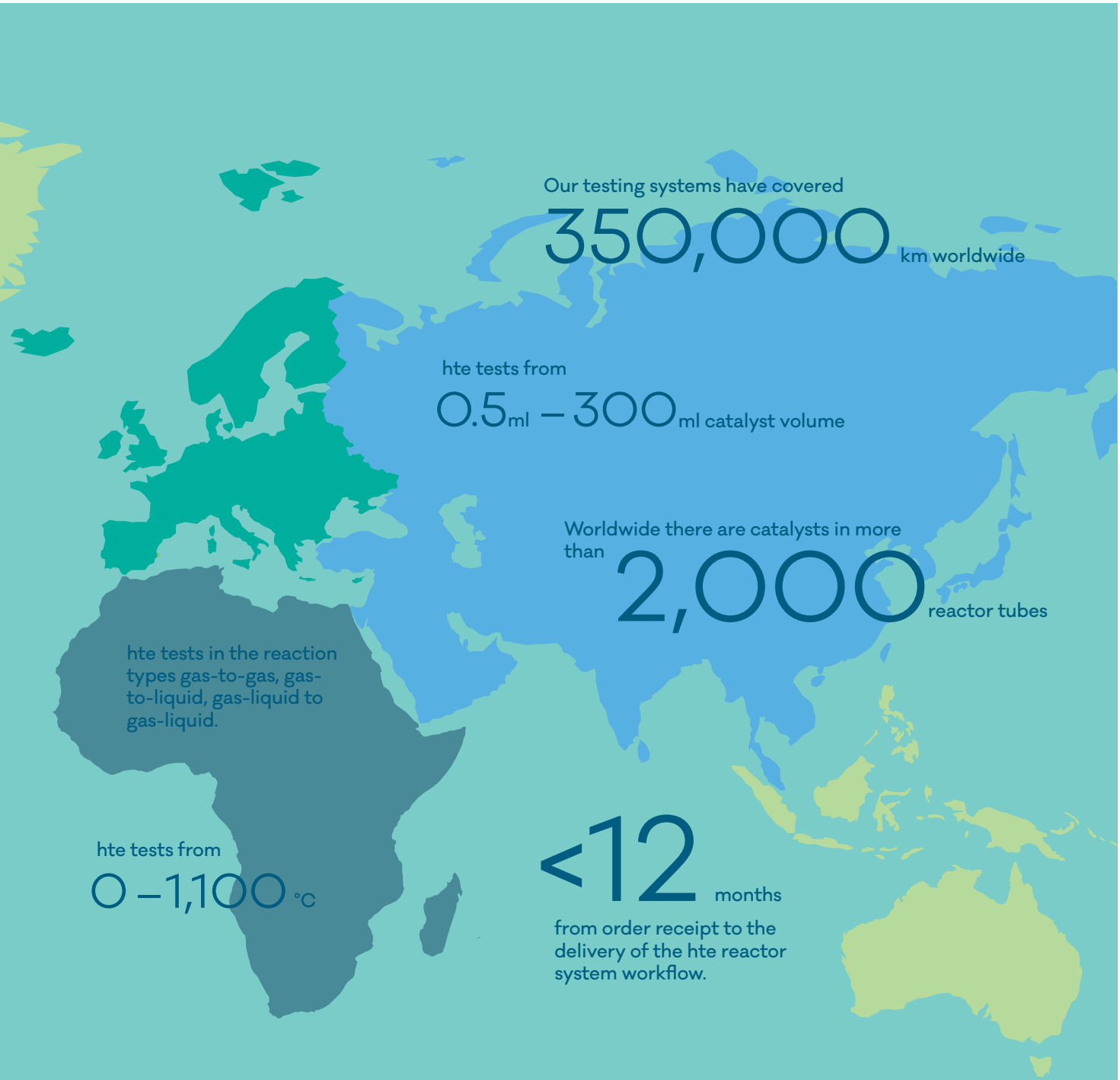
**Stefan Haser**
**Team Leader Service Service Team**

Stefan coordinates all service requests worldwide, so that our international customers receive fast and competent support. Customer satisfaction is therefore always top priority for him.

**Terence Meneers**
**Technical Expert R&D Solutions Synthesis Lab**

Terence is the specialist for loading reactors with samples for catalytic tests. He also speaks five languages fluently: German, English, French, Swahili, and Burundian.


# hte ACROSS THE GLOBE




| ORDER | DESIGN | MANUFACTURING | START-UP | COMMISSIONING |
|---|---|---|---|---|
| Customer provides specifications and commissions hte | Inhouse Design & Engineering<br>Basic and detailed design<br>• Process Engineering<br>• Mechanical Engineering<br>• Electrical Engineering | Inhouse Construction<br>• Purchasing & procurement<br>• Manufacturing<br>• Assembly | In our laboratories<br>• Set-up and validation (physical and chemical)<br>• Dispatch preparation<br>• Training | At customer's site<br>• Acceptance test<br>• Training<br>• After-Sales services |

Dr. Mathias Haake, Director Research & Development Solutions, in conversation with Denis Hürtgen, Director Technology Solutions, about the synergies of plant engineering and contract research at hte.

# MORE THAN A PIECE OF IRON AND STEEL

**What makes the high throughput technology from hte stand out from the competition?**

**DH:** In plant engineering we don't just offer a piece of iron and steel, but a complete and functioning solution. The respective application is defined together with the customer and our team of scientists. We now cover a big variety of applications. In the end, the reactor system is validated with a chemical experiment.

**MH:** Alongside the technology I would also mention the software integration – after all, hardware and software all run together as a system. We have developed a complete workflow consisting of synthesis, reactor loading, testing, sample logistics, analysis, data evaluation, and reporting. Generating data is one thing, but providing data in a reliable and precise way in order to make evaluations at high speed is the real highlight at hte.

**hte offers both research services and reactor systems. What synergies do you see?**

**DH:** We benefit greatly from having more than a hundred users of our own technology in-house who can give us intensive feedback on a daily basis. Our scientists set the bar high. These requirements are the reason why our technology platform was developed in the first place and it has grown over the years. It is the complete solution that makes us strong, and I think that customers appreciate this.

**MH:** R&D Solutions (RDS) benefits from the professionalization in plant engineering that took place at hte. This is a must to be in the position to deliver a testing unit to another continent in the first place. I think hte would not have been as successful if we didn't combine precisely these two business fields under one roof. As a result of the synergies of these two departments, we now offer the highest quality in this area of technology worldwide. No-one else offers this combination with such a significant and dedicated headcount. This is what makes us stand out from the competition and makes us so successful.

**DH:** We have a large number of interfaces, for example in technology development. When a customer approaches RDS with a certain requirement for which we do not yet have a reactor system technology, we develop a prototype in cooperation with RDS.

**MH:** A typical development path that we take together begins with unit design, which is followed by prototyping and validation, ultimately resulting in a robust, reliable reactor system that runs in a fully automatic 24/7 mode.

**DH:** Further interfaces are the modification and servicing of the testing units. After all, they need to be maintained and kept up-to-date.

**MH:** When Technology Solutions (TS) supplies a reactor system and certain chemical experiments need to be conducted, or when commissioning the unit, RDS is involved in the projects that are managed by TS.

**When a customer already has a unit from hte, which projects does the customer execute on his testing system and which are performed at hte?**

**MH:** Projects for hte arise out of challenges that customers cannot solve themselves – typically, the most challenging R&D projects land in our court. In areas where you encounter really fundamental questions, it is vital to have an integrated team that is capable of finding new solutions using hardware, software, and innovative analytical methods.

**How do customers see hte?**

**DH:** As a very dynamic and technically competent company. That's my impression and the feedback we receive from customers. This is also the reason why customers do not build the test systems themselves – because collectively we can simply achieve more than the customer alone.

**MH:** In RDS projects the customers value our flexibility and speed. Our methods enable us to start and implement a project with a large number of experiments easily, quickly, and in a competent manner. In large companies it can sometimes take more than six months before they're even ready to start. The speed and flexibility we offer – coupled with the competence to really solve a problem – is something the customer really appreciates about us.

**What motivates you about your work?**

**DH:** Even after many years in the field I find the topic of plant engineering incredibly exciting, as we never stop looking for new developments and innovations. I also simply enjoy working with the people here at hte. The climate at the company, that is the "hte DNA", just suits me.

**MH:** What motivates me every day is the fact that you can make a difference at hte, that you can work at the front line and with highly relevant content with our high-tech systems. We carry out research on topics of relevance to our society, such as what the energy and raw material supply of the future will look like. These are specific questions that we discuss together with our international customers. For this purpose we have technology that is unique worldwide. And the infrastructure at hte is also superb: our entire working environment is open, light-flooded, and state-of-the-art. The doors are open, we are not isolated from one another – it's fun to work here.

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