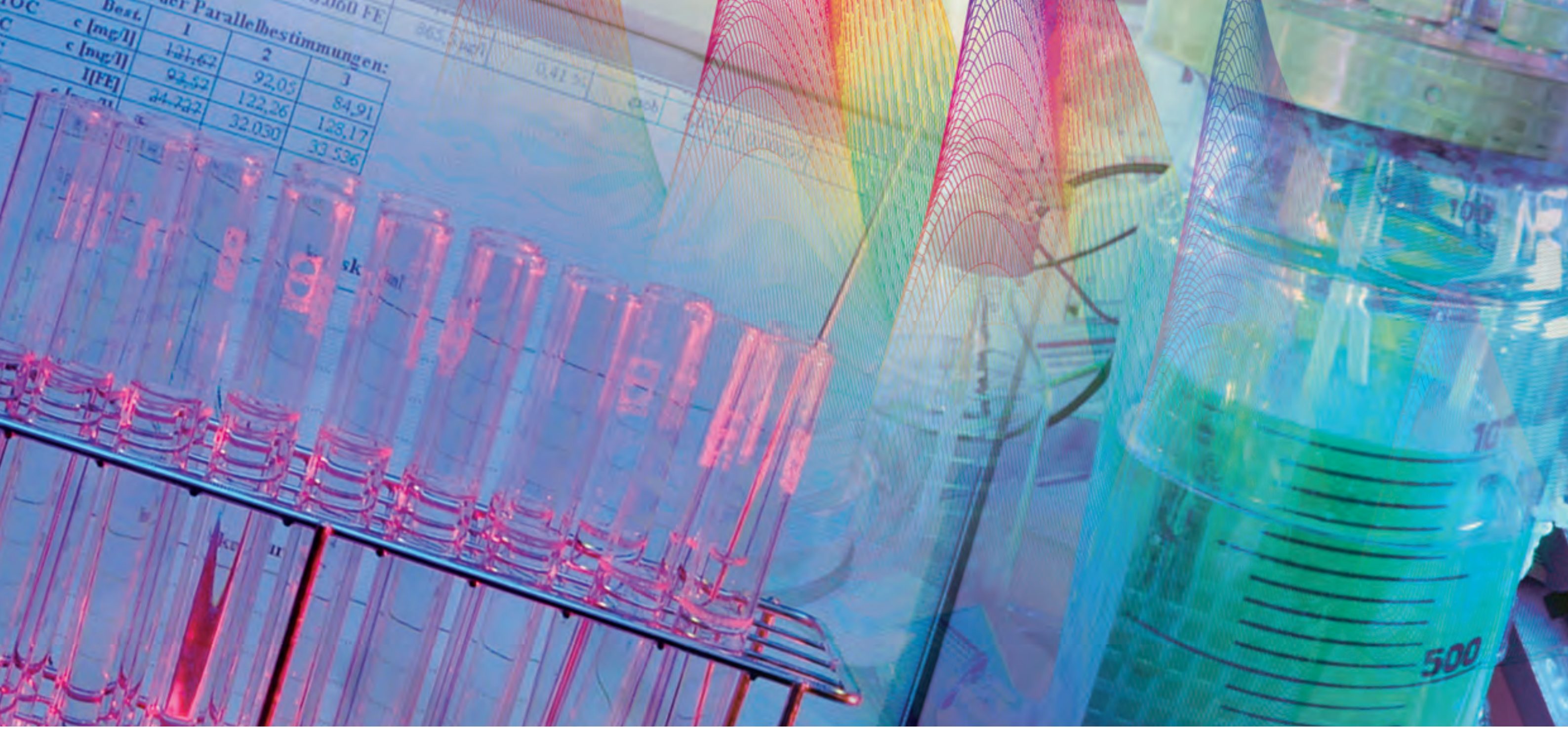

SCHOOL OF PROCESS AND CHEMICAL ENGINEERING

STUDY PROGRAMS

RESEARCH CENTERS

INSTITUTES

CLUSTERS OF EXCELLENCE

TUHH

Hamburg University of Technology

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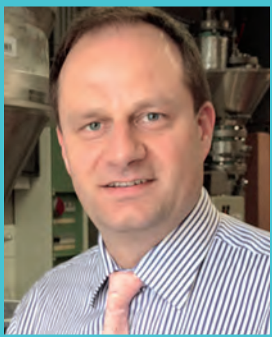
SCHOOL OF PROCESS AND CHEMICAL ENGINEERING

Editorial



The School of Process and Chemical Engineering at the Hamburg University of Technology includes 9 institutes with 13 professors and approximately 100 scientific assistants. Every year about 150 graduates are awarded their bachelor, diploma or master's degree and some 15-20 engineers their doctorates/PhDs.

The research covers a wide and exciting array of activities ranging from fundamental research in biotechnology to traditional fields of chemical engineering, and it is particularly committed to the development of processes and high quality products for the chemical, food, pharmaceutical, and bioengineering industries. The school is also working on environmentally friendly energy supply concepts that are sustainable in respect to the spent resources and additionally preserve the climate. At the same time safe process operation is in focus. Our laboratories and lecture halls are modern, extensive and well-equipped.

The school collaborates widely and its contacts include joint research projects with industrial and academic partners worldwide. We are also active within different Clusters of Excellence, either as research members or as leading scientific and managing coordinators.

The research of the school is structured in three university wide research centers:

- Climate-protecting Energy and Environmental Engineering
- Integrated Biotechnology and Process Engineering
- Regeneration, Implants, Medical Technology

In order to strengthen the collaboration and exchange of the institutes with the industry the knowledge transfer is managed by an own company TuTech Innovation GmbH (TuTech).

In teaching, the school offers process, bioprocess and chemical engineering courses in German and English language. The bachelor and master courses prepare the students for interesting careers in chemical, pharmaceutical, food, and environmental engineering as well as in emerging areas such as biotechnology and nanotechnology. Our teaching methods include lectures, project based learning, tutorials, practical laboratory courses and computer classes. We also have strong links with key employers who provide projects and work placements for our students and recruit our graduates on a regularly basis.

Our brochure aims to inform you about the fascinating world at the School of Process and Chemical Engineering. Our doors stand open to you.

Dean of the School of Process and Chemical Engineering

Prof. Dr.-Ing. habil. Stefan Heinrich

SCHOOL OF PROCESS AND CHEMICAL ENGINEERING

Professors of the School of Process and Chemical Engineering

from left to right: Prof. Dr. Kerstin Kuchta, Prof. Dr. Wolfgang Calmano, Prof. Dr. Rudolf Müller, Prof. Dr. An-Ping Zeng, Prof. Dr. Andreas Liese, Prof. Dr. Georg Fieg, Prof. Dr. Michael Schlüter, Prof. Dr. Garabed Antranikian, Prof. Dr. Martin Kaltschmitt, Prof. Dr. Stefan Heinrich, Prof. Dr. Rudolf Eggers, Prof. Dr. Irina Smirnova, Prof. Dr. Frerich Keil

STUDY PROGRAMS

In German language

PROCESS AND CHEMICAL ENGINEERING

Three-year Bachelor of Science Course

Process and chemical engineering is the engineering discipline that researches, develops and implements processes for changing materials. As a cross-cutting science, it is concerned with using physical, chemical and biological processes to transform the nature, characteristics or composition of materials with the goal of producing useful intermediate or end products such as fuels, sugar, plastics, proteins, cosmetics, dyes, alcohols, pesticides or medicines.

To achieve these goals, a training in process and chemical engineering should enable students to identify and formulate principles to be applied in planning, calculating, designing, building and running pieces of equipment, machines and entire production systems. The aim is to achieve the required product qualities using safe, environmentally friendly processes and with rational use of raw materials and energy.

Two-year Master of Science Course

Process and Chemical Engineering is the engineering discipline that investigates, develops and realizes material change processes. As a cross-cutting discipline, it is concerned with applying physical, chemical and biological processes to transform the nature, characteristics or composition of materials, with the aim of generating useful intermediate or final products such as fuels, sugar, plastics, proteins, cosmetics, dyes, alcohols, pesticides, or medicines.

To achieve the said goals, training in process and chemical engineering should enable students to recognize and formulate laws whereby apparatuses, machines and entire production systems can be planned, calculated, designed, built and operated. The required product qualities should be achieved using safe, environmentally friendly processes that involve a rational use of raw materials and energy.

The Master Program in Process and Chemical Engineering includes a wide-ranging special study of process and chemical engineering, along with scientific consolidation of training, building consecutively on the Bachelor in Process and Chemical Engineering.

In German language

BIOPROCESS ENGINEERING

Three-year Bachelor of Science Course

Bioprocess Engineering (also called Biochemical Engineering) is an important area of Biotechnology which primarily deals with conversion of raw materials (mostly renewable biomass) into useful products such food, feed, medicines and other essential commodities by using microorganisms and enzymes. It also contributes to environmental protection by developing efficient processes for biodegradation and waste treatment and to combat climate change by developing bio-based products to replace fossil-based ones. It thus builds the foundations for sustainable development of our environment and society and for the needs of the human being.

The development of bioprocesses requires an interdisciplinary application of natural sciences (especially biology, chemistry and mathematics) and engineering. The BA course Bioprocess Engineering emphasizes a deep understanding of the fundamentals and practical issues of unit operations and the whole process for manufacture of different bioproducts using microorganisms and enzymes. The students also acquire additional knowledge in social or related areas for advanced studies or as responsible engineer in a wide range of professional fields.

Two-year Master of Science Course

Bioprocess Engineering is becoming a more and more interdisciplinary field with broader applications. For many important or specialized areas such as Industrial Biotechnology or Pharmaceutical Biotechnology additional knowledge and training are essential for the career development of students.

The Master program in Bioprocess Engineering at the TUHH comprises a broad bioprocess engineering course and more in-depth academic training, building directly on the Bachelor course in Bioprocess Engineering. Emphasis is put on problem or objective based learning and practical training with increased touch to real bioprocess development. This is made possible by the strong and wide research and industrial application activities of the institutes involved in the program. In a sense, we keep the German tradition in training engineers by emphasizing a solid engineering understanding and practical handling. Uniquely, we train a new generation of bioengineers with a deep molecular, quantitative and engineering understanding of biological processes and with a high potential for lead-ship in related professional fields

In German language

ENERGY AND ENVIRONMENTAL ENGINEERING

Three-year Bachelor of Science Course

Forms of energy are used in a variety of ways in industry, domestic households and transportation, so energy is now as important a part of our daily lives as water. Increasingly, attention is paid to sustainable use of energy, without imposing long-term strains on coming generations. Cross-linked training in the foundations of and current issues around energy technology takes account of this situation. One increasingly important concern is to reduce CO_2 emissions responsible for the greenhouse effect. In pursuit of this, energy-saving opportunities are pursued and increasing use is made of regenerative energies. Though fossil fuels will still have to be used for a long time to come, efforts are made to reduce CO_2 emissions by increasing efficiency and by capturing the CO_2 their use generates and storing it underground. These processes in particular make it essential for energy engineering and environmental engineering activities to be closely linked.

Two-year Master of Science Course

Different forms of energy are used in diverse ways in industry, in private households and in transport. Consequently, energy now plays as important a role in everyday life as water. Increasing attention is paid to the sustainable use of energy without imposing long-term strains on future generations. This cross-linked training in the basic principles and current problems of energy and environmental engineering meets this concern. One increasingly important issue is that of reducing CO_2 emissions responsible for the greenhouse effect. To this end, possibilities to save energy are explored and increasing use is made of regenerative energies. Since fossil fuels will continue to be needed for a long time to come, efforts are made to reduce CO_2 emissions by increasing efficiency and by capturing the CO_2 emitted and storing it underground. This process, especially, necessitates close cooperation between energy engineering and environmental engineering.

The aim of the Energy and Environmental Engineering course, which is supervised jointly by the schools of Process Engineering and Mechanical Engineering, is to qualify students to solve these problems by process engineering. The course is geared to practical professional requirements, which result from technical, economic, ecological and social developments.

The Master program in Energy and Environmental Engineering includes broad-based studies in process engineering and mechanical engineering, along with academic consolidation. Students are also required to complete compulsory elective courses applying process engineering to relevant processes. Students also undertake industrial internships. The Master program concludes with the Master's thesis.

In English language

CHEMICAL AND BIOPROCESS ENGINEERING

Two-year Master of Science Course

This multidisciplinary program offers a possibility to gain a broad knowledge in both biotechnological processes and classical chemical engineering. Close collaboration of these disciplines is a special feature of the engineering departments at TUHH in both education and research. Apart from the basic knowledge in biological and biocatalytic processes, separation technologies, mechanical and reaction engineering, master students will get an insight into the most challenging problems on the boundaries between these disciplines and participate in the collaborative research of several departments.

The master's degree course in Chemical and Bioprocess Engineering replaces the master's degree courses in Biotechnology and Process Engineering, which will no longer be offered at TUHH as from winter semester 2009.

All courses are certificated by ASIIN

CLIMATE-PROTECTING ENERGY AND ENVIRONMENTAL ENGINEERING

What with algae as resource and energy suppliers, more efficient energy storage, multiple use of energy in urban areas, and power stations where the carbon dioxide is removed from flue gas? The research center "Climate-Protecting Energy and Environmental Engineering" is working on energy supply concepts that are especially easy on the climate and on resources and yet ensure safe operation.

How can energy supplies be easy on the environment and on resources and at the same time improve security of supply? This question will pose the overriding technical and societal policy challenge of the years ahead, and it is a challenge that the TUHH's research center "Climate-Protecting Energy and Environmental Engineering" has already taken up actively.

Unfortunately, there are no simple solutions in this area because it is clear there will never be a totally climate- and environment-compatible power supply. Every energy supply chain from source to consumer will involve a certain amount of irreversible energy and materials conversion. Energy from biomass is desirable, but if its share were to increase strongly in future, problems such as soil depletion and primeval forest clearance would be a foregone conclusion. That is why the utilization of bioresources from solid waste and wastewater is of special importance. In the final analysis, every end product in the energy conversion chain has a lasting effect on the environment. In the best case we may, however, succeed in minimizing irreversible energy and materials conversion as far as possible.

Lack of knowledge about different energy and materials chains and links between them has repeatedly led to errors of judgment in the past, as for instance in the case of nuclear energy, where the final storage issue has yet to be resolved. That is why an overall view of energy and materials conversion processes of this kind is absolutely essential, and in view of the complexity of the subject and the many overlapping specialized aspects, this scientific overview can only be gained within the framework of an interdisciplinary research group.

The TUHH's accumulated structures and extended strengths make it ideally suitable for the research center "Climate-Protecting Energy and Environmental Engineering". Due to its proximity to shipbuilding and aeronautics technology, for example, the university has a traditional focus on research into complex systems. Hamburg's competence as a capital city of transport logistics is a further advantage in developing energy-saving and environment-friendly transportation processes. As even with a local energy supply large-scale power stations cannot be dispensed with entirely, a further advantage is that the TUHH has nationally and internationally acknowledged institutes in this area that are strong in research. This sound knowledge infrastructure enables institutes participating in the research center to investigate the entire energy conversion chain from primary to final energy effectively for improvement potential.

In spite of their diversity, projects at research center "Climate-Protecting Energy and Environmental Engineering" can be roughly divided into three subareas: efficient energy conversion and distribution, efficient utilization of biomass, and energy- and water-efficient settlement technology. Specific issues are, for example, a coal-fired power station with carbon dioxide separation, putting wastewater and solid waste to energy use in urban areas, energy-saving and heat recovery in water supplies, or assessing the consequences of climate change for agriculture in north Germany. Work is also under way on improving insulation of old buildings, on more efficiently cooled batteries and on better air conditioning systems.

In collaboration with power utilities, consideration is also being given to how many small-scale gas-fired power stations can create a large virtual power station, how algae can be utilized as a source of biomass, and how water systems can be optimized.

Although each individual project in which the research center is involved aims to improve the entire energy conversion chain, attention is also paid to whether there may be alternative approaches and to the repercussions that the different approaches may have on the climate or the environment. In addition, common basic methods are to be developed in the individual projects to evaluate energy paths, for instance, or for numeric modeling of the different process chains. Public and internal workshops, seminars - especially postgraduate seminars - and above all joint projects provide the framework for this interdisciplinary work.

In its ambitious scientific projects the research center "Climate-Protecting Energy and Environmental Engineering" thereby strengthens and utilizes the especially cross-research system approach at the TUHH, which requires an overall view of technical correlations from the outset.

Coordinators

Prof. Dr.-Ing. Ralf Otterpohl

Prof. Dr.-Ing. Gerhard Schmitz

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• Information & Contact: *www.tuhh.de/fsp-energieumwelt.html*

INTEGRATED BIOTECHNOLOGY AND PROCESS ENGINEERING

Research in the field of Integrated Biotechnology and Process Engineering paves the way to a sustainable usage of the world's limited natural resources. The aim of this interdisciplinary research center is to achieve significant improvements in economic value creation, keeping German industry competitive and preparing the students of today to the employment situation of the future.

Industrial biotechnology – also known as white biotechnology – uses biological systems for the sustainable manufacture of (fine) chemicals, active substances, new materials and energy carriers from renewable raw materials. It is geared to the model of sustainability and also develops concepts ensuring ecological and social compatibility.

The classical disciplines of chemistry and biology provide catalysts that can be used in organic synthesis. In principle, the task of process engineering is to transfer these reactions, which are usually undertaken on a laboratory scale, to an industrial scale and thereby to ensure their economic feasibility. The aim of the research center "Integrated Biotechnology and Process Engineering" is to develop and take forward the potentials of white biotechnology in order to be able to make active use of them in the future. This includes developing new and unusual biocatalysts as well as developing and optimizing processes with a view to achieving a marked increase in energy and resource efficiency.

Implementing these scientific projects poses great challenges to research and technology. Only by means of the latest methodical developments can the increase in efficiency, required to make generating power from biomass or biotechnological processes competitive, be achieved. These processes must harness unusual reaction conditions and systems or use innovative materials and mathematical modeling of biological systems. Therefore, active interdisciplinary collaboration between microbiologists, chemists, biotechnologists and engineers in the structure of the research center is absolutely essential. A network of SMEs associated with the research center, and of large chemical and life science enterprises, ensures that research is not undertaken in an "ivory tower" and that tasks with practical relevance and high industrial implementation potential are taken up and worked on.

Waste derived from plants such as straw or wood can and is intended to be used in this way, as a source of both energy and raw material. Work is also in progress on expanding the palette of commodities that are suitable for biomass power stations so as to counteract competition with sources of food. The economic efficiency of biorefineries can be increased further by combining the production of biogas and biofuels and of further products and recyclables for the chemical industry.

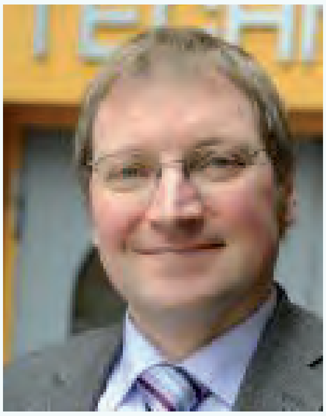
To accelerate the pace of research activity and put it on a wide basis, the institutes participating in the research center "Integrated Biotechnology and Process Engineering" aim to initiate and coordinate joint interdisciplinary third-party funding projects at different levels and to establish a collaborative research center at the TUHH. The scientific knowledge newly acquired in this way is intended to achieve widely visible external publicity for the TUHH.

By coordinating the two BMBF-funded research clusters "BIOKATALYSE2021-Sustainable Biotechnology Along New Lines" and "BIORAFFINERIE2021-Energy from Biomass" and the DFG-funded priority program "Porous Media with a Defined Pore Structure in Process Engineering - Modeling, Application, Synthesis", and by taking part in the Hamburg Excellence Initiative, the research center already has several lighthouse projects. The TUHH's excellent infrastructure also contributes towards the success of many research projects. Consequently, the research center can handle the entire process chain from gene to complex process on a pilot plant scale. In this way new, environment-friendly developments at the research center can be converted quickly into applied technologies.

At the intersection of engineering, molecular sciences and materials sciences the TUHH's research center "Integrated Biotechnology and Process Engineering" with its high potential for innovation thereby makes an active contribution toward extending Germany's scientific, technological and economic lead.

Coordinators

Prof. Dr. rer. nat. Andreas Liese



Prof. Dr.-Ing. Michael Schlüter

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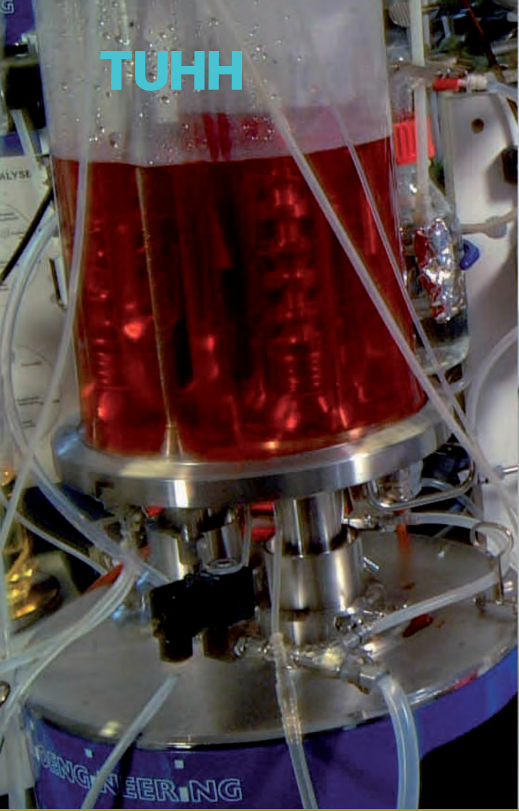
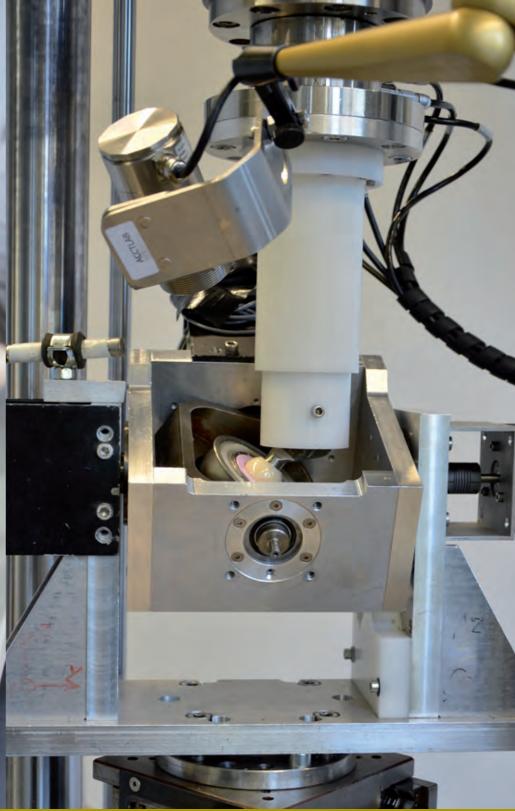
• Information & Contact: *www.bioprozesstechnik.de*



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REGENERATION, IMPLANTS, MEDICAL TECHNOLOGY

An improved patient care, increased life expectancy and quality of life, and relieve of the health insurance - the expectations of modern medical technology could hardly be higher. The research center "Regeneration, Implants, Medical Technology" is responding to the challenges ahead, in collaboration with competent partners in the health care practice, for effective solutions.

It is still little more than a vision that patients will one day be supplied on a routine basis with organs or tissue from a bioreactor – just as reliable as a cardiac bypass operation on the heart today. The research center "Regeneration, Implants, Medical Technology" TUHH is working to ensure that this vision can really come true. Its relevance is obvious due to the demographic trends forecast for Germany. According to the Federal Statistics Office there will be fewer and fewer children and a significantly larger number of older people. Due to this aging of society, the number of cases of disease in Germany will increase sharply in the coming decades to come.

To find sustainable solutions to the complex scientific – and economically relevant – issues that are associated with this trend, the research center "Regeneration, Implants, Medical Technology" research center seeks active cooperation with various prestigious institutions in and around Hamburg, such as the University Hospital Eppendorf, the Helmholtz-Centre for Materials and Coastal Research, and various medical technology companies. The TUHH institutes participating in the research center can contribute their outstanding engineering competence in medical technology – a competence that is acknowledged well beyond the city's borders.

To meet the requirements of the strong interdisciplinary nature of research projects in medical technology, scientists from wide-ranging disciplines are joining their forces in the research center "Regeneration, Implants, Medical Technology". These range from laser and plant systems technology, thermo-fluid dynamics, mechanics and ocean engineering via thermal process engineering, nanoelectronics, metrology, and numeric simulation to bioprocess and biosystems technology, biomechanics, and plastics and composites.

In 2008/09, research scientists in these different fields, all of which are important for medical technology, raised over four million euros in funding. The aim of the research center is to deepen the already existing, successful medical research content under one roof, or to expand the research groups. The work group that emerged from the TUHH quality offence "Tissue Engineering" is one of the focal points of "regeneration". Its research scientists are, for example, are working on biohybrid implants, which connect biological and technical components such as cells and electrodes, and which can be grown in special bioreactors.

The work group can build on knowledge gained at the TUHH in an already completed project to develop a biohybrid joint implant. It seeks collaboration with highly specialized tissue engineering firms. Alongside tissue engineering, other collaborative research activities will take shape as a result of interaction, cooperation and knowledge transfer between individual institutes. A group of research scientists has been established to look into Bioreaction Technology for Tissue Cultivation, for example, and another is to deal with Implants and Medical Technology.

Ongoing research deals inter alia with implant technologies to warn against the occurrence of aneurysms in the aorta or monitor body functions such as heartbeat or brain waves, with the influence of electric fields on cell growth, and with an artificial hand. The last-named project is undertaken in close cooperation with the Federal Research Ministry. Subjects dealt with are continuously extended, updated, and evaluated; thereby laying the groundwork for a dynamic research landscape and enabling long-term bundling of the participating institutes' different research interests. The research center "Regeneration, Implants, Medical Technology" is very much open to new members because new ideas boost quality.

Coordinators

Prof. Dr.-Ing. Wolfgang Krautschneider

Prof. Dr.-Ing. Ralf Pörtner

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• Information & Contact: *www.tuhh.de/forschung/fsp*

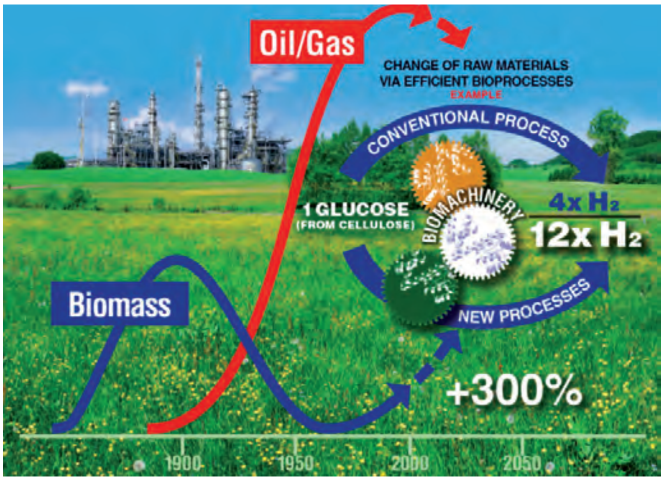
V-1

BIOPROCESS AND BIOSYSTEMS ENGINEERING

Founded in 1986 as one of the first university research institutes in Bioprocess Engineering in Germany, IBB has a long tradition and wide expertise in bioprocess development. Present research focus is on designing novel biocatalysts (enzymes and cells) at molecular level and developing integrated bioproduction systems for chemicals, fuels and pharmaceuticals from renewable materials. To this end, we develop and integrate methods and tools ranging from molecular and pathway design (Synthetic Biology) over modeling (Systems Biology) to integration of bioconversion and product recovery in miniplant under industry-relevant conditions. Such a molecular and multiscale Biosystems Engineering approach is demonstrated to be highly efficient in developing several new bioprocesses such as for diols and amino acids.

RESEARCH AREAS

The objective of our research is to develop new and highly efficient bioproduction systems for chemicals, fuels and pharmaceuticals which overcome the major limitations of present bioprocesses such as limited product yield and titer, use of a narrow range of substrates and processing with cells in aqueous solution. These new bioproduction systems should be economically competitive and ecologically superior to competing chemical processes based on fossil resources and thus contribute to the paradigm change of raw material basis in the new age of bioeconomy.



Our approach is to develop biomachinery and cell factory by molecular design and biosystems integration which enable bioproduction near theoretical maximum and under hereto unthinkable process conditions. In particular, synthetic biology is applied to create biosystems working with the highest efficiency. This is envisaged with the bioproduction of H_2 in a cell-free system with a synthetic metabolic pathway which can increase the yield by nearly 300 % compared to conventional bioprocess.

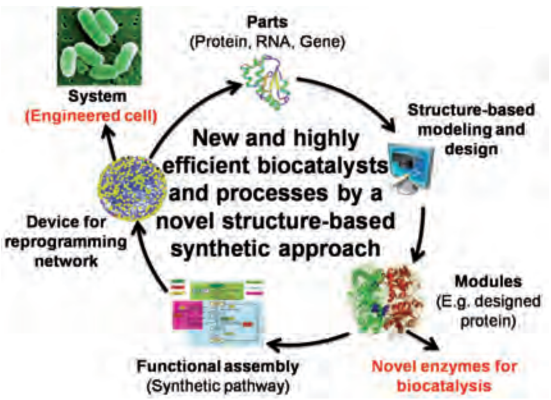
HIGHLIGHTS OF PROJECTS

Research at IBB is done mainly along two lines: 1. Methodology und fundamental studies and 2. Product and process development. In fundamental study we focus on structure-based synthetic biology for designing enzymes and cells. Methodologically, we incorporate molecular and multiscale modeling and micro-technologies into biocatalyst and bioprocess development.

Bioproducts and bioprocesses studied at IBB include: 1,3-propanediol, optically active 2,3-butanediol, n-butanol, propionic acid, 3-hydroxypropionaldehyde/acrolein, amino acids (e.g L-lysine), microbial polysaccharides (e.g. alginate), bio-H_2 and biogas, recombinant proteins at high cell density with microbial and cell cultures, cells (tissue) as product for medical applications (e.g. cartilage) and special bioreactors for 3D-tissue culture. In the following we highlight some of the projects.

- **STRUCTURE-BASED DESIGN OF BIOCATALYSTS**

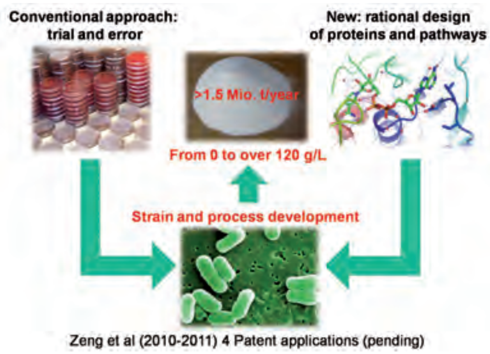
Synthetic biology is a new research area at the interface between biology and engineering. It aims to understand cellular processes in a modular approach and to design molecular parts, modules and devices for developing biological systems with new functions and mostly high efficiency. We have proposed a structure-based synthetic biology approach for the design of parts, modules and devices which can be either directly used as novel enzymes for biocatalysis or assembled into metabolic pathways and cells.



A major method in our approach is rational protein and pathway design. For this purpose genomic information is explored for evolutionary statistic analysis of proteins and pathways and molecular dynamic modeling is used as an essential tool. In recognizing the importance of protein dynamics for function we proposed energy dissipation as a new concept for modeling protein dynamics and signal transduction within proteins and between subunits of enzyme complexes. These methods are further developed for de novo design of proteins and protein complexes as modules or biomachinery for biosynthesis.

- **FROM ZERO TO HERO IN SHORT TIME: AMINO ACIDS BIOPRODUCTION**

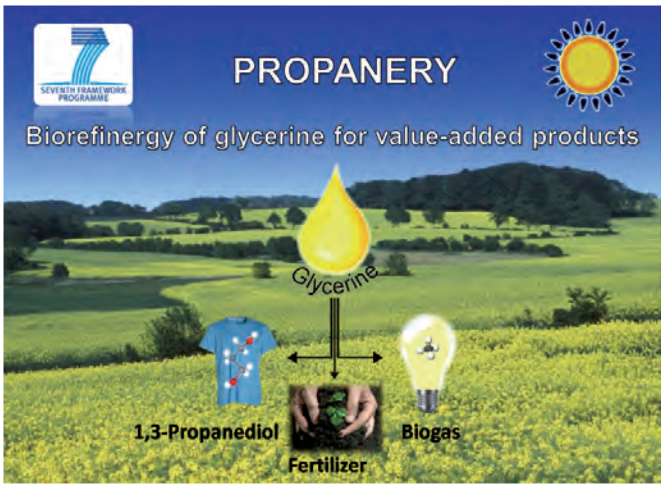
We have successfully implemented the structure-based synthetic approach to design a novel strain for the biosynthesis of L-lysine as an example of bioprocess development for amino acids. Our approach goes beyond the conventional metabolic engineering, the latter only modifies enzyme concentrations by either gene overexpression or knockout and is not efficient in dealing with limitations of enzyme activity (e.g. feedback inhibition by products). With L-lysine production by Corynebacterium glutamicum we demonstrated how protein design can be effectively used to alleviate allosteric inhibition of key enzymes by products, to enhance precursor availability, to increase cofactor (NADPH) supply and to dynamically control metabolic fluxes. More importantly, our engineering of proteins and cell is defined and predictive. By a single mutation of a key enzyme we could engineer a non-producer (0 g Lysine/L) C. glutamicum to a hyper producer (over 120 g/L) in a very short time. Typically, the time required for the design of a successful mutant is now within a few months compared to years by conventional approach of strain development.



The synergetic effects of multiple target manipulations are being studied. We expect to go significantly beyond 150 g/L. The approach is also applied to develop an efficient process for the production of other amino acids like threonine.

- **BIOREFINERY FOR VALUE-ADDED PRODUCTS**

Biorefinery is a major concept for integrated production of chemicals, fuels and materials. We work on this concept in several collaborative projects such as the EU 7th FP project Propanergy (Integrated bioconversion of glycerine into value added products and biogas at pilot plant scale), EuroBioRef (EUROpean multilevel integrated BIOREFinery design for sustainable biomass processing) and the BMBF project Bioraffinerie 2021.



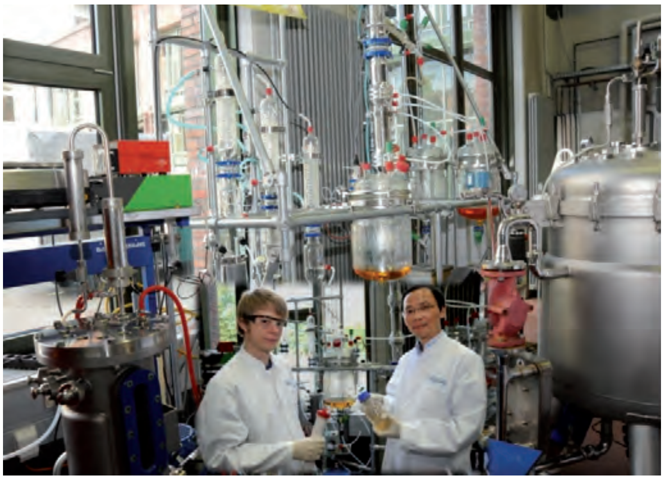
The products and processes developed at IBB with the biorefinery concept include 1,3-propanediol (PDO), 3-hydroxypropionaldehyde acrolein, butanol and biogas. In particular, the microbial conversion of glycerol to PDO and other products has been studied by the group of Prof. Zeng for many years from laboratory to pilot plant scales. He was the coordinator of two EU 5th and 7th FP projects targeted at PDO. In the 7th FP project Propanergy a biorefinery approach was successfully implemented and demonstrated at pilot plant scale with an industrial partner, resulting in a strongly simplified and costly effective process to produce PDO from raw glycerol of biodiesel plant at costs below 1 €/kg. Microbial communities are also explored as an effective production systems in our biorefinery projects.

• BIOGAS

IBB has worked with biogas production from waste materials for many years. Presently, two on-going projects deal with converting residues/waste (organic acids from PDO fermentation and stillage from bioethanol process) into biogas in the frame of biorefinery.

• MINIPLANT FOR BIOPROCESS INTEGRATION

IBB is active in integrated bioprocess development by using miniplant technology. The IBB miniplant includes substrate pretreatment step (e.g. desalination), fermentation and product purification steps (e.g. ultra-filtration, evaporation, extraction and rectification). It can be used to produce product in kg scale at high purity for application test.



• CELL CULTURE AND SYSTEMS BIOLOGY

In the area of mammalian cell culture technology IBB works on transient gene expression, especially for fast recombinant protein production in high cell density. A model-based development of expression systems and processes is implemented. Another research area is the systems biology of mammalian cells. Prof. Zeng coordinates two BMBF-supported research consortia in this area. Presently, we concentrate on metabolomic analysis of mammalian cells, especially concerning the compartmentalization of metabolism. We are particularly dealing with the metabolomic analysis of the central metabolic pathways, their connection with mitochondria and their interference with cell cycle control. To overcome the problems of low metabolite concentrations and fast metabolic turnover rate we develop microfluidics based lab-on-chip systems.

• TISSUE ENGINEERING

The loss and damage of tissues cause serious health problems. Here engineered tissue substitutes, meaning artificial three-dimensional (3D) tissues from human or mammalian cells generated in vitro could open new strategies for the restoration of damaged tissues. Within the research group of Prof. Pörtner the following topics are addressed
Generation of cartilage-carrier-constructs for implantation in joint defects

- 3D-tissue culture for drug screening and toxicity tests
- Mass cultivation of stem cells
- Bioreactors and sensor systems for 3D tumor models

Tissue Engineering activities are embedded in the TUHH research center „Regeneration, Implants, Medical Technology", where several groups from TUHH and UKE are working closely together for about 15 years.

• HAMBURG EXCELLENCE CLUSTER SYNBIO

Within the Hamburg State excellent cluster "Fundamentals for Synhetic Biological Systems-SynBio" (Coordinator Prof. Zeng) we are working in close cooperation with 9 project partners from TUHH, University of Hamburg and European Molecular Biology Laboratory (EMBL) at DESY at the interface of biology and engineering. The objective of this interdisciplinary project is to develop highly effective biocatalytic modules and systems for cell-free biosynthesis of chemical and energy. For this purpose enzymes are studied in microsystems which incorporate nano-structured materials.

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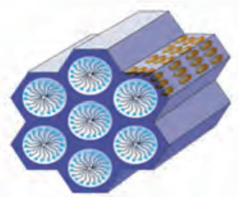
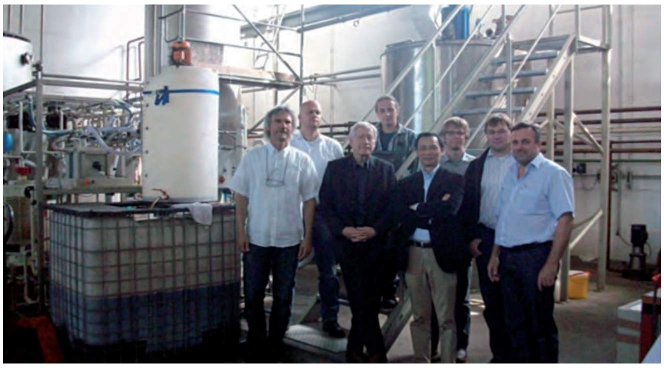


EDUCATION

We are actively involved in several BSc and MSc programs in Chemical Engineering, General Engineering Science and Bioprocess Engineering. Following the German tradition in training engineers we emphasize a solid engineering understanding and practical handling. We train a new generation of engineers with a deep molecular, quantitative and engineering understanding of cellular processes.

COLLABORATIONS WITH INDUSTRY

We collaborate with industrial partners in different ways, such as contract research and development, consulting and feasibility study, production of product samples in our pilot plant or collaboration in publicly funded research projects. In particular, our miniplant and pilot plant bioreactors up to 300 L can be used to produce product samples with purity for application studies. Together with industrial partners we can develop the whole process from strain development and optimization to pilot plant scale production.



FACILITIES AND SERVICE

- Laboratories for microbial and molecular biological work at safety level S1 and S2
- A pilot plant with bioreactors up to 300 L and corresponding downstream processing equipment
- Bioreactors (stirred tank, fixed bed, membrane dialysis reactor etc.) in lab scales (up to 5 L) for microbial systems
- 100 mL to 10 L bioreactors for mammalian cell culture
- Bioreactor systems for tissue engineering
- Automated fast-sampling equipment for metabolomic analysis
- Lab-on-Chip microfluidic systems for ultra-fast metabolomic anaylsis
- FPLC for protein purification
- (Bio)chemical analytic equipment (GC, Micro-GC, HPLC, HPIC, Fluorescence Microscopy, Confocal Microscopy etc.)
- LC/MS/MS (quadrupol Time-of-Flight mass spectrometer)
- Bruker mass spectrometer with ETD/PTR technologies
- Equipment for 2D-proteomic analysis
- Equipment for molecular biological work (PCR, gel electrophoresis, blot and hybridization techniques, electroporation)
- On-line process analytic and process control systems
- A mechanical work shop

DIRECTION OF THE INSTITUTE

Prof. Dr. rer. nat. habil. An-Ping Zeng

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RESEARCH CENTERS

Integrated Biotechnology and Process Engineering
Regeneration, Implants and Medical Technology

V-2

CHEMICAL REACTION ENGINEERING

Our institute is interested in understanding of chemical catalysis on a molecular level. For this purpose the underlying phenomena like adsorption, diffusion inside pores, modeling of porous media, and chemical reactions at the active sites are described on a molecular level. Various approaches ranging from quantum chemistry (DFT, ab initio methods up to CCSD(T), CASSCF etc.), classical molecular simulations (Monte Carlo, Molecular Dynamics), statistical thermodynamics, transition state theory (TST), microkinetic modeling, and microscopic reactor modeling by means of ordinary and partial differential equations. These approaches are combined in hierarchical models which consistently transfer data from lower level simulations to the next. The linker models which connect detailed approaches with coarse-grained models are still under investigation. Our experimental investigations comprise diffusion and reaction measurements in various reactors.

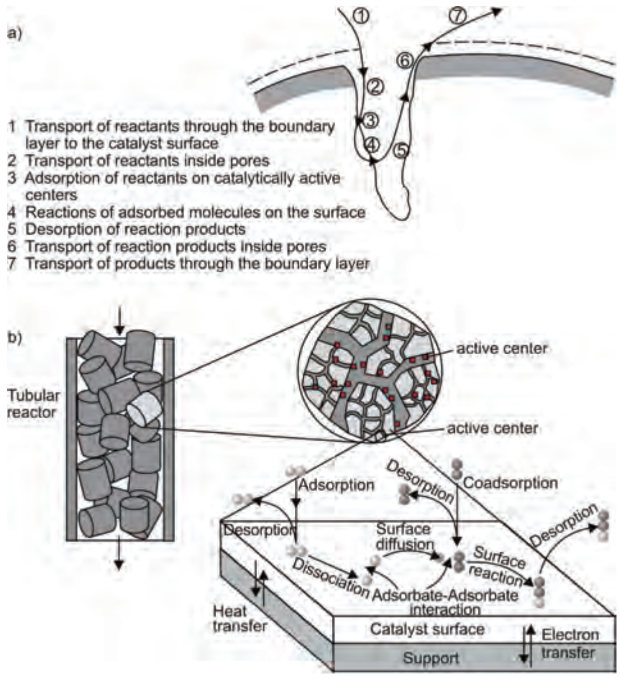
RESEARCH AND APPLICATIONS

Understanding Catalysis

Catalysts accelerate reactions and increase their selectivity towards desired products. Compared to reactions without employing a catalyst, the catalyst, in general, changes the reaction mechanisms. At present, catalyst development is in essence an experimental discipline, but computational approaches play an ever increasing role in catalysis research. The final goal is the design of a catalyst on a rational basis. Currently, computational catalysis can already give deep insight into details of catalytic reaction mechanisms, diffusion inside catalyst supports, and adsorption processes which cannot be obtained experimentally. The most useful approach is a combination of experiments, like various surface spectroscopic methods, gas chromatography, mass spectrometry and computational methods. First, one has to describe the active centers which can be sites on a metallic (mostly from the group VIII B of the periodic system) nanoparticle or a single site atom. The structure of a catalytically active nanoparticle undergoes changes of its structure in the course of catalytic reactions.

Modeling catalytic processes, one is faced with the following problems:

- proper description of the porous structure and its optimization
- identification of active sites
- describing the chemical reaction network
- multicomponent adsorption of reactions and products
- multicomponent diffusion of reactants and products inside the pores

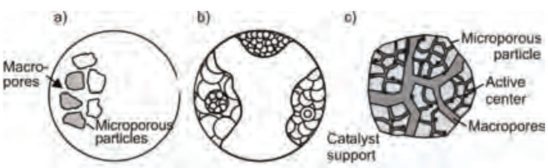


Phenomena in porous catalyst supports. (a) transport, adsorption and reaction an (b) pore structure and phenomena on catalytically active crystallites

Practical applications need further macroscopic modeling of the fluid flow and the entire reactor. Our research aims at solving these problems for concrete catalytic processes.

DESCRIPTION AND OPTIMIZATION OF POROUS STRUCTURES

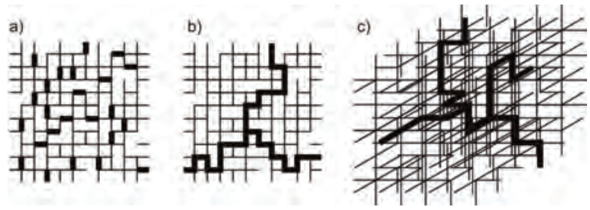
Most catalyst supports are formed by pressing a suitable powder into a mold. The particles themselves are porous (microporous), but pressing them together will also create a system of macropores that are in fact the interstices of the powder particles which span the entire catalyst pellet.



Catalyst support manufactured by compression of microparticles. (a) Two-dimensional cut. (b) Three-dimensional view. (c) Pore network, made of transport pores (macropores) and micropore.

Gas reactions catalyzed by solid materials occur mainly on interior surfaces of the catalyst support where the catalytically active nanoparticles are distributed. The specific rate of reaction is, therefore, also a function of the accessible surface area. The surface of the support shows mostly a fractal structure.

We have modelled the porous supports by three-dimensional networks which realistically represent bimodal catalyst pellets.



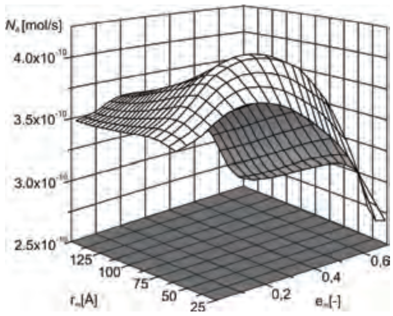
Cubic random pore network models. (a) Two-dimensional random micro/macropore network. (b) Macropores spanning the entire network. (c) Three-dimensional micro/macropore network, the macropores span the entire network.

Random three-dimensional networks are advantageous in several respects:

- Any type of network can be modelled (e.g., regular, irregular, and Voronoi).
- The effect of pore connectivity can be taken into account.
- Any pore size distribution and any pore geometry (e.g., cylindrical, slit-like) can be used.
- Local heterogeneities, for example, spatial variation in mean pore size, can be modelled. This is an important point, as Hollewand and Gladden detected that pellet pore structures are quite heterogeneous.
- Any distribution of catalytic active centers may be taken into account. Due to various impregnation and reduction methods, the distribution of active centers will be different. This causes different diffusional fluxes in the pore network.
- Percolation phenomena can be described. This is particularly useful for modeling deactivation phenomena.
- The pore walls can be smooth, irregular, or fractal.
- Of particular importance is that parameters like tortuosity can be avoided. Tortuosity is a fitting parameter that, in most cases, contains all model deficiencies.

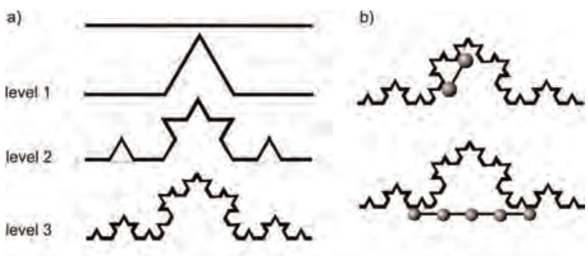
For a real catalyst support one has to find out its textural parameters. These parameters have a considerable influence on diffusion/reaction phenomena. Standard procedures are mercury porosimetry and nitrogen adsorption where, however, the results depend on the data evaluation algorithms. As the diffusion in the macropores (transport pores) is relatively fast compared to the micropores, but the micropores contain far more active sites per unit volume, an optimization problem occurs:

For obtaining a maximum of product, how should the micropore and macropore volume be distributed? We have solved this problem for various processes. The following figure shows the result of such an optimization for a hydrodemetallation catalyst support:



Optimization of catalyst support structures, specific demetallization rate as a function of microporous radius r_m, and micropore volume ε_m.

Besides the shape of the Euclidian pore space, approximated as pores, the surfaces of the pores are of importance for diffusion and reaction. Self-similar fractals turned out to be useful for the description of the surfaces.

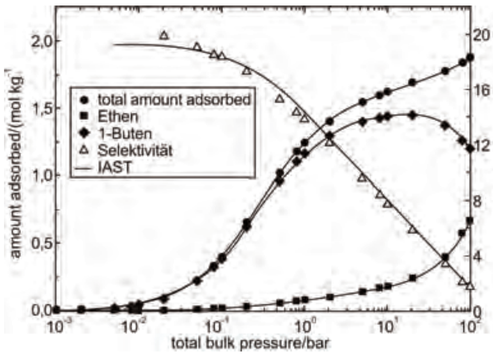


Self-similar objects. (a) Koch curve. (b) Molecules of different size on a Koch curve.

Contrary to amorphous pores, crystalline materials, like zeolites or metal-organic frameworks (MOFs), have well-defined porous structures which can often be downloaded from data banks.

ADSORPTION

As reactants firstly adsorb at the outer surface of pore mouths of a catalyst support, one has to model multicomponent adsorption. Adsorption isotherms are equilibrium properties which represent the number of molecules adsorbed on a surface at a given temperature T, volume V, and chemical potential μ. We simulate multicomponent adsorption isotherms by Monte Carlo approaches in the so-called grand canonical ensemble (μVT)(GCMC). In a GCMC simulation three types of moves are performed. The first one is a displacement of particles, where a particle is selected at random and given a new position. The second type of trial move is the insertion of a particle at a randomly chosen position; alternatively, a randomly selected particle is removed. For mixtures a fourth type of trial move can be used, namely swapping a particle which consists of changing the identities of the adsorbed positions or orientations. Each of the above mentioned trial moves has its particular acceptance rule. These trial moves are repeated until the chemical potentials inside the pores and in the bulk gas phase are the same.



Simulated adsorption isotherms for a binary mixture of ethene and 1-butene for a fixed equimolar bulk phase composition at 400 K and selectivity of 1-butane with respect to ethene.

A useful linker model which calculates mixture adsorption isotherms from pure component adsorption isotherms obtained by GCMC is the ideal adsorption solution theory (IAST). As can be realized from the figure, the IAST isotherms coincide very well with molecular simulations.

DIFFUSION

Four different diffusion mechanisms have been observed in porous catalyst particles: Knudsen diffusion, molecular diffusion, surface diffusion, and single-file diffusion. We have modelled multicomponent diffusion processes by Molecular Dynamics (MD) which solves Newton's equations of motion. One obtains, depending on the method of data evaluation, various diffusion coefficients, like self-diffusivities or transport diffusivities. These data are needed as the transport of the reactants to the active sites has to be calculated. A useful linker model is here the Maxwell-Stefan approach.

REACTION

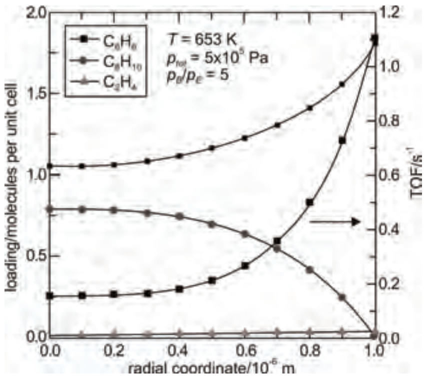
The reactions at the active center are calculated by quantum chemical approaches as bond breaking and bond formation are genuinely quantum mechanical phenomena. Methods of various sophistication are employed: density functional theory (DFT), Møller-Plesset 2, coupled cluster methods or complete active space self-consistent field (CASSCF) calculations. The calculations result in adsorption energies, activation barriers, equilibrium geometries of reactants, products and transition states, etc. at zero Kelvin. These values have to be corrected for real conditions of the catalytic process by statistical thermodynamics.

We have developed two methods for finding transition states which are available in commercial programs (e.g. VASP, Q-Chem).

The next step is the set-up of kinetic expressions. Chemical intuition is needed for the inclusion of the full set of the reactions which occur, or at least the important reactions. The reaction system has to be thermodynamically consistent. For this purpose we use techniques of microkinetic modeling.

MULTISCALE MODELING

After having executed all the steps mentioned above, they can be included into a macroscopic model of the entire pellet and finally the reactor. A complete example of such a procedure was executed for the alkylation of benzene over H-ZSM-5. The industrial Envinox process (UHDE Ltd., Dortmund) has also been modelled on a molecular level in our institute. A typical composition profile inside a profile is presented in the figure below.



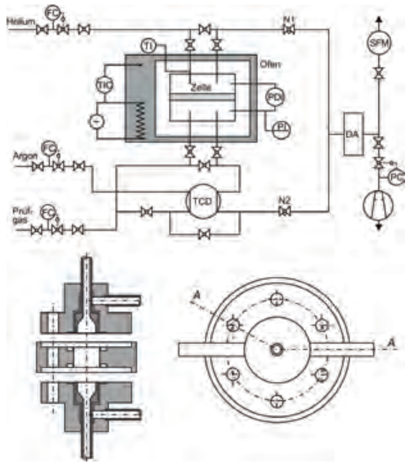
Radial concentrations and turnover frequencies (TOFs)

SERVICE FOR INDUSTRY

We have executed many different investigations for industrial companies, ranging from product engineering to the development of entire chemical processes. Some tasks dealt with model development for process control and optimization.

EQUIPMENT

For executing the calculations we operate a large Linux cluster. Furthermore we use a Supercomputer in Berlin/Hannover. The experiments are executed in Wicke-Kallenbach devices which are suitable for reactions, and differential and integral reactors.



- Linux cluster with several hundred multicore processors
- several gas chromatographs
- mass spectrometers
- combined gas chromatograph/mass spectrometer
- DRIFT spectrometer
- Wicke-Kallenbach device for reactions
- ultrasound reactors
- several differential and integral reactors

DIRECTION OF THE INSTITUTE

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RESEARCH CENTER

Integrated Biotechnology and Process Engineering

V-3

SOLIDS PROCESS ENGINEERING AND PARTICLE TECHNOLOGY

The research focus of the institute is the fluidized bed technology and its industrial applications. We investigate physical and chemical processes like classification, drying, adsorption, heating and cooling of solids, combustion, pyrolysis, carbonization, gasification, calcination as well as particle formulation by coating, granulation and agglomeration. Experimental investigations with novel measurement methods are supported by hierarchically structured theoretical approaches. The model development includes particle based methods (DEM, population balances), continuous models (FEM, CFD) as well as steady-state and dynamic flowsheet simulations of solids processes, whereas simulations consider individual particles, bulk solids and multiphase particle laden flows.

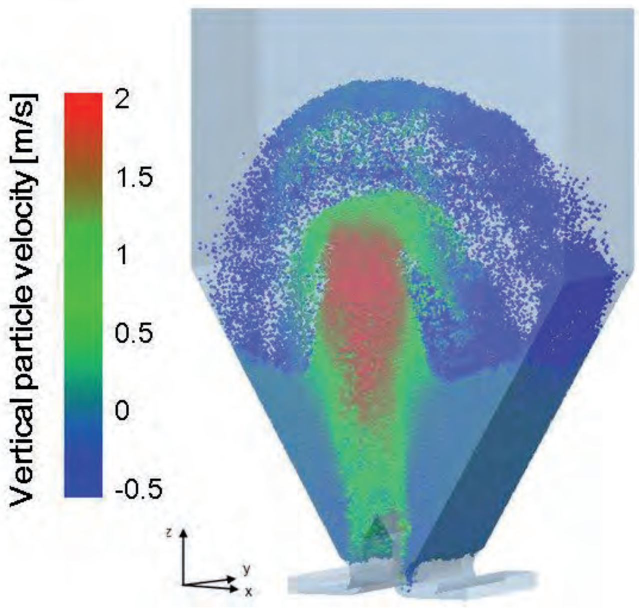
RESEARCH AND APPLICATIONS

• PARTICLE FORMULATION

A focus of our research is the processing and analysis of particles in the nm- and mm-range for a multitude of applications, ranging from the food industry, over fine chemicals, biotechnological and pharmaceutical powders to applications in materials science and energy technology. The particle formulation is based on coating, encapsulation, granulation and agglomeration processes in order to manufacture powder granules from liquid educts with novel and improved properties. As an example, we agglomerate and coat prestructured µm-sized composite particles to formulate hierarchically structured composites, which are then further processed to novel highly-filled ceramic-polymer composite materials with customized mechanical properties. This is done in cooperation with other institutes within the Cluster of Excellence 'Integrated Materials Systems' and will be further extended within the DFG Collaborative Research Center SFB 986: Tailored Multiscale Materials Systems. The investigated formulation techniques are based on spray drying, fluidized bed and spouted bed technology. Another studied apparatus is the fluid bed rotor processor, which is particularly useful for formulating particles with high mechanical strength and sphericity.

• MULTISCALE SIMULATION OF SOLID SYSTEMS

The multiscale modelling concept is based on a coupling between different time and length scales of the description of particle rate processes and used to obtain more detailed simulations and kinetics. The simulation on lower levels in opposite to the macroscopic description allows considering the apparatus geometry and material microproperties, which play an important role. The microscale simulation of solids processes is performed in the length scale of 10^{-5} m and is based on the



Discrete-Element-Method (DEM) with coupled Computational Fluid Dynamics (CFD) method. On the macroscale the dynamic and steady-state flowsheet simulation systems are used. Finally, the subsystems on different scales are combined by interscale communications into one multiscale simulation environment.

- **FLOWSHEET SIMULATION OF SOLID SYSTEMS**

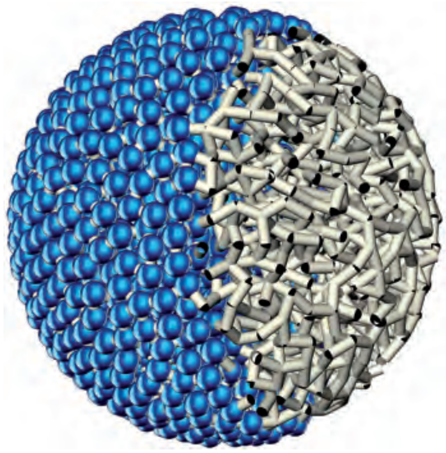
While flowsheet simulation tools are well established in Chemical Engineering for processes dealing with fluids, the use of such tools is not very common yet for processes involving solids.

For this reason during the last decade a flowsheet simulator has been developed at the institute, which is specially designed to simulate solids processes and to handle the complex properties of particulate matter. Meanwhile the system is commercially available and the institute is using it for the simulation and study of complex solids processes. Within this research work also new unit models are developed.

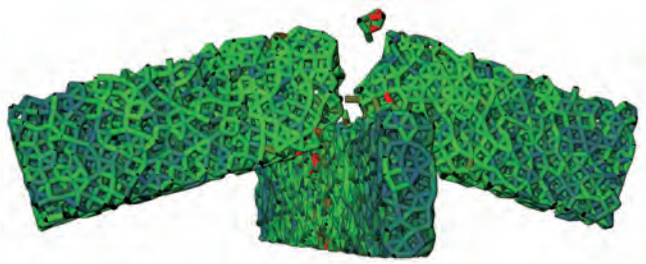
A more recent branch of research in this area is the development of a dynamic flowsheet simulator on the base of the previously developed stationary process simulator. For this purpose the simulation frame work has to be extended and dynamic models of the different unit operations for solids processing and the respective apparatuses have to be formulated. This work will be done within the DFG Priority Programme SPP 1679 "Dynamic Simulation of Interconnected Solids Processes (Dynamische Simulation vernetzter Feststoffprozesse)", which has been granted in 2012 and is headed by Prof. S. Heinrich.

- **CONTACT AND BREAKAGE MECHANICS OF PARTICLES**

During transportation, storage and handling the particles are mechanically stressed due to particle-particle and particle-wall contacts which can lead to the unwanted breakage or attrition phenomena. The focus of our research in this area is the physical based study of the contact deformation and breakage behaviour of the particles and agglomerates under various mechanical loading conditions: compression, tension, shearing, bending, impact et al.



Using different experimental setups, e.g. compression tester (Texture Analyser®), impact gun, free fall apparatus, shear and attrition tester, high speed analysis, we obtain the basic mechanical properties of single particles and powders: modulus of elasticity, stiffness, yield point, hardness, strength, cohesion, friction, restitution coefficient, flowability et al. Based on the experimental data we develop the contact models to describe the mechanical interaction of solid particles sized from few micrometres to the millimetre range. Moreover, the breakage criteria of the particles and agglomerates will be described depending on the microstructure (porosity, packing structure and adhesion mechanisms of primary particles) and material parameters (elastic, elastic-plastic or plastic behaviour, viscoelasticity and glass transition temperature).



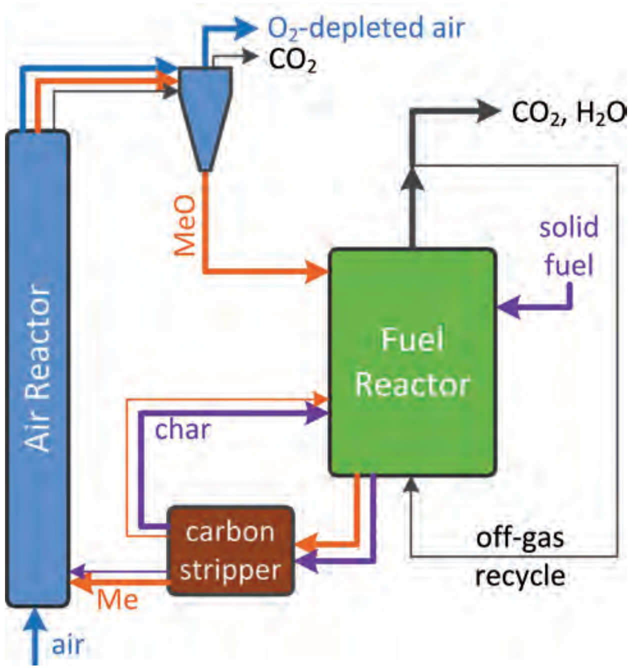
We aim to provide fundamental knowledge on the mechanical behaviour of the granular materials under wet conditions in order to predict the dynamics of different industrial multiphase processes, e.g. for coating, granulation and agglomeration.

The developed models are used in the Discrete Element Simulations of the particulate systems to predict the breakage probability and breakage function, particle dynamics as well as agglomeration probability in different industrial processes, like agglomeration, mixing, pneumatic transportation and milling. The institute participates in the DFG Priority Program SPP 1486 "Particles in Contact" (experimental study and simulation of the fine particles), Collaborative Research Centre "Maßgeschneiderte Multiskalige Materialssysteme" (production, modelling and characterisation of ceramic composit materials), Program of Federal Ministry of Education and Research „New Methods in Systems Biology" (simulation of breakage behaviour of biological cells)

• NOVEL CONCEPTS IN ENERGY TECHNOLOGY

· Chemical-Looping Combustion

In the joined (IET TUHH, IFK University Stuttgart and TUHH-SPE) research project CLOCK (Federal Ministry of Economics and Technology) the chemical-looping combustion (CLC) of coal is investigated. In the CLC-process the regular combustion chamber of a power plant is substituted by two interconnected fluidized bed reactors. In the first fluidized bed reactor the fuel reacts with a solid oxygen carrier (e. g. metal oxide). The chemically reduced oxygen carrier is re-oxidized in a second fluidized bed reactor with air. Employing this technology, it is possible to achieve an almost pure stream of CO_2 – after water condensation – as off gas from the fuel reactor. This results in the significant advantage of an inherent CO_2 separation. At the SPE chemical-looping combustion of coal is experimentally investigated in a pilot-scale coupled fluidized bed system. The fluid-mechanical behaviour of the system is studied in a cold-model. Reaction kinetics are measured in a laboratory scale fluidized bed reactor. Furthermore, the process is modeled under consideration of reactions, attrition and particle size distribution.



· Pyrolysis of Biomass

As partner in the joint research cluster BIOREFINERY2021 of academia and industry, the expertise of the institute in particle and energy technology contributes to the overall goal to enhance the state of the art bio-refinery with processes for value added production from waste products. In this context it is investigated if lignin as a waste product can be used for the production of chemicals with high value instead of combusting it for energy production, as practiced today. Pyrolysis of the waste products in a stationary fluidized or circulating fluidized bed reactor is a promising technology in achieving this goal.

At the institute the pyrolysis research is focused on the investigation of a system of coupled fluidized beds. The pyrolysis takes place in a circulating fluidized bed, producing pyrolysis oil, which is containing the desired products. The by-products of the process are coke, tar and permanent gases. For the supply of the endothermic pyrolysis reaction heat, the by-products are combusted in a stationary fluidized bed. The heat is transported via the circulating bed material. Both reactions shall be integrated in one process to avoid heat loss. Furthermore it is presumable that the yield of the desired chemicals will be increased by the reduction of the coke loading on the bed material.

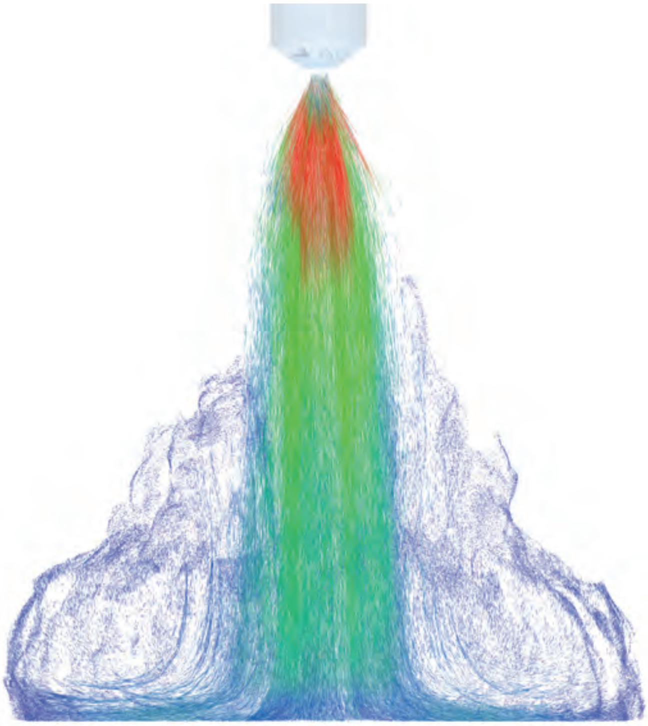
EQUIPMENT

- Particle strength measurements (compression, impact and attrition)
- Particle size analyser (dry, wet)
- Bulk characterization of powders: cohesion and friction properties
- Particle structure and morphology (helium pycnometer, optical microscopes, calorimeters)
- High-speed camera
- 3D phase doppler anemometer

- Process gas analyzers (online, batch, continuous)
- Fluidized bed processes (batch and continuous)
  - granulators (top and bottom spray)
    - spouted bed – Glatt ProCell5
    - Wurster coater – Glatt GF7
    - rotor processor – Glatt Rotor300
    - pilot plant granulator – Glatt GF/ProCell25
    - various laboratory-scale granulators
  - reactors for gasification, pyrolysis and combustion
    - bubbling
    - circulating

SERVICE FOR INDUSTRY

- Software development for particulate processes
- Fluidization processes for drying, granulation and agglomeration
- Investigation of combustion processes and emission behaviour of solid combustors
- Flowsheet simulation of solids processes
- Discrete Element Modelling (DEM) of granular materials
- Discrete Particle Modelling (DEM-CFD) of fluidized and spouted beds
- Breakage behaviour of granules and agglomerates
- Particle characterization: chemical, physical and mechanical properties



DIRECTION OF THE INSTITUTE

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RESEARCH CENTERS

Integrated Biotechnology and Process Engineering
Climate Protecting Energy- and Environmental Engineering

NETWORK

EFCE Working Party Agglomeration

V-4

PROCESS AND PLANT ENGINEERING

The Institute for Process and Plant Engineering was established at TUHH in 1985 and is involved in the development of system-oriented modeling basics, steady-state and dynamic simulation of complex process engineering systems including cost driven optimization. This involves a linkage between fundamental scientific principles and engineering based approaches.

Our scientific activities are based on a range of commercial and customized software tools, numerous experimental facilities, data acquisition systems and storage of data both at lab and pilot plant scale.

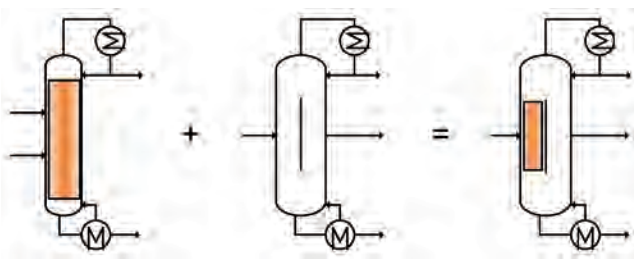
RESEARCH AND APPLICATIONS

- **MODELING, SIMULATION AND VALIDATION OF THE DIVIDING-WALL COLUMN TECHNOLOGY**

The dividing wall column is a famous example of a way to increase process efficiency in the area of distillation, as it leads to a smaller and more energy-efficient technology. Thus, dividing wall columns are very interesting both from the ecologic as well as from the economic point of view. By introducing a vertical wall into the column, this innovative apparatus allows for the separation of mixtures with three or four components in one step into streams with high purities. This implies that dividing wall columns can effectively replace two or three traditional distillation columns. It is reported that the implementation of dividing wall columns can reduce both investment costs and energy requirements by up to 30 %.

These advantages are the reason why our institute does research on this energy saving technology. On the one hand, a rigorous mathematical model of dividing wall columns was developed, which is capable of predicting stationary and dynamic process behaviour. At the same time, a dividing wall column with a total height of 11 meters and a total number of 20 theoretical stages is operated at our institute. Thus, our research in this area consequently combines model-based theoretical analysis of dividing-wall columns with detailed experimental validation of the model predictions.

Now, the next step towards further process intensification is done. A reactive dividing wall column will also be operated and modeled at our institute. With this, the foundation is laid for the inexpensive and rapid model-based realization of optimal design and control strategies for both conventional and reactive dividing wall columns.

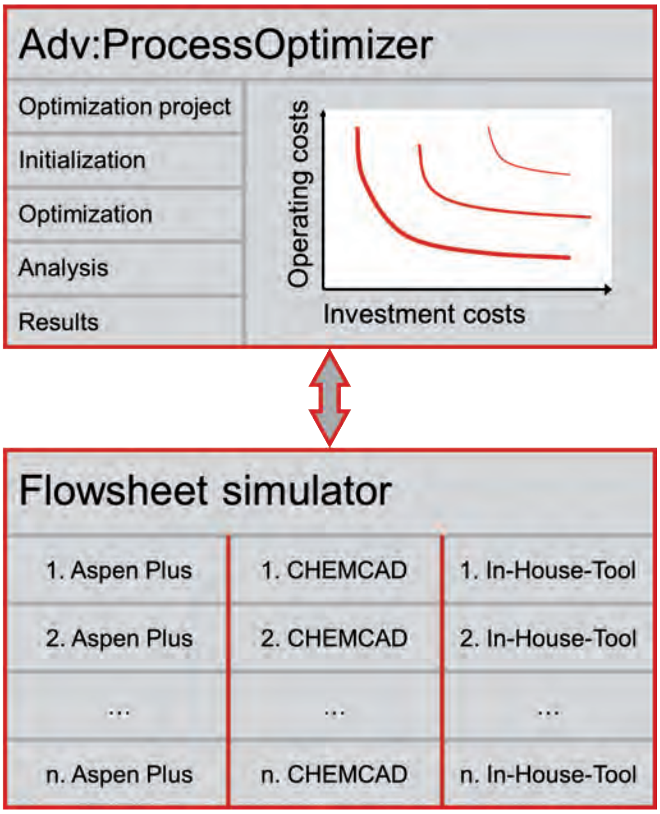


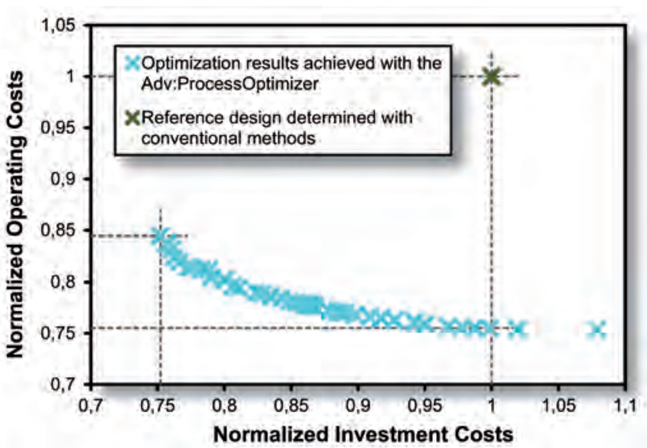
• **A NOVEL APPROACH FOR EFFICIENT DESIGN OF PROCESSES BASED ON A MULTI-OBJECTIVE COST-DRIVEN OPTIMIZATION**

In the process industry a wide range of heuristic rules, short-cut methods and software-tools is used during the design of processes. Within the design several alternatives as well as manual improvements of operational and constructive parameters are considered. Despite the high manual effort the results are often unsatisfactory as the complete solution space of possible investment and operating costs was only investigated point wise. Although an investigation of the complete solution space would be necessary in order to find the set of best compromises of both types of costs for a specific project.

To overcome these disadvantages a novel approach has been developed to guarantee finding the set of best compromises of both types of costs with low manual effort. This approach raises the conventional design to a higher level as it overlays the design with a simultaneously performed multi-objective optimization of both types of costs. So, the conventional design process is replaced by a single design step. In this step, a specially tailored optimization algorithm with high global search ability determines the set of process design alternatives with the best compromises of both types of costs automatically.

To make the use of the developed method in industrial practice easy, a software-tool, named Adv:ProcessOptimizer, was developed. The modular structure of the Adv:ProcessOptimizer allows the user to design with an overlaid optimization of both types of costs an arbitrary process which is modeled in a flowsheet simulator. Own industrial applications of the Adv:ProcessOptimizer have shown clearly that the achieved results were significantly better according to both types costs.





EFFICIENT SYNTHESIS OF HEAT EXCHANGER NETWORKS COMBINING HEURISTIC APPROACHES WITH A GENETIC ALGORITHM

Production processes in chemical industry usually exhibit a large energy consumption. Therefore, the integration of a heat exchanger network (HEN) can have a major impact on energy consumption and sustainability of a production plant. With increasing heat recovery the energy costs are decreasing, whereas the investment costs are increasing. Thus, the design of a cost optimal HEN can be considered as a classical optimization problem.

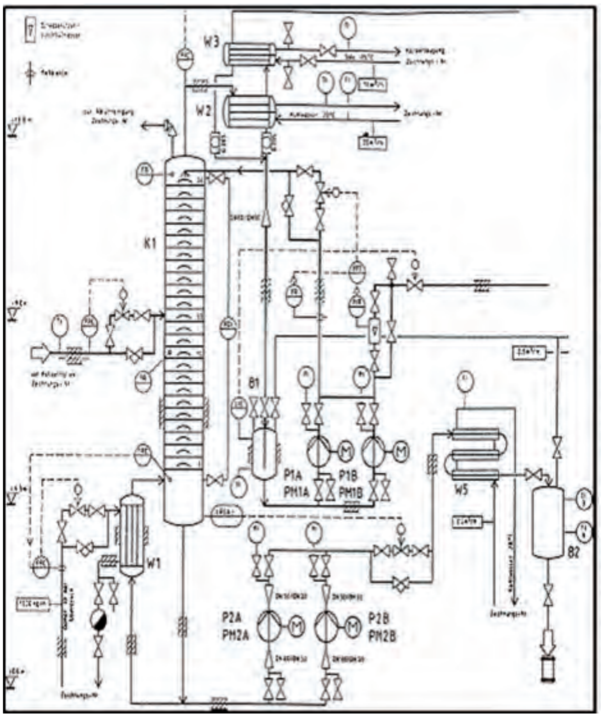
Due to availability of special software and the strong sequential procedure, in industrial practice the most common used method for HEN synthesis is the well-known pinch design method. On the other hand, recent research activities have shown that problem-tailored genetic algorithms are very capable of finding even better HEN structures. However, because of the huge amount of optimization variables the computation time is very high especially for large-scale HEN. In order to overcome this disadvantage a new synthesis method has been developed, which reduces the computational time massively. This new method is based on the idea of subnets. A subnet represents a part of the whole network that does not have any contact to other parts of the HEN. Thus, it can be considered and treated like a single sub problem, which can be easily solved by the genetic algorithm. The application of this innovative method on industrial relevant problems yielded a reduction of the total annual costs of up to 31 %. An additional improvement of process control is achieved by the estimated subnets within the HEN. Actually, a sophisticated software SynthHEX is developed in cooperation with our industrial partner.

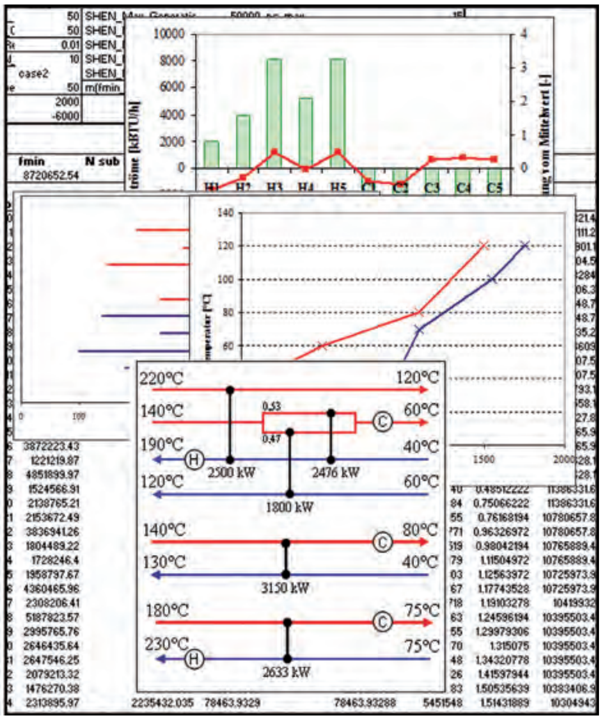
APPLICATION OF IMMOBILIZED ENZYMES IN PACKED BED REACTORS: MODELING, SIMULATION, VALIDATION AND PROCESS OPTIMIZATION

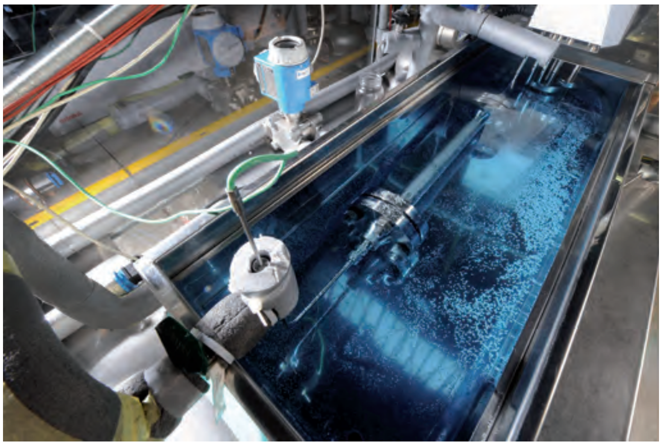
The sector of white biotechnology is becoming more and more important for industrial application. Compared to conventional synthesis processes the enzymatic-catalyzed ones allow a high selectivity and product purity, and therefore the reduction of waste and downstream processing. The application of immobilized enzymes in packed bed reactors is especially beneficial for the production of high value chemicals in smaller quantities.

Until today the design of these processes is very time consuming, expensive and driven by a lack of knowledge. Hence, an optimized process design cannot be guaranteed by present methods. With the focus on batch processes using packed bed reactors we therefore have developed with STEP a model-based Simulation Tool for Enzymatic Processes. Based on detailed investigations on reaction kinetics and hydrodynamics a sophisticated process model was created, further developed to the sequential modular simulation tool and thoroughly validated. The tool includes a packed bed reactor model with axial dispersion, a stirred tank model with flash and the piping. By developing an optimization tool the full potential as a design tool can be exploited. For user given objectives (e.g. minimization of manufacturing cost) and constraints (e.g. output quantity and quality) this approach allows the identification of the optimal process design and control strategy.

We investigate not only two-phase, but also three-phase systems with special focus on its hydrodynamic complexity and implications for an optimal design. Currently, several approaches for process intensification are analyzed.







EQUIPMENT

Our institute offers technical equipment and experimental analyses as services connected to the current main research focus. Practically all research projects carried out involve the implementation of software for scientific computing. Some implementations have evolved to software that is useful beyond the project it originated from.

TECHNICAL EQUIPMENT

Many distillation columns in lab and pilot scale (with trays and packings), Multivessel batch-distillation Dividing-wall distillation column (DWC, Petlyuk-structure), Sieve-tray extraction column, Rotary and Thin-film evaporator, Reverse osmosis, Pervaporation, Membrane distillation, Plant for membrane tests, Batch reactor (up to 200 bar), Packed bed reactor with immobilized enzymes , Sonoreactor, Distributed control systems (WinErs, LabView), Process analytics (Gaschromatography (Perkin Elmer Clarus 500), Chrompack, HPLC, Karl-Fischer Coulometer C30 (Mettler-Toledo))

SIMULATION TOOLS

Flowsheeting (Aspen Plus, STEP (bioprocesses), Heat recovery systems (Energy Analyzer, SyntHEX), Optimization tools (Adv:ProcessOptimizer, evolutionary algorithm), property databank (ProSim), Operator training system for DWC (OTS DWC), Process control development tool (ConStruct DWC

SERVICE FOR INDUSTRY

Our institute is working on industrial projects in close cooperation with different industrial partners. We develop, plan and operate test equipment, which are conceptualized in close cooperation and coordination of industrial partners based on their individual needs. This is further supplemented through the available extensive experience in the areas of modeling, simulation and optimization. Our core competence lies in the systematic optimization of complete production processes. This includes the identification of bottlenecks and development of secure basis for investment decisions based on process analysis. Moreover, the optimal utilization of resources, equipment and manpower (optimum production planning) as well as the reduction of energy costs and production wastes through integral process analysis remain the central part of our activities. The development of new or improvement of the existing control strategies for production processes (automation concepts) also encompasses our services.

The main objectives of all activities are the reduction of manufacturing costs and minimization of the environmental impact.

DIRECTION OF THE INSTITUTE

Prof. Dr.-Ing. Georg Fieg

STAFF

• **Senior Scientist** Dr. B. Neumann • **Technical Staff** H. Fitschen, L. Kulka • **PhD Students** M. Ajmal, C. Brandt, C. Buck, K. Ebert, C. Ehlers, P. Ernst, C. Hiller, J. Kleeberg, P. Krause, J. Lawen, M. Leipold, J. Liang, H. Mayer, G. Niggemann, M. Schröder, M. Vargas, P. Zitzewitz

RESEARCH CENTERS

Integrated Biotechnology and Process Engineering
Climate Protecting Energy- and Environmental Engineering

TUHH Institute of Multiphase Flows ims

V-5

MULTIPHASE FLOWS

The Institute of Multiphase Flows deals with multiscale transport phenomena to intensify chemical and biochemical reactions. With the aid of novel measurement techniques and numerical simulations a modeling of transport processes from interfaces into the surrounding fluid becomes possible and enables a reliable scale up and design of apparatus for industrial applications.

RESEARCH AND APPLICATIONS

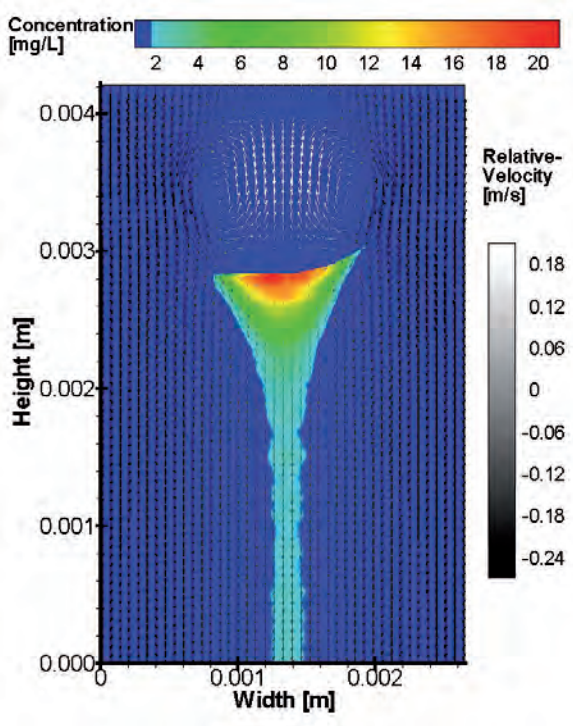
• MULTI-SCALE TRANSPORT PROCESSES IN CHEMICAL AND BIOCHEMICAL APPLICATIONS

Today the design and optimization of multiphase reactors is mostly done with the help of semi-empirical models and matching coefficients. Most of data and correlations, that are used, are based on water/air systems at ambient conditions. Up to now there is no validated model available to calculate fluid flow mass transfer and reaction simultaneously.

Therefore bridging the gap between basic research and industrial application is necessary. Scale-up strategies and design rules have to be developed for large scale systems. In doing so it is essential to consider multi-scale effects and to create a dimension independent description. The validation of simulations requires experimental data with high spatial and temporal resolution (e.g. bubble size distribution, gas hold-up and mass transfer coefficients) which must be captured under industrial conditions (high temperature and pressure) and in industrial systems (e.g. organic solvents). To approach the problems described above the joint project from industry, universities/research institutions and small and medium-sized companies "Multi-Phase" is funded by the Federal Ministry of Education and Research (BMBF). This has emerged as a pilot project from the scientific network „Campus Bubble Columns" by ProcessNet. Just the combined application of experiments and numerical simulation by taking into account physical basics and industrial requirements can lead to more reliable models for scale up and design of multiphase reactors.

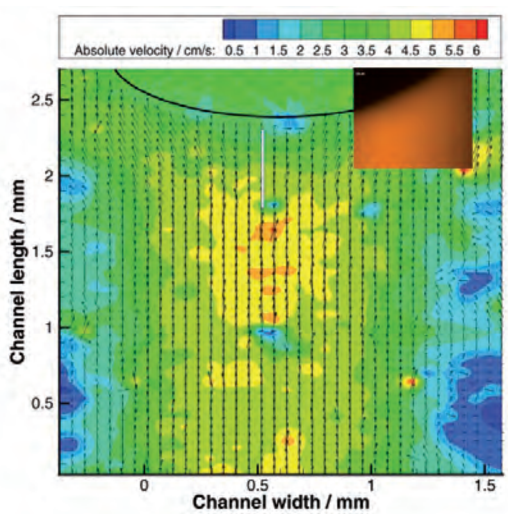
• TRANSPORT PROCESSES IN REACTIVE TWO-PHASE FLOWS

To get a deeper insight into local mass transfer phenomena in reactive gas-liquid flows, investigations on rising single spherical bubbles are performed at the IMS. Oxygen as gaseous phase reacts with a sodium sulfite/water solution with well defined kinetics. Thereby bubble wakes can be considered as local mixing areas which make a high contribution to meso- and micro-mixing in multiphase flows.

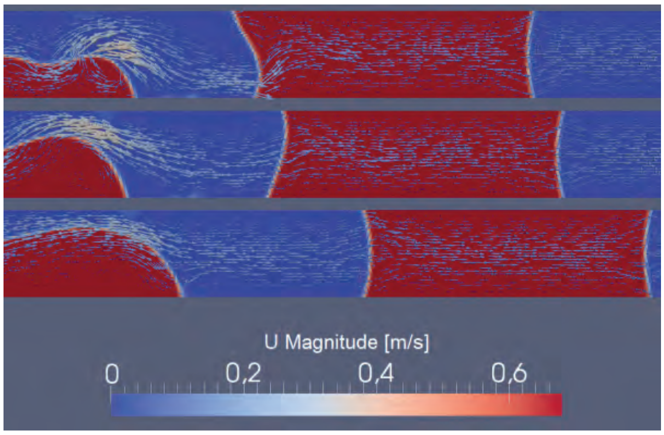


An increased understanding of the mass transfer processes in the vicinity of the interface creates new perspectives of process intensification and selective reaction engineering. Within the framework of the German Research Foundation (DFG) package PAK 119 the analysis of mass transfer in the vicinity of the interface is carried out by measuring velocity and concentration fields. Thereby the velocity and concentration fields are captured using the Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) to investigate local hydrodynamic effects and local concentration gradients at the interface. In close collaboration with the Center of Smart Interfaces (TU Darmstadt) and the Department of Chemical Engineering (University of Paderborn) the calculation of local mass transfer rates and prediction of mass transfer enhancement by a chemical reaction becomes possible.

• MICROSCALE TRANSPORT PROCESSES AT INTERFACES

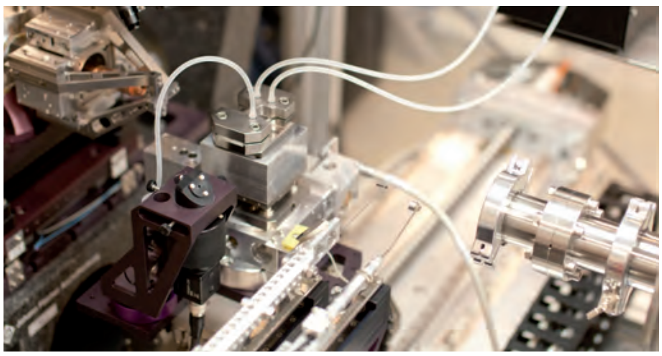


For more detailed information of mass transfer limitations by surfactants, mass transfer processes are investigated under well-defined conditions in a gas/liquid capillary Taylor Flow. In square and circular capillaries with a inner diameter of 2 mm, local velocity and concentration fields are analyzed by Micro-Particle Image Velocimetry (µ-PIV) and Confocal Laser Scanning Microscopy (CLSM), respectively. This project is supported by the German Research Foundation (DFG) within the priority program 1506 "Transport Processes at Fluidic Interfaces".
A further project, associated to the DFG Priority Program 1506 "Transport Processes at fluidic Interfaces", aims the modeling, calculation and experimental analysis of two-phase flows in Y-Y shaped microreactors.



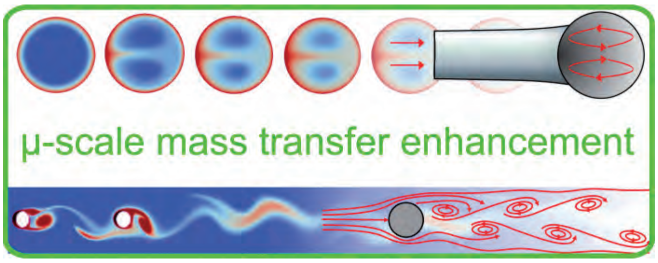
The objective of this project is the simulation of a chemical reaction (e.g. a polymerization reaction) in one phase and the necessary validation with own experimental data (local velocity and concentration fields). A Direct Numerical simulation (DNS, OpenFOAM®) is used to calculate the flow field and mass transfer across the interface of two immiscible fluids (VOF method with a special focus on the interface) for a wide range of hydrodynamic parameters. As one result, the development of analytical functions for simplified models will be possible, aiming the prediction of chemical reactions in the vicinity of fluidic interfaces.

To get a deeper insight into molecular transport processes at interfaces, the interaction between fluid flows and chemo- or biocatalytic active surfaces are studied in a close collaboration with the Deutsches Elektronen-Synchrotron (DESY).



The chemo- or bio-catalysts are fixed on a carrier and suspended in a liquid. As a result of the interactions of catalytic surfaces with the flow extensive influences of the chemical or biochemical reaction are expected. In order to investigate the interaction between flow, field and catalytic surfaces measurements are necessary of both the shape of the macromolecules and the flow field. The combination of X-Ray Scattering and µ-PIV will form the basis of the investigation of macromolecules in a boundary layer.

For a better understanding of mass transfer effects on biocatalytical reactions and a more efficient reactor design the investigation of transport processes in micro-bioreactors by means of computational fluid dynamics (CFD) and experimental analysis are studied in a DFG funded project. Miniaturization, realized in the design of micro-bioreactors, is a method of allowing defined reaction conditions (short diffusion paths, adjustable residence time distribution etc.) in modern process engineering. It allows a continuous operation mode, short diffusion paths and control of shear stress. Modern biotechnological systems have complex requirements on process engineering, e.g. high demand of oxygen supply and high sensibility to shear stress at the same time. Consequently, traditional apparatus like bubble column or aerated stirred vessels are not appropriate. An unfavorable consequence of this miniaturization is the use of small flow rates and ineffective laminar mixing. In micro scale, transport mechanisms in boundary layers play a major role, but are widely unknown. In an interdisciplinary working group (Leibniz University of Hannover/Germany, Hamburg University of Technology (TUHH)) novel designs of hollow-fiber membrane modules are developed, aiming a more efficient operation than conventional modules. The studies are based on multi-scale experiments and simulations, taking into account the use of secondary flows for passive mixing, e.g. Dean vortices in helical formed membranes.

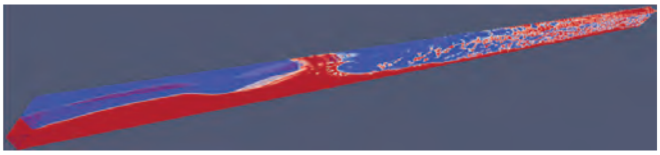


This way oxygen transfer rates can be more than doubled. Miniaturization turns out to be an all appropriate method for various fields of bio process engineering. To work straightforward, numerical simulations are performed and validated by experiments by means of µ-LIF in conjunction with a Confocal Laser Scanning Microscope and µ-PIV.

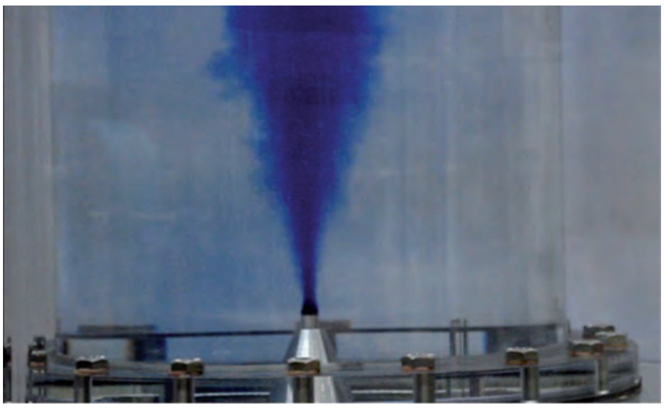
- **TRANSPORT PROCESSES IN MULTIPHASE FLOWS WITH PHASE TRANSITION**

Phase transition in multiphase flows plays a dominant role in many technical applications e.g. by condensation induced water hammer and deep sea oil drilling.

Numerical and experimental analysis of condensation induced water hammer in countercurrent two phase flows of steam and water are performed. The main objective is the setup of a test facility for the investigation of condensation induced water hammer by experimental determination of the flow and temperature fields using PIV and LIF. Furthermore the main physical phenomena of a condensation induced water hammer are studied by numerical simulation (OpenFOAM®) and transferred to commercial calculation programs.



This project is associated to the joint research project "CIWA – Condensation Induced Water Hammer" and supported by the Federal Ministry of Education and Research (BMBF).
The experimental study of multiphase flows with phase transition under extreme environmental conditions is done at the IMS as part of the C-IMAGE Consortium (Center for Integrated Modeling and Analysis of the Gulf Ecosystem), sponsored by the Gulf of Mexico Research Initiative (GRI). The main tasks are the modeling and calculation of the fluid pathways of the Deep Water Horizon blowout that caused the oil spill 2010 in the Gulf of Mexico. The modeling of the fluid dynamic behavior of a multiphase petroleum jet that forms a rising plume with bubbles, droplets and methane hydrate in seawater is a challenging problem. In a special pressure laboratory the bubble and drop size distribution is measured by means of Endoscopic Particle Image Velocimetry (EPIV) under deep sea conditions. The objective is the near field modeling of the oil distribution caused by a blow out in close collaboration with the Texas A&M University and the University of Calgary.



RESEARCH AND DEVELOPMENT FOR INDUSTRIES

Scale-Up strategies
Development of novel design and scale-up strategies for heat and mass transfer apparatus based on fundamental research by considering of multi-scale models.
Process intensification
Optimization of chemical and biochemical reactions, using multi-scale transport phenomena.
Hydrodynamic optimization of components:
Optimization of plant components by computational fluid dynamics with experimental validation
Development of measurement techniques:
Development and application of non-intrusive measurement techniques for single and multi-phase flows
Scientific support
Support in pilot tests with experimental analysis and computational fluid dynamics

INFRASTRUCTURE

Measurement techniques

- Loop reactors (acryl glass), DN 300, height 2.0 m
- Bubble column (glass), DN 100, height 1.6 m
- Test facility for the experimental analysis of condensation induced water hammer in countercurrent two phase flows of steam and water, DN 200/PN 40
- Macroscopic Particle Image Velocimetry (PIV) – Intelligent Laser Applications (ILA GmbH)
- Endoscopic Particle Image Velocimetry (EPIV) – Intelligent Laser Applications (ILA GmbH)
- Microscopic Particle Image Velocimetry (μ-PIV) – Intelligent Laser Applications (ILA GmbH)
- Laser-induced fluorescence (LIF) technique in conjunction with a tunable dye laser – Intelligent Laser Applications (ILA GmbH)
- Confocal laser scanning microscope Olympus FluoView 1000 (Multi-line Argon laser – 457/488/515 nm, detection channels with an independent diffraction grating and slit for spectral separation, simultaneous confocal fluorescence observation and independent laser light stimulation with a 405 nm Laser Diode)
- Multi-channel fiber optic oxygen transmitters in conjunction with non-invasive oxygen sensors and sensor probes - PreSens - Precision Sensing GmbH
- Rotational Rheometer Malvern Instruments Kinexus pro (torque range – viscometry: 0.05 μNm to 200 mNm (continuous), Normal force range 0.001 N to 20 N)
- Calorimetry: Setaram low temperature Calorimeter BT 2.15 (from -196° C to 200° C), resolution 0.1 μW, and a rapid, non-destructive thermal conductivity and effusivity testing instrument C-Therm Technologies TCi (both are part of the research center "Climate Protecting Energy- and Environmental Engineering"

SIMULATION

- Standard and adapted OpenFOAM® solvers on an institutes own cluster of 36 nodes

DIRECTION OF THE INSTITUTE

Prof. Dr.-Ing. Michael Schlüter

STAFF

• **Senior Scientist** Marko Hoffmann • **Technical Staff** Heiko Koenig, Bernhard Pallaks • **Team Assistances** Cornelia Susanne Heinz, Alexandra Kalski • **PhD Students** Melanie Bothe, Frans Jan de Jong, Florian Kopf, Ulf Daniel Kück, Katrin Laqua, Christoph Meyer, Christian-Ole Möller, Stefan Mosler, Steffen Richter, Christian Urban

RESEARCH CENTERS

Integrated Biotechnology and Process Engineering
Climate Protecting Energy- and Environmental Engineering

NETWORKS

ProcessNet research network "Campus Bubble Columns"
EFCE Working Party Multiphase Fluid Flow
German Japanese Network on Multiscale Multiphase Process Engineering

V-6

TECHNICAL BIOCATALYSIS

The Institute of Technical Biocatalysis covers technical and fundamental aspects of the application of whole cells and isolated enzymes in biocatalysis and environmental biotechnology. Process engineers, biotechnologists, chemists and microbiologists interact in an unique interdisciplinary way in laboratories equipped with state-of-the-art equipment for research and education. The institute is subdivided into three research groups: Technical Biocatalysis, MicroBioTechnology and Biodegradation. The institute focuses on the development of novel bioprocesses, the investigation of biocatalytic as well as chemoenzymatic reaction sequences to produce complex molecules and the establishment of online analytics for reaction monitoring of biotransformations.

BIOPROCESS DEVELOPMENT

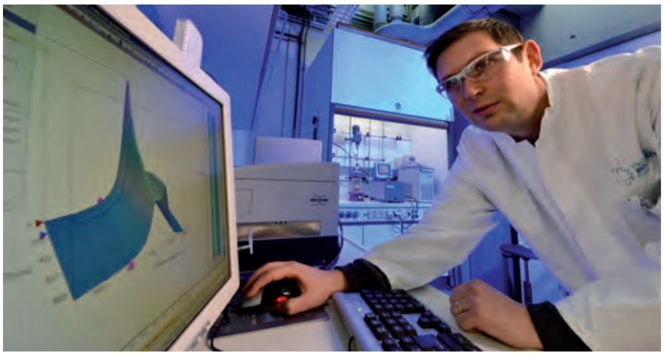
The sustainable production of chemicals is of increasing importance to chemical and biotechnological industries. Biocatalysts have a great potential for industrial processes, because they catalyze only a single defined reaction under mild reaction conditions in view of pH, temperature and pressure. They also demonstrate a high stereo- and regioselectivity. Due to their high selectivity, specifity and catalytical efficiency the significance of biological catalysts (enzymes) in industry is greatly increasing, one example being in the cosmetic industry. Nevertheless, one key prerequisite for their application is the appropriate technology, namely reaction engineering. Thus, the production cost can be reduced. With detailed kinetic and thermodynamic knowledge of the specific biocatalytic reaction systems dedicated reactors are developed that allow an easy up scaling of the process. At this stage of process development also downstream processing becomes of major importance, even leading to hybride reaction system, meaning direct integration of reaction and downstream processing in one step.

REACTION SEQUENCES

Biocatalyzed reaction sequences are coming more and more in focus. Mimicking the synthesis processes in nature, where highly complex chemical molecules (i.e. peptides, oligosaccharides) are formed, syntheses by highly selective enzymes are to be established. Furthermore, using biocatalysts, an intermediate separation and purification, as is common for classical organic syntheses, because of incompatibility of the reaction steps, in general is not needed. The kinetics of multiple reactions can be reduced to combinations of two primary reactions types: the sequential and the parallel reaction pathway. The analysis of the reaction kinetics and the establishment of simulation models are important steps for the optimization of such reaction sequences. In summary, the use of reaction sequences offers the possibility to produce complex molecules from simple building blocks under mild conditions with high selectivity.

ONLINE ANALYTICS

The implementation of online process analytics is of great importance for fast reaction monitoring. Using spectroscopic methods, an effective and fast control of bioprocesses can be realized. Productivity, product quality and process stability are increased improving the ecologic and economic process management.



The application of online analysis tools additionally offers the possibility to monitor multicomponent systems *in situ*, which are even difficult to analyze with offline methods. Here spectroscopic methods have a great potential in view of online process analytics due to the large amount of data which can be obtained at different wave lengths. Wherein the information about the structure of molecules rises with increasing wavelength. By building a chemometric model, based on multivariate statistics, it is possible to monitor the concentration of multiple compounds in a reactor simultaneously advantageous for process control. Next to FT-IR spectroscopy, online fluorescence spectroscopy and online Ultra-Violet (UV) spectroscopy are applied for the analysis of biocatalytic reactions in solvents and solvent free systems.

TECHNICAL BIOCATALYSIS (PROF. DR. ANDREAS LIESE)

The establishment and implementation of industrial relevant bioprocesses in novel process windows, meaning non-conventional reaction conditions is promising. New processes and technologies are developed in collaboration with different research groups and companies. Currently, in technical symmetric as well as asymmetric synthesis, different biological principles are already being applied and where reaction engineering has additionally been integrated, very efficient production processes have been designed. This gives rise to high expectations for the future of a sustainable, technical (asymmetric) catalysis. The challenge is to understand selected biological principles, as well as processes in chemical terms, to transfer, apply them to and combine them with the traditional concepts of chemical catalysis, i.e., homogeneous catalysis. Simultaneously, the aim is to design and to develop novel reactors, i.e., engineered systems based on these biological principles. Process intensification is gained by addressing the catalytic system (considering enzyme activity, stability and selectivity), kinetics, as well as thermodynamics and process development (considering reactor type, enzyme recovery system and appropriate downstream processing) in an integrated way. The main research field of the Technical Biocatalysis group covers technical and fundamental aspects of the application of biocatalysts in industrially relevant biotransformations.

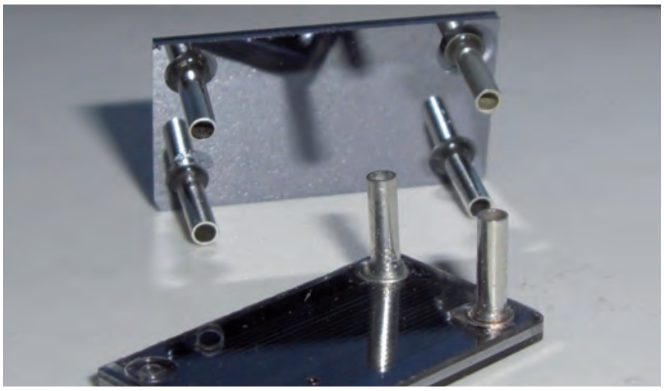
RESEARCH FIELDS

We implement non-conventional biotransformations, develop novel bioprocesses and on-line analytics of reactions. In the field of non-conventional biotransformations, we focus on solvent free biotransformations (e.g. esterification and polymerization), biocatalysis in high viscous media, as well as biocatalysis at high pressures up to 3000 bar. Additionally, biocatalysis is also considered in suspensions. Furthermore, we develop bioprocesses, which involve the progress of new reactor concepts (e.g. bubble column and modular hollow fiber reactor), the immobilization of biocatalysts using new carrier materials, as well as the development of reversible immobilization procedures. For the online reaction analysis in view of control and regulation of biotransformations, three measurement methods are operational: Fourier Transform Infrared Spectroscopy (FT-IR), fluorescence spectroscopy and *in situ* video microscopy.

MICROBIOTECHNOLOGY (DR. LUTZ HILTERHAUS)

In comparison to chemical processes, where heat exchangers as well as temperature and pressure control of the reaction are crucial parts, the key parts of bioprocesses are the biocatalysts, which can be enzymes or whole cells. These biocatalysts exhibit a certain activity and selectivity towards a specific substrate. Both, activity and selectivity regarding a certain reaction, can be characterized by kinetics as well as thermodynamics of the reaction. Apart from parameters like temperature or pH, the solvent also plays an important role for enzyme activity and especially enzyme stability. All this needs to be quantified when setting up a bioprocess. Finally, questions regarding the choice of reactor type, catalyst recovery and downstream processing need to be answered.
This is where micro reaction technology can contribute its promising potentials. Using micro reactors, a downscale of the reaction can be realized. Also, other unit operations, like membrane separation processes as they are often used in

biotechnology, can be characterized on a small scale. Usually, the characterization of each unit operation of a process is done independently, where every single unit operates with its own conditions and limitations ("process window"). However, micro system technology offers the possibility to characterize combinations of unit operations, whereby the process window of the combined systems is restricted by the overlap of the unit operations. Initially, only process windows, which are acceptable for all necessary unit operations, are evaluated. Therefore, this approach can drastically reduce development times, by omitting laborious investigations of conditions which are not applicable within the final process anyway.



RESEARCH FIELDS

We use molecular biological methods for the adaption on enzymes with a focus on immobilization. This immobilization is realized on different carrier materials as well as directly in μ-reactors. Different covalent and reversible immobilization strategies are under investigation. We use μ-reaction technology for multistep enzyme catalysis, as well as chemoenzymatic reaction sequences. The focus is the combination of continuous reactions with downstream processing. Enzyme screening and parameter studies are conducted under process conditions in order to characterize the process chain. We establish rapid analytics by μ-reaction technology for the determination of reaction parameters, as well as enzyme and substrate screening by means of online UV-Vis spectroscopy and online Fourier Transform Infrared Spectroscopy (FT-IR).

BIODEGRADATION (PROF. DR. RUDOLF MÜLLER)

Biodegradation is one of the key processes that occur in nature for the removal of environmental pollutants. In many cases, bioremediation has been used successfully for the cleanup of contaminated sites. Generally, microorganisms are responsible for the degradation of pollutants in the environment. Microorganisms possess a wide variety of enzymes, which are involved in these biodegradations. The understanding of the processes occurring in biodegradation is the key to understanding the environmental fate of chemicals released into the environment and to improve their degradation. For many chemicals the biological degradation pathways are not yet known. For others the degradation is only known under certain conditions. For example, the degradation pathways for the main components of mineral oil are well studied under ambient conditions. However, nothing is known, how the degradation changes, when the spill occurs at low temperatures, like in the accident of the Exxon Valdez of the coast of Alaska or at high temperatures like in the Red Sea during the Gulf War off the coast of Kuwait. Therefore, examine the biodegradation of novel compounds, which are newly synthesized and which may enter the environment. We also examine known pathways under extreme conditions. We identify pathway intermediates and characterize the enzymes involved in the degradation. Finally we are investigating, if we can use our knowledge on biodegradation and enzymes, not only for the solution of environmental problems, but also for the production of novel sustainable products from waste.

RESEARCH FIELDS

This working group focusses on the elucidation of the biodegradation pathways of environmentally problematic compounds. We examine the degradation of mineral oil components at high and low temperatures, and recently also under high pressure as it occurred during the oil spill from the Deep Water Horizon platform in the Gulf of Mexico in 1500 m water depth. Chemicals that were examined, whose degradation pathways were not known before, include several chlorinated hydrocarbons, iodinated x-ray contrast agents, odor compounds from food industries like pyrazines and amines, and the chlorinated artificial sweetener sucralose.
The knowledge gained from biodegradation was used to design a novel process for the enzymatic production of foaming agents from keratin and in a new biotechnological process for the production of high quality bast fibers.

EQUIPMENT

The laboratories of the Institute of Technical Biocatalysis are equipped with all standard tools for organic synthesis. Carried out in batch or continuous mode, including purification and downstream processing. Large assortments of diverse bioreactor systems are available, such as enzyme membrane reactors (EMR), bubble column reactors, mini plant, contifuges, hollow fiber microreactors and further reactor types in different sizes. For the production of enzymes, all equipment such as thermoshakers, centrifuges, protein purification and 2 or 10 L fermenters is available. Moreover, membrane filtration (MF/UF) up to pilot scale and a process controlled high density fermentation exist. The Institute of Technical Biocatalysis has strong capacities in on-line process analytics and process control systems, complemented by chromatographic methods.

ANALYTICS

The Institute of Technical Biocatalysis is equipped with various analytic methods. Four systems for gas chromatography (GC) coupled to different detectors like FID, as well as mass spectrometry (GC-MS), are available for achiral and chiral analysis. Four systems for High Performance Liquid Chromatography (HPLC) using achiral and chiral columns, as well as two systems for gel permeation chromatography (GPC), are operated. Spectroscopy, especially as an online tool, is realized by means of different FT-IR spectroscopy and fluorescence spectroscopy. Finally, the electronic nose and oxygen sensors (optodes/electrodes) are established.

TEACHING

Our institute takes part in different educational programs: Several B. Sc. and M. Sc. programs in chemical engineering, general engineering science and bioprocess engineering, the education of biological technical assistances (BTA) and chemical technical assistances (CTA). Courses are offered in fundamentals of bioprocess engineering, technical biocatalysis, biochemistry, biocatalysis and enzyme technology, as well as advanced study topics.

KINDERFORSCHER

KINDERFORSCHER AN DER TUHH

The children of today are the engineers of tomorrow: The Institute of Technical Biocatalysis runs the unique "Kinderforscher" programs. School children, together with their teachers, are motivated for science and technology in especially designed teaching units. Pupils have the possibility to carry out experiments in the labs of the TUHH.

For detailed information check www.kinderforscher.de

SERVICE FOR INDUSTRIAL PARTNERS

The Institute of Technical Biocatalysis offers a wide range of possible services for industrial partners. The conduction of kinetic and thermodynamic analysis, as well as the mathematical simulation of processes and biotransformations are central services offered. Feasibility studies are a further one. In addition, the optimization of biotransformations is carried out in close cooperation with and considering the general requirements given by the industrial partner. The development of novel process and production of novel bioproducts can be done. Moreover, the Institute of Technical Biocatalysis offers the possibility to carry out biosynthesis of g up to kg scale. Biodegradability tests and advisory service in microbial contamination problems are offered. Last but not least, the institute functions as a consultant in the research field of biocatalysis.

DIRECTION OF THE INSTITUTE

Prof. Dr. Andreas Liese (Head of the Institute)

Prof. Dr. Rudolf Müller

Dr. Lutz Hilterhaus

STAFF

• **Senior Scientist** Dr. Boris Galunsky • **Technical Staff** Maren Breuer, Uta Neafken, Thi Lien Tieu-Schröder • **Team Assistances** Ulrike Zimmermann, Miranda Liephout • **Post Docs** Dr. André Rieks, Dr. Daniel Sellin, Dr. Ana Gabriela Valladares Juárez • **PhD Students** Jan-Christoph Antony, Sören Baum, Jan Brummund, Jose Luis Garcia, Jakob Gebhard, Katharina Götz, Bastian Kannengiesser, Dennis Kaufhold, Martin Kisch, Britta Lämmerhirt, Getachew Shibabaw Molla, Janosch Fagaschewski, Jan Simons

RESEARCH CENTER

Integrated Biotechnology and Process Engineering

V-7

TECHNICAL MICROBIOLOGY

The Institute of Technical Microbiology lead by Prof. Garabed Antranikian is renown for its research in the field of extremophilic microorganisms. These fascinating organisms are able to withstand and to thrive at temperatures between -10 and 122°C, at pH values between 0 and 10, or at salt concentrations up to 30 %. Studying the features enabling life under these conditions and using these organisms for application in industrial biotechnology is the focus of our research.

The institute is located on the campus of Hamburg University of Technology only a 20 minutes train ride to down-town Hamburg. Since its foundation in 1990 over 90 students conducted their bachelor, master and Ph.D. thesis under the supervision of Prof. Antranikian. Currently, over 20 researchers, graduate students and technical assistants are working in modern laboratories set up in January 2001 equipped with the most advanced technologies needed for modern biotechnology.

RESEARCH AND APPLICATION

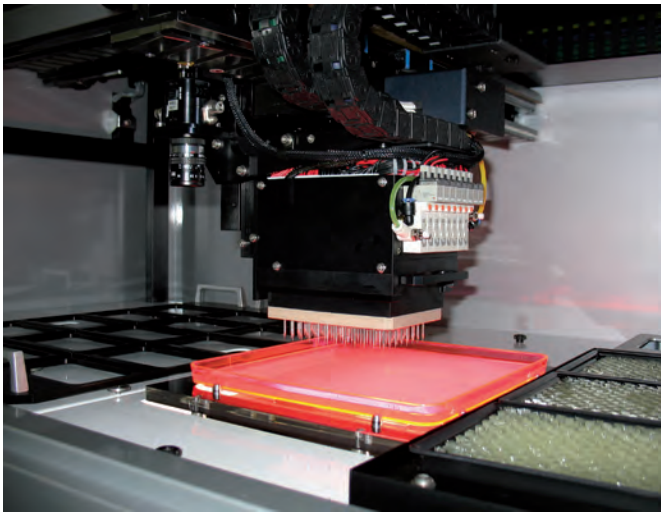
In times when global challenges like finite fossil energy reserves, demographic changes, environmental pollution and climate change demand innovative solutions and substantial structural changes from an oil-based to a bio-based industrial production, biocatalysis is one of the key technologies helping to take responsibility for the future supply of food, sustainable raw materials and energy. Improving this technology by applying extremophilic microorganisms and their cellular components is the focus of our research. Compared to mesophilic organisms, extremophiles have several specific advantages for application in industrial biotechnology. Due to their high ability to tolerate environmental changes such as fluctuations in pH and temperature they are robust towards extreme operating conditions tolerating e. g. high temperature process technologies. Increased process temperature offers advantages like better substrate solubility, higher mass-transfer rates, and a lower risk of microbial contamination. In addition, thermostable enzymes have a significantly improved half life compared to their mesophilic counterparts at moderate reaction temperatures leading to economic benefits through extended usability.

Based on classic cultivation-based methods combined with metagenomic and genomic approaches we unlock the natural wealth of microbial life and their biocatalysts for research and application in food, pharmaceutical, chemical, and textile industry as well as in biorefinery. Furthermore, we are optimizing enzymes by molecular and synthetic biology and work on improving production of recombinant enzymes by high-cell-density fermentation.

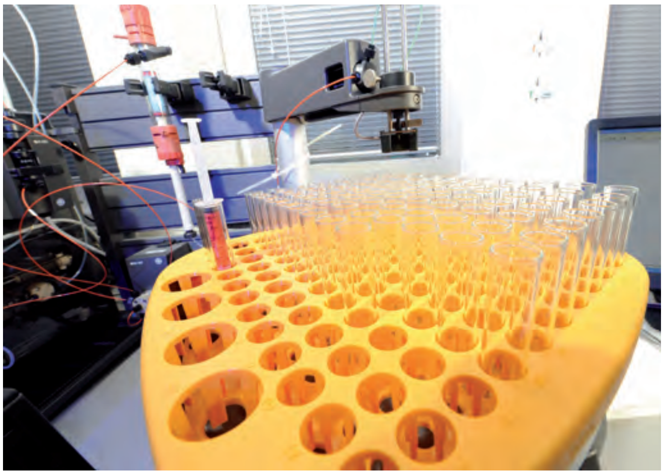
- **EXTREMOPHILIC MICROORGANISMS**
  - Isolation, characterization and phylogenetic affiliation of extremophilic bacteria and archaea: psychrophiles, (hyper-) thermophiles, thermoalkaliphiles, thermoacidophiles and halophiles
  - Cultivation of aerobic and anaerobic microorganisms, physiological studies, metabolism of polymeric natural compounds (e. g. lignocellulose, lipids, pectin, keratin)
  - Population dynamics in natural and man-made habitats

- **EXTREMOZYMES**
  - Screening, purification and biochemical characterization of biocatalysts and bioactive substances from extremophilic microorganisms like hydrolases, oxidoreductases, DNA-modifying enzymes, compatible solutes etc.
  - Molecular cloning and (over-)expression of genes encoding biocatalysts from extremophiles
  - Optimization of enzymes/synthetic biology
  - Enzyme production using high-cell-density fermentation

- **HIGH THROUGHPUT SCREENING**
  - HT-screening using picking and pipetting robots
  - Genome mining



- **APPLICATION**
  - Development and optimization of biocatalysts for sustainable biotechnological applications and environmentally friendly processes in the field of white biotechnology
    - Biotransformation
    - Second generation biorefinery
    - Biosensors
    - Industrial waste water treatment

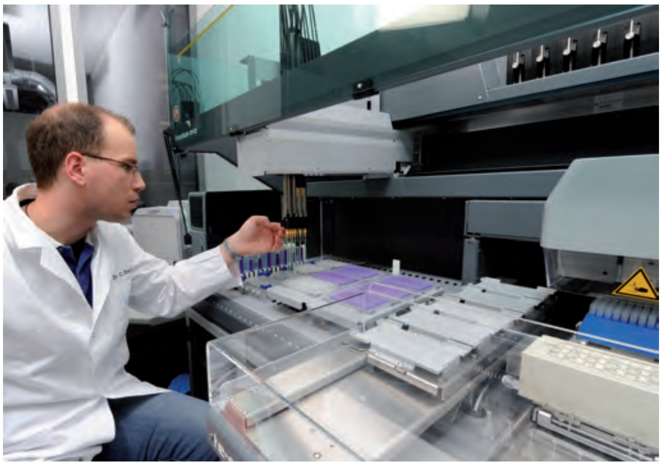


BIOCATALYSIS – SUSTAINABLE BIOCATALYSIS OPENING NEW PATHS

Based on several interdisciplinary research cooperations with national and international partners from industry and academia the Institute of Technical Microbiology is pursuing the goal of systematically investigating the enormous potential of biocatalysts from microorganisms for their possible application in industry. Primary goal is the use of new biocatalysts achieving novel synthetic effects by subjecting them to unconventional conditions (extreme temperatures, pressures, pH values, concentrations of salt and solvents). The enzyme systems are to be used both as final products and in subsequent processes for the production of fine chemicals and active agents.

In the course of achieving this aim Prof. Antranikian initiated the Cluster BIOCATALYSIS2021, supported by the *German Federal Ministry of Education and Research (BMBF)*. The Cluster combines the unique expert knowledge of the academic sector in five Federal States of Northern Germany with the economic and innovative power of globally operating companies throughout the Federal Republic of Germany.

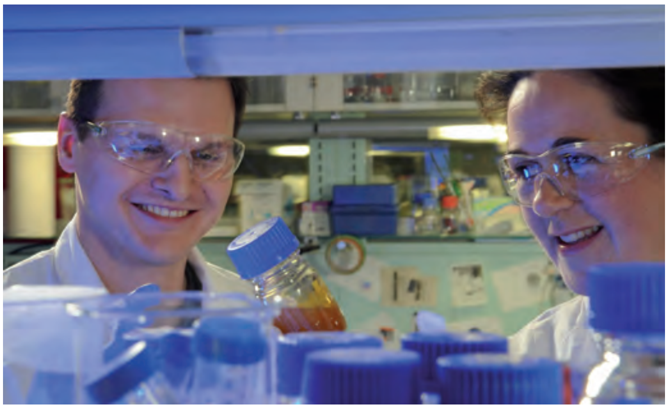
To provide a platform for intensive exchange of know-how and cutting-edge research the Institute of Technical Microbiology has been organizing the biannual Biocat conference series since 2002 at Hamburg University of Technology *(http://biocatconference.de)*. Until now the International Congresses on Biocatalysis attracted more than 2000 participants from industry and academia from over 35 countries.



BIOREFINERY

Due to the fact that fossil resources are limited, lignocellulose is considered to be an attractive alternative resource for the production of energy, fine chemicals, pharmaceuticals, and biopolymers in an approach called second-generation biorefinery. However, costs for biorefineries still exceed those of classic oil-based refineries, with one of the major bottlenecks being the conversion of complex carbohydrates into fermentable sugars. The search for suitable enzymes to degrade lignocellulytic raw material is a major factor towards a commercially viable, industrial process. Thermoactive and thermostable enzymes are of particular interest, because the process requires enzymes, which are operationally stable at high temperatures.

With industrial and academic partners from all relevant fields required to develop the biorefinery of the future the Institute of Technical Microbiology searches and optimizes enzymes using classic and synthetic biology to fulfill the specific needs of lignocellulose-based biorefinery.



EQUIPMENT

The laboratory is well equipped with microbiological devices for aerobic and anaerobic cultivation, including 5 fermenters ranging from 2-L to 300-L pilot scale, glove box and clean bench. In addition to standard molecular biology equipment the institute has high-throughput screening facilities such as a liquid-handling robot (Tecan) and a picking robot (Genetix). For protein purification two Äkta systems (GE Healthcare) are available. Analytics can be done using HPLC and GC. A DGGE-D code system (Biorad) and a fluorescent microscope (Zeiss) equipped with a digital imgaing system can also be used.

TEACHING

The institute is involved in German and international master programmes for bioprocess, environmental and general engineering offering courses in basic and and applied microbiology, genetics, bioprocess engineering as well as advanced study topics. Furthermore, we take part in an education program for technicians in biology (BTA).

SERVICE FOR INDUSTRIAL PARTNERS

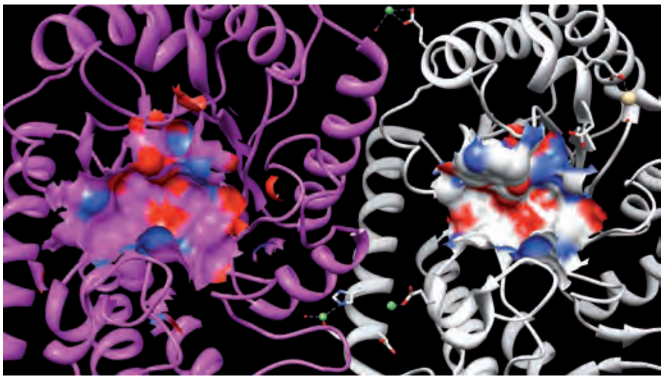
The Institute of Technical Microbiology holds an extensive collection of microorganisms and enzymes, ready to be screened for specific applications. Supported by the Deutsche Bundesstiftung Umwelt (DBU) the BicoatCollection has been set up in 2007 and aims at making biodiversity available to academia and industry (http://www.biocatcollection.net/cms/). The activities of the BiocatCollection comprise:

- A comprehensive collection of enzymes and enzyme kits
- Internet-based information on enzymes
- Service offers in the field of applied enzymology

By offering a complete and professional service portfolio around the application of biocatalysts, the BiocatCollection helps to find solutions for existing problems and for novel enzyme-based processes.

In addition the Institute of Technical Microbiology offers high-throughput screening (HTS) for rapid identification of microorganisms or genes of interest. Screening assays compatible with HTS can be developed and thousands of microorganisms can be screened a day in 96-well plates using a colony-picking robot processing up to 4,600 colonies per hour, and a liquid-handling robot to analyze the picked clones.

Our fermentation expertise allows anaerobic and aerobic high-cell-density fermentations in volumes of up to 300 L.



DIRECTION OF THE INSTITUTE

Prof. Dr. Dr. h.c. Garabed Antranikian

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RESEARCH CENTER

Integrated Biotechnology and Process Engineering

Thermische Verfahrenstechnik

V-8

THERMAL AND SEPARATION PROCESSES

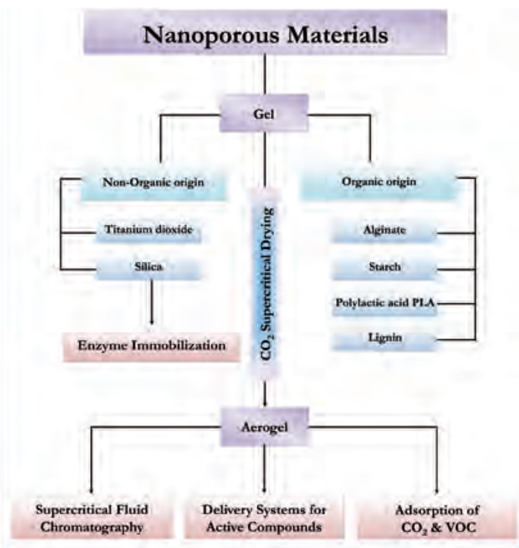
The institute Thermal Separation Processes consists of two scientific groups headed by Prof. Irina Smirnova (head of the institute) and Prof. Rudolf Eggers. The research interests of Prof. Smirnova's group are focused on the application of the methods of classical thermodynamics and unit operations in life sciences. The purpose is especially to describe the transport and/or partitioning of active agents in complex bio-relevant objects. Both classical and innovative unit operations such as supercritical and micellar extraction, adsorption, crystallization, and chromatography are implemented in the production of pharmaceutical formulations or downstream processes in biotechnology. The Group Heat and Mass Transfer led by Prof. Eggers concentrates on Energy and Process Engineering, Interface Phenomena, High Pressure Chemical Engineering and Food Technology.

GROUP OF PROF. SMIRNOVA

NANOPOROUS MATERIALS

- **AIM: THE PREPARATION OF NANOPOROUS MATERIALS, TAILORED FOR DIFFERENT APPLICATIONS.**

Two main approaches: sol-gel process and supercritical extraction are involved. The overview of the materials and applications under study are given below:



The main issue is the possibility to produce a stable gel from the precursor used. For some research area (enzyme immobilization), the resulting wet gel is directly used. Other applications need the dry materials. In this case, supercritical extraction (drying) is applied. Supercritical drying enables the replacement of the gel inter-porous solvent with air without destroying the inner 3D-network structure.

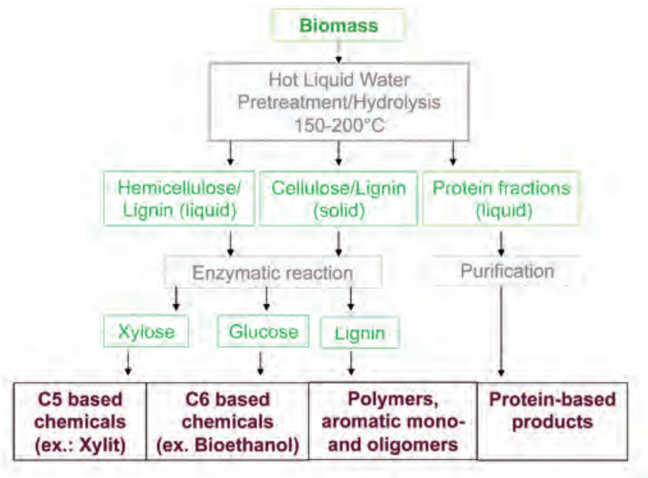
Material produced by supercritical extraction is called aerogel. It is a nanoporous material with an open pore structure and high porosity. Holding 15 entries in Guinness book of properties, aerogels are unique materials with a high potential for many challenging problems. A number of scientific groups have investigated applications of aerogels in space engineering, as thermal insulation materials, solar-energy collectors, Cherenkov detector, waste treatment systems, drug delivery and targeting systems and many others. In our group, gels and aerogels are produced from different precursors: organic (starch, alginate, polylactic acid, lignin, etc) and inorganic (silica, titanium dioxide).

BIOREFINERY

- **AIM: ADDED VALUE IN BIOREFINERY PROCESSES BY MEANS OF INTEGRATED SUPERCRITICAL EXTRACTION, PRESSURIZED HOT WATER AND ENZYME TECHNOLOGY**

As the petrol era is facing its end, new resources for base chemicals, polymers and energy production need to be explored. Therefore the bioconversion of biomass to high value products such as fine chemicals and biofuels attracts the interest of scientists from academia and industry. Established processes are mainly based on the utilisation of starchy substrates, leaving lignocellulose, the largest constituent of biomass resources, unused. Lignocellulosic biomass consists mainly of cellulose, hemicellulose and lignin followed by proteins and lipids.

Our motivation is to isolate these compounds or compound mixtures from natural source, and to convert these into platform materials like glucose. Those materials can be introduced into a sustainable production of scale for almost all needs in life science, energy and polymer producing technologies. These processes are contained in the term "biorefinery". Sequential isolation and possible use of the single fractions can be summarized as follows:



Processes: Liquid Hot Water (LHW) pre-treatment and fractionation of biomass as well as conversion of certain fractions.

Recent Work

- Optimization and technical realization of LHW pre-treatment of lignocellulosic biomass
- Combination of thermal and enzymatic hydrolysis
- Influence of pressure on enzymatic hydrolysis: Thermodynamic considerations.
- Fractionation and valorisation of proteins
- Production of nanoporous polymers from lignin

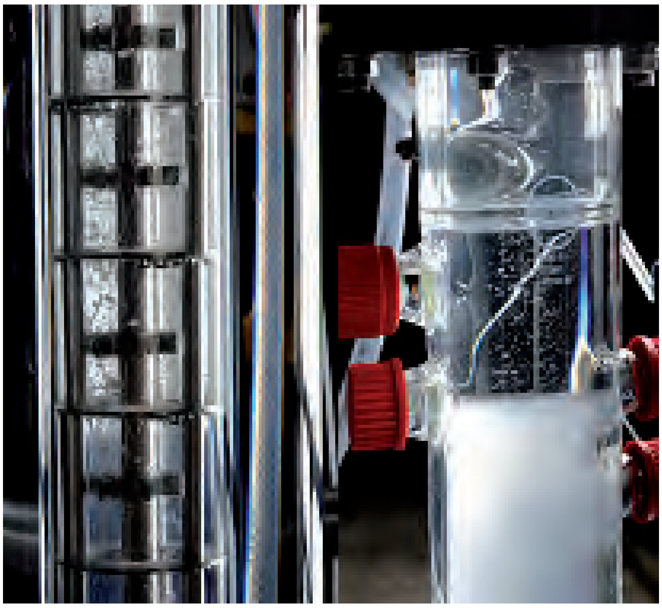
Service: Lignocellulose hydrolysis, lignin production

SURFACTANT BASED SEPARATION PROCESSES

- **AIM: INNOVATIVE SURFACTANT BASED SEPARATION PROCESSES FOR COMPLEX MIXTURES.**

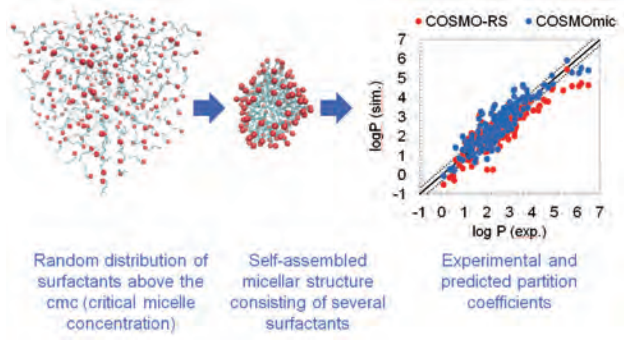
Novel separation processes require non-volatile, stable and cheap solvents with high selectivity and capacity. Micellar systems can easily meet these criteria and are applied in reaction engineering, environmental technology and in the area of pharmaceuticals to solubilize hydrophobic catalysts in aqueous solutions, to separate pollutants and can be used to estimate the partitioning of active substances in physiological systems. The environmental compatibility of many surfactants, as well as their good availability and their high selectivity and capacity highlights the potential of surfactants for thermal separation processes.

Beside the selection of appropriate surfactants for a given system, parameters like temperature, pressure, pH and additives like alcohols and salts have a significant influence on the phase behavior of micellar solutions. A fundamental prerequisite for the establishment of surfactant based separation processes is the precise knowledge of the phase behavior of these systems. Our group determines partition equilibria as well as LLEs by means of micellar enhanced ultrafiltration and the micellar liquid chromatography. Based on these experiments a continuous surfactant based extraction process is established.



Lab scale counter current separation column for surfactant based separation processes

In addition to our experimental work we apply and extend the thermodynamic model COSMO-RS and combine it with MD simulations. Based on the molecular structures partition equilibria in complex mixtures can be predicted a priori. COSMO-RS is an established model to predict partition equilibria in simple systems. Our group evaluates and extends the applicability of COSMO-RS for complex mixtures containing electrolytes. Furthermore we intend to use the model COSMO-RS in order to predict thermodynamic properties of macromolecules like proteins.



Prediction of partition coefficients in micellar system with COSMO-RS, based on the MD simulations of the micellar aggregates

GROUP OF PROF. RUDOLF EGGERS
TRANSPORT DATA IN HIGH PRESSURE PROCESSES

- **AIM: MASS TRANSPORT OF COMPRESSED GASES IN CONTACTING FLUID OR SOLID PHASES AT HIGH PRESSURES**

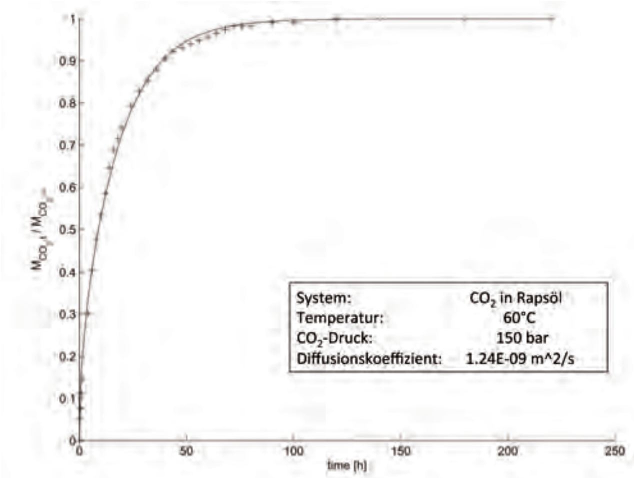
Based on high diffusivity of dissolved components in supercritical fluids one might face the question, if and to what extent the diffusion of compressed gases occurs in contacting, fluid or solid phases in high pressure processes.

In high pressure spray processes for extracting high value components, carbon dioxide as a frequently used solvent dissolves in the droplet phase and changes its viscosity as well as the droplet-size-determining interfacial tension. In refrigerant circuits operated with the natural cooling medium carbon dioxide the fluid dissolves in the lubricating oil of the reciprocating compressor and performs a viscosity decreasing impact. At the same time, carbon dioxide can diffuse into polymer seals under high pressure, where swelling processes can be initiated, which lead to adverse effects on the seals. Another field is high pressure pipelines, whose walls have to be built up of diffusion resistant polymer material. Process intensification in gas-supported processes can be achieved by means of displacement and dissolution of compressed gases at oil production.

The basic question for all processes in common is the diffusivity of the fluid gas or gas mixtures at high pressure.

Experimentally, diffusion coefficients of compressed gases in fluids and solids are determined gravimetrically and optically in high pressure magnetic suspensions and high pressure view cells. The diffusion is measured in specimen of simple geometry (flat plate, cylinder, sphere). As a peculiar challenge, possible changes of the specific volume of the specimen can occur during diffusion by swelling and expanding processes. In these cases, concentration dependent diffusion coefficients are reached. These coefficients increase with proceeding dissolution by decrease of viscosity.

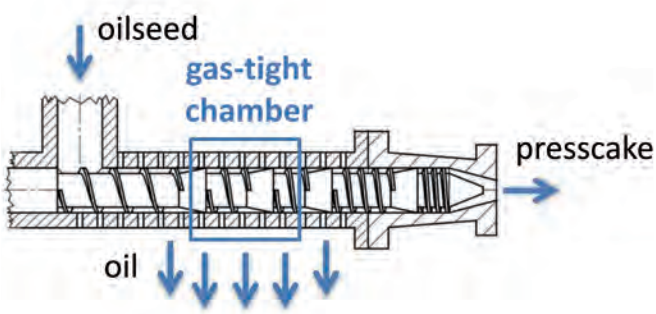
The knowledge of diffusion coefficients improves the possibilities of designing the mentioned high pressure processes.

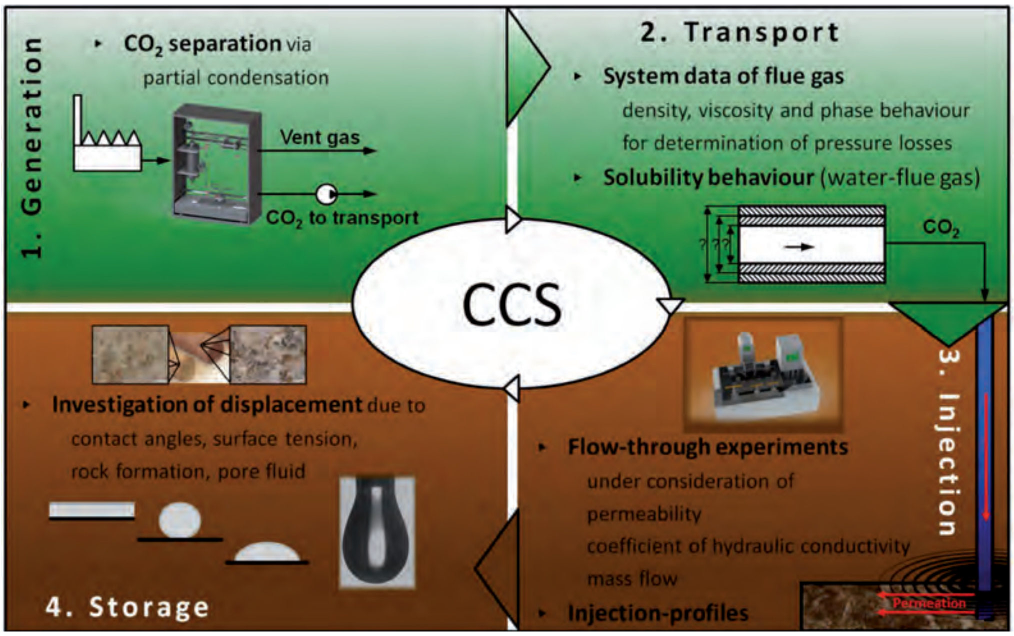


GAS ASSISTED PROCESSES

- **AIM: OILSEED PRESSING PROCESS INTENSIFICATION**

Gas assisted pressing (GAP) of oilseeds is a solid-liquid separation procedure using the assistance of supercritical CO2 to enhance efficiency of oilseed pressing processes. In the recent past the use of solvent-free produced rapeseed oils acquired an increased interest, while its press cake is used as high value feedstuff. Therefore, the technology of gas assisted pressing is applied for oil yield and product quality enhancement e.g. in rapeseed or soybean pressing. The industrial GAP-process is performed in modified cage screw presses. GAP benefits from the solubility of the assisting gas CO2 into the oil first of all by affecting physical oil properties leading to an easier drainage.



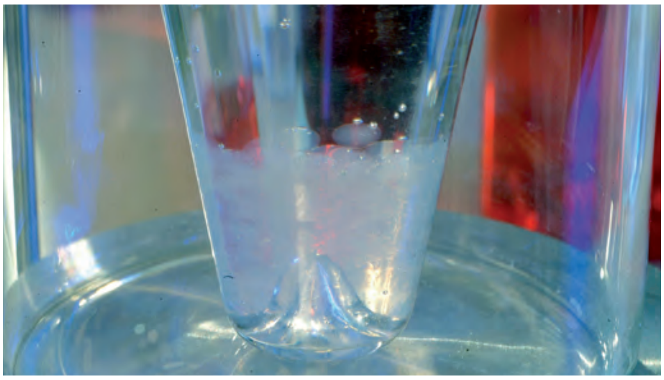


CARBON CAPTURE AND STORAGE

- **AIM: DETERMINATION OF BASIC SYSTEM DATA FOR CO2 SEPARATION, PIPELINE TRANSPORT, INJECTION AND STORAGE**

For the designing and processing of Carbon Dioxide Capture and Storage (CCS)-Technologies several chemical data of the flue gas components has to be known.

In the first step the flue gas has to be dried to avoid ice and hydrate formation during the cryogenic separation. Therefore adsorption isotherms under elevated pressures are determined. Further on heat transfer coefficients for partial condensation of carbon dioxide from flue gases are investigated. For pipeline transport system data as density and viscosity have an important action. If free water appears the solubility behaviour, water-flue gas, is necessary, too. The injection is influenced by the system data and the chosen rock formation, by permeability and its free porosity and by coefficient of hydraulic conductivity. Storage capacities vary with interfacial tensions, densities and wetting behaviour dependant on the present temperature and pressure conditions.



DIRECTION OF THE INSTITUTE

Prof. Dr.-Ing. Irina Smirnova (Head of the Institute)

Prof. Dr.-Ing. Rudolf Eggers

STAFF

• 2 Professors • 3 Post Docs • 21 Scientific Staff
• 5 Technical Staff

RESEARCH CENTERS

Integrated Biotechnology and Process Engineering
Climate Protecting Energy- and Environmental Engineering

IUE

V-9

ENVIRONMENTAL TECHNOLOGY AND ENERGY ECONOMICS

The Institute of Environmental Technology and Energy Economics (IUE) deals with questions related to technical, environmental and economic aspects of energy and industrial systems. There is a clear focus on renewable sources of energy. The overall goal of all these activities is a better understanding of the technical, economic and environmental factors determining these systems and how they can be optimised on the background of realising more sustainable systems. To realise these targets flow sheet and other models are developed, new assessment methods based e.g. on the overall life cycle are compiled, lab experiments and highly sensitive measurements are carried out, on-site surveys e.g. at existing semi-commercial and commercial plants are realised and approaches to assess specific sustainability criteria are developed.

RESEARCH AND APPLICATION

Activities of the Institute include among others the generation of solid, liquid and gaseous fuels, the recovery of electricity and heat out of biomass using thermo-chemical, physico-chemical and bio-chemical conversion processes, the geothermal generation of electricity and heat, the electricity generation from wind energy and renewable energies in conventional energy systems. Additionally, chemical and electro-chemical procedures are developed for pollutant immobilization in contaminated soils and sediments and for pollutant extraction from industrial wastewater. Technology validation is applied to biomass incineration by eco-toxicological testing of fine dust. Beside this, in the field of resource management procedures are developed for the reclamation of rare earth elements from electronic scrap, for methane and hydrogen generation from municipal bio-resources and for the production and utilization of algae biomass. Projects on landfill sites aim at concepts to control methane emissions and to aerobically stabilize sanitary landfills in situ. Within the following explanations some examples of topics investigated within IUE are explained in more detail.

Identifying and quantifying energy demands on a high spatial distribution
The energy demands of towns, districts and states are modeled to identify dependencies and to analyze controlling measures, in view of renewable energy sources and alternating framework requirements. Part of this energy demand can be covered by geothermal energy (e.g. low temperature heat). Thus the goal is to identify the share of the heat demands which can be covered by geothermal heat taking into consideration that geothermal heat is only available at certain areas in Germany and can only be provided under economic aspects with the help of a district heating system. The aim of one ongoing project is to identify the demand potential of geothermal energy in Germany on a high regional distribution.

BIOMASS INVENTORY ASSESSMENT

Concepts are developed for the optimal recovery of available biomass relating to technical and economic efficiency at minimum environmental impact. The aim is to analyze and assess the possibilities and constraints of the biomass for energy production from the resource side on current and future trends in various countries (e.g. Germany, Mexico). For example, first results show that biomass for energy production may account to almost 50 % of Mexico´s final energy consumption in 2010, but this potential may be decreasing in the next decades due to an increasing competition with food production and the expected deforestation. Therefore, opportunities and threats to integrate sustainable biomass for energy production into the current and future energy system are analyzed in detail. Another example is Germany. Here a potential equivalent to 10 to 15 % of the entire primary energy consumption has been identified. To learn more about these potentials to exploit them in a sustainable way the amount, the precise location, the seasonal occurrence, quality and composition as well as physical, biological and chemical parameters need to be known. This usually requires an extensive data acquisition and processing. Therefore a system is currently under development, which enables users to determine parameters relevant for the identification, collection and utilisation of bio-resources without the need to perform time consuming data acquisition. The system is based on GIS (geographic information system) in which the bio-resources data are determined by using area dependent input values.

BIOENERGY MARKETS UND BIOENERGY USE

Energy production from bio-resources is mainly based on energy crops (like wood plantations), agricultural waste or waste wood. Additionally other sources like organic waste and waste water from urban areas offer a certain potential. But there are often no reliable records on the origin and/or the amount of biomass collected and utilised especially in developing countries. Therefore, methods and procedures are developed and applied for certain countries (e.g. Sudan, Paraguay) to assess the bioenergy use as well as the biofuel markets. Based on these data the driving factors of the markets will be analysed and assessed with respect to the locally given sustainability criteria. The goal is to develop proposals for political measures to transform the local and national bioenergy market towards a more sustainable system which is a hot topic in lots of developing countries.

BIOMASS FOR PELLET PRODUCTION

In recent years pellet boilers have been increasingly used as domestic wood furnaces. Pellets are normally made of wood residues, so their price depends on the availability of e.g. saw dust. But there is a shortage foreseeable due to the significant market expansion. For this reason, other types of biomass like straw from cereal production are considered as raw material for pellet production. But straw is difficult to pelletize due to its low lignin content, its fibrous structure and waxy plant cuticula. Compared to wood pellets, straw pellets show an inferior abrasive strength and a lower bulk and particle density. In addition, straw pellets have compared to wood less promising thermo-chemical properties concerning ash content, sintering and dust emissions due to a high potassium, sulfur and chlorine content. Thus the goal of these activities is to identify and assess mixtures of wood and straw fulfilling the fuel demands of existing boilers. For this reason pelletizing experiments with wood-straw mixtures are carried out to improve and optimize the properties of pellets. Additionally combustion related properties can be modified by the addition of certain additives. For example sintering and slagging of ash of such mixtures can be prevented by use of Ca- or Al-containing additives. The challenge is to find an optimum between mechanical-physical and thermo-chemical properties to successfully produce pellets, which meet the technical standard concerning abrasion, water content and ash melting temperature.

MODELING OFFSHORE WIND FARMS' OPERATIONAL PHASE

The cost-efficient maintenance of the offshore windparks currently under development is a challenging optimization task due to the weather conditions and the various other influencing parameters. Thus, a model is developed for cost effective maintenance strategies and to assess their overall costs. Therefore factors like reliability and accessibility of turbines, site and weather conditions, maintenance demands for different types of wind mills, personnel, transportation, spare parts and their coherence are taken into consideration. The challenge is to find an appropriate methodological approach to allow for a realistic modeling as well as for a subsequent optimization of such problems taking the varying weather conditions and the limited reliability of the existing weather forecasts into consideration.

ELECTROMOBILITY IN COMPARISON TO OTHER OPTIONS FOR INLAND TRANSPORTATION

Energy supply for transportation causes a major part of the anthropogenic greenhouse gas emissions responsible for climate change. Therefore, several governments have introduced measures to promote electric drive trains or biofuels based on agricultural feedstock in order to decrease greenhouse gas emissions and to reduce the import dependency on oil. Future perspectives might be the application of hydrogen in fuel cells or second-generation biofuels derived from lignocellulose biomass in order to reduce pressure on agricultural land. Against this background, the alternative drive trains and mobility concepts

- electric cars
- fuel cell vehicles and
- cars driven with biofuels

are investigated in order to allow for a fair comparison with respect to efficiency, environmental aspects and economics. Therefore, always the whole life cycle of the cars and transportation devices are investigated, including construction and disposal of vehicles as well as the whole pre-chain of energy supply for the different fuels: electricity, hydrogen, and biofuels. The objective is to identify efficient and sustainable applications of alternative mobility options that complement or replace fossil based energy carriers in the mobility sector.

HYDROGEN REFUELLING STATION HAMBURG

In Hamburg the local utility and the department of public transport have cooperated since 2003 regarding hydrogen fuel cell busses and the corresponding infrastructure. A pilot refuelling station has recently been commissioned which is an important step for the development of hydrogen as fuel for public transport. This project covers the installation and operation of a hydrogen refuelling station including production, storage, and distribution. It is planned to produce 350 kg of hydrogen each day. This size marks a new dimension in technical development. Science and industry can now test new components and the whole system under realistic conditions. It is essential for the production and storage of hydrogen that every single component meets the requirements and is compatible to the others. At the moment it is the most advanced system worldwide for traffic supply with hydrogen. It is now possible for the first time to collect and assess data on the capacity, efficiency, durability, life-cycle-cost and CO_2-emissions. Thus an expensive scientific monitoring is carried out including a flow sheet simulation of the refuelling station as well as the overall provision chain, a life cycle analysis for the assessment of the various environmental effects associated with the provision and use of hydrogen as a transportation fuel and an overall economic assessment.

JOINT PROJECT BURNFAIR

From 15 July to 27 December 2011 an Airbus A321 flew eight times per day between Hamburg and Frankfurt where one engine of the aircraft has been fuelled with a 50 % mix of biofuel and kerosene. Due to the lively discussion about biofuel in general and here in particular bio-kerosene not only the technical realization has to be assessed. Also suitable feedstock has been evaluated regarding the availability and the economic feasibility under the overall goal of reducing CO_2-emissions without damaging the local ecosystems. As a second step the conversion process from biomass to bio-kerosene has to be optimized also regarding the technical requirements, the economic feasibility and the greenhouse gas emissions. Goal of this project is it to identify and assess according to technical, economic and environmental aspects such promising provision routes for bio-kerosene fulfilling the valid sustainability criteria issued by the European Commission and demanded by various NOG's.

CONTAMINATED SEDIMENTS

Management of contaminated sediments is a key issue in order to establish a sound development of the Baltic Sea and contributing to the EU Strategy for the Baltic Sea Region (EUSBSR). This issue is addressed by the project SMOCS (www.smocs.eu). The main delivery of SMOCS comprises a guideline, including tools for assessment of sustainability, and decision support. The general aim is it to incorporate sustainability into a management guideline for contaminated sediments in the Baltic Sea. In order to do this we aim for a shared interpretation of the sustainability concept in the Baltic Sea region. Furthermore, for a more realistic risk assessment of sediments, bioassays are taken into account in a tiered approach which is described in a technical guidance document for deriving environmental quality. The project provides a forum for discussion between scientists, practitioners and legislators, with the objective to compare the scientific progress and the possibilities of implementation into legislation and to find a consensus on a concept on how sustainability should be incorporated into a guideline.

RECYCLING OF PHOSPHOROUS

Currently the phosphate demand is covered by natural mineral deposits, which are limited and expected to be exhausted within a couple of years. In order to cut down on these natural resources phosphorus should be retrieved from wastewater and wastewater sludge. A promising method is its precipitation as struvite. This mineral consists of equimolar amounts of magnesium, ammonium and phosphate. Because of its low solubility under neutral conditions it is an effective fertilizer with repository effect. Relative to ammonium and phosphate the concentration of magnesium in wastewater is small, so it needs to be added to activate struvite precipitation. Magnesium salts are expensive. Therefore, a seawater nanofiltration concentrate from desalination plants is used as a cheap magnesium source. However, calcium as an accompanying ion promotes the precipitation of calcium phosphate with less favorable properties. Measures are devised to suppress the formation of this phase. In wastewater the formation of struvite is also challenging because of low phosphate concentration and phosphorous being present in organically bound forms.

RECYCLING OF RARE EARTH METALS

Europe as one of the world's largest consumers of rare earths needs techniques to recycle e.g. neodymium as supplement and alternative to the intensive exploitation of the respective resources. Neodymium as one example for the whole group of rare earth metals is for example used for the production of the powerful magnets (energy density 200 to 420 kJ/m³). Neodymium-based permanent magnets are used in wind power generators, electrical traction engines for vehicles and for miniaturized components of the information and communication technology. So far, large amounts of neodymium from small electrical appliances like mobile phones or earphones end up in household waste. Magnets in hard disks weigh between 2 and 10 grams. They are coated with alloys of copper, stannic, zinc or nickel for protection against corrosion. The molar composition of the neodymium-rich phase is approximately 26.7 % Neodymium, 1 % Boron and 72.3 % Iron. In total, the content of neodymium in a hard disk magnet is around 15 % by weight. Furthermore, neodymium is used for voice coil motors in hard disks and in spindle drives for CD-drives in computers. In total there is an average potential of up to 4 gr of Neodymium per computer. The sales figures of 2011 in Germany are 13.3 million computers. Therefore a theoretical potential of 52 Mg Neodymium per year can be estimated. The recycling of Neodymium is ecologically meaningful, because its concentration in electronic and electrical devices is usually higher than in mineral deposits. Neodymium is analyzed in magnets of read/write heads of computer drives using X-ray fluorescence analysis and atomic absorption spectroscopy. Techniques are devised for the disassembling and chemical extraction of neodymium bearing components. Most appropriate is the recovery of neodymium as sulfide or oxide. Rare earth metals in dilute extraction liquids are recovered by biosorption using algae. The processes are classified for recovery rate and energy efficiency as well as economic and environmental criteria.

EQUIPMENT

Analysis of liquids
Atomic absorption spectrometry (flame and graphite furnace)
Gas chromatograph-mass spectrometer coupling (GC-MS)
Microwave device for chemical extraction
Accelerated solvent extractor (ASE)
Ion chromatograph
TOC-Analyzer, UV/VIS-Fotometer

Testing facilities
Laboratory lysimeters
Climatic chambers
Anaerobic testing systems
Pellet mill

Biological analytics
RTPCR-Thermocycler
Laboratory fermenter
Steam autoclave
Mikrotiter-plate fotometer and -fluorometer
Clean bench

DIRECTION OF THE INSTITUTE

Prof. Dr.-Ing. Martin Kaltschmitt (Head of the Institute)

Prof. Dr.-Ing. Wolfgang Calmano

Prof. Dr.-Ing. Kerstin Kuchta

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RESEARCH CENTERS

Integrated Biotechnology and Process Engineering
Climate Protecting Energy- and Environmental Engineering

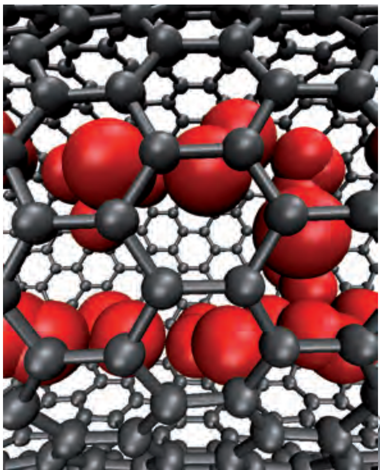
DFG PRIORITY PROGRAMS

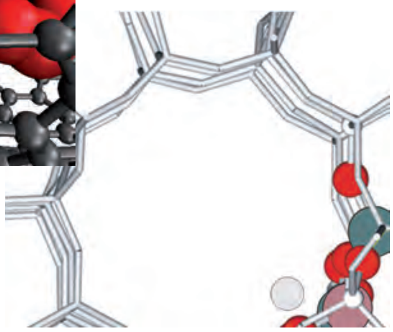
DFG PRIORITY PROGRAM 1570

Porous media with defined porous structure in Chemical Engineering – modeling, applications, synthesis
Coordinator: Prof. Dr. Dr. h.c. Frerich Keil

The present priority program (SPP 1570) has been started in 2011. It is a cooperation of 13 groups from various universities in Germany and abroad. The goal of the priority program is the investigation of recently developed methods of synthesis of porous media with a defined pore structure, augmented by their modeling.

Porous media are ubiquitous in chemical engineering, for example, as catalyst supports, adsorbents, insulation material, membranes or chromatographic columns. From simulations it is well-known that properties of materials may be improved considerably by optimization with respect to given criteria. Not until the last few years, new experimental methods allowed for the targeted synthesis of defined pore structures. Cooperation of chemical engineers and chemists will utilize the new possibilities in chemical engineering.





The optimal porous media for the respective applications shall be developed in close cooperation with chemists who work on the particular problems. In detail the following aims shall be achieved:

- Pore models should be developed, which give insights into processes inside the pores. These models could be network models, inverse pore structures from x-ray data (for example, for amorphous media), or well-defined crystalline structures based on crystallographic data. For particular cases effective pore models may be employed.
- Transport phenomena inside the pores may be described by suitable multicomponent pore models (for example, Stefan-Maxwell equations), heat conductivity equations or molecular approaches (Monte Carlo, Molecular Dynamics, density functional theory (DFT)). Solutions resultant from these simulations are used for the optimization calculations.
- The pore structures should be optimized with respect to particular applications, applying relevant optimization criteria. This will be done by means of modern approaches of convex optimization, genetic algorithms, parallel tempering, etc.
- The optimal pore structures shall be synthesized in close cooperation with chemists.
- The synthesized porous media will be applied for the respective chemical processes.
- New high-resolution imaging processes (Magnetic Resonance Imaging) are to be employed making the liquid distribution inside pores visible, in particular for drying processes and three-phase reactors.
- The synthesized porous media are then to be used for the respective process technology applications, where they should demonstrate their improved properties in experiments. Some applications will only be made economically feasible by new synthesis procedures.
- As overall goal a rational design of pore structures is striven for. Detailed insight into the molecular processes inside the pores, followed by targeted synthesis of optimal pore structures, according to given criteria, should be achieved.

DFG PRIORITY PROGRAM 1679

Dynamic Simulation of Interconnected Solids Processes
Coordinator: Prof. Dr.-Ing. Stefan Heinrich

Conversion process in chemical and energy technology consist in most cases of multiple apparatuses, which are interconnected by streams of mass, energy and/or information. This interconnection influences significantly the operating behavior and especially the dynamics of the whole process. Therefore for design and optimization of such processes, especially with respect to saving of resources and energy, it is not sufficient to simulate the separate units independently, but the whole process should be simulated as an entity. For this purpose flowsheet simulation systems are used frequently in the design and optimization of fluid processes. In contrast, similar systems without restriction to certain applications only are not widely available for solids processes. Main reason for this lack of systems and dynamic models is the complicated and complex description of solids with their multivariate and distributed properties.

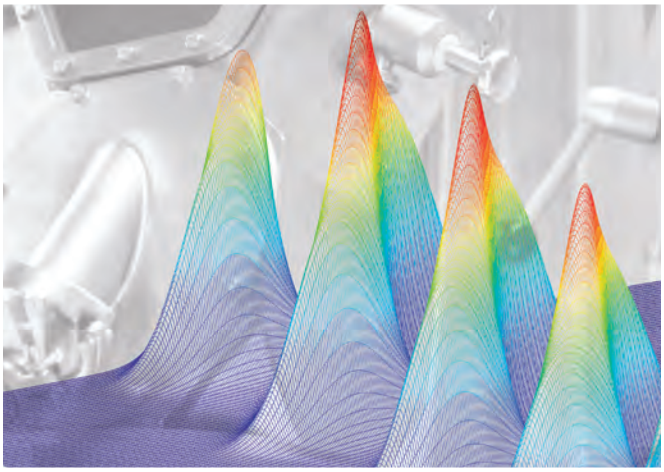
Therefore, it is the general aim of the Priority Program to develop numerical tools for the dynamic simulation of interconnected solids processes. To reach this aim dynamic models of the many different apparatuses and machines for solids processing have to be developed and to be implemented. Required are physically based predictive models, which allow a sufficiently accurate description of the process, have not too high requirements for computing resources and are widely applicable. With respect to the use within a flowsheet simulation framework, they should not be restricted to certain materials or classes of materials. Furthermore, they have to consistently treat the disperse properties of the solids. These distributed properties are not the particle size only, but may also be e.g. the density, composition, shape or porosity of the particles.

Beside the development of new process models also new and extended models for the description of solid materials and particles are needed. These models are required to deduce information about product quality or required product properties as for example the solubility or flowability of powders from the disperse properties calculated by the process models. Furthermore, the material models are required to determine concentrated parameters identified during the model reduction from easy to measure particle properties.

Simulation of solids processes under consideration of distributed properties leads commonly to systems of population balances, in which equations for the conservation of mass and energy are coupled with equations for the description of the population. For the solution of such systems existing solvers for univariate systems shall be improved and be extended to the solution of multivariate population balance systems.

The research work of the Priority Program is divided into three areas:
A – New physically based dynamic models of processing units
B – Material models for solids processes
C – Algorithms and process simulation

Within the Priority Program scientists of different disciplines and from different universities will cooperate. The program is planned for a duration of six years and is financed by the German Research Foundation (DFG).



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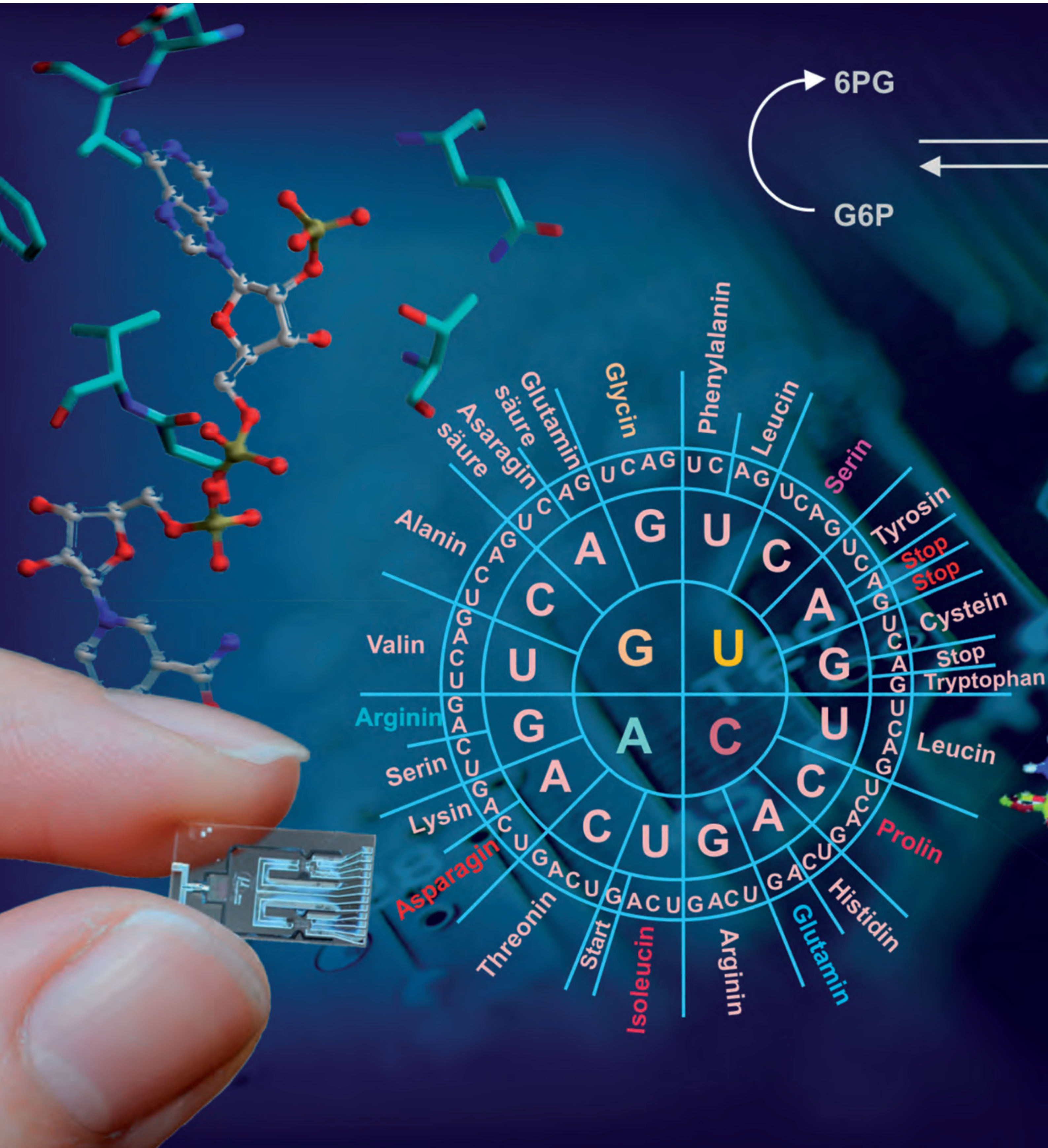

FUNDAMENTALS FOR SYNTHETIC BIOLOGICAL SYSTEMS (SynBio)

Both biology and engineering are entering new areas owing to rapid advances in enabling technologies such as genome sequencing, functional genomics, computation, microfluidics, nanotechnology, systems and synthetic biology.
The cluster SynBio studies biological and technological fundamentals of synthetic biology as an emerging new field. In addition to better understanding natural bioprocesses synthetic biology particularly aims at generating efficient and interchangeable parts by molecular-biological and engineering tools or directly from natural biology by screening and assembling them into technologically artificial but useful biological systems. Synthetic biology has thus a high potential for applications such as targeted synthesis of biopharmaceuticals, sustainable chemical industry and energy generation, and production of smart (bio)materials. Parallels have been drawn between the design and manufacture of semiconductor chips in information and communication technologies (ICTs) and the construction of standardized biological parts (also called biobricks) in synthetic biology. Whereas semiconductor and microelectronics have revolutionized ICTs, it is expected that synthetic biology in combination with microfluidics and nanotechnology has similar impacts for biotechnology and life sciences in the near future.
The structural and scientific objectives of SynBio are to establish an interdisciplinary and excellent research cluster in Hamburg with focus on studying fundamentals for developing novel synthetic biocatalytic pathways and systems with applications in biotechnology and life sciences.

Coordinators

Prof. Dr. rer. nat. habil. An-Ping Zeng

Prof. Dr. Dr. h.c. Garabed Antranikian

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Participating Institutes
TUHH • Institute of Bioprocess and Biochemical Engineering • Institute of Technical Microbiology • Institute of Thermo-Fluid Dynamics • Institute of Technical Biocatalysis • Institute of Microsystems Technology • Institute of Thermal and Separation Processes • **University of Hamburg** • Inorganic and Applied Chemistry • Center for Bioinformatics • **European Molecular Biology Laboratory** (EMBL), DESY

• Information: *www.tuhh.de/synbio*

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INTEGRATED MATERIALS SYSTEMS (IMS)

The „Integrated Materials Systems (IMS)" Cluster of Excellence is based on a cooperation between the Hamburg University of Technology, Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research, Research Centre DESY and University of Hamburg. The objective of this research project is to develop microstructurally controlled, damage tolerant and lightweight materials with integrated sensing and actuating functions. The scientific challenge is to explore the high potential of IMS by combining the degrees of freedom of microstructural design with lightweight and functional materials. In the metropolitan region of Hamburg and its neighbouring North German states, major economic driving forces include the aircraft and automobile industries, wind power plants, medical technology and the Hamburg harbour, where lightweight structural parts are key components for future system development.

The scientific objective of the Cluster „Integrated Materials Systems" (IMS) is to break the existing limitations of today's materials technologies by exploiting integrated materials systems. This class of materials shall evolve from completely new ways of combining a designed microstructure with a desired functionality. Such a development requires new concepts for the hierarchical design of interpenetrating microstructural networks with controlled topologies. The realisation of multiphase materials with controlled positioning of dispersed functional particles is envisaged by applying physics- and chemistry-based approaches such as bottom-up and top-down strategies, or combinations thereof to design the envisioned IMS on different length scales. The goal is to obtain novel exceptionally damage tolerant lightweight materials with integrated sensing, including health monitoring and actuating functions with adaptive properties.

Coordinators

Prof. Dr. rer. nat. Gerold A. Schneider (TUHH)

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Participating Institutes

TUHH • Institute of Advanced Ceramics • Institute of Solids Process Engineering and Particle Technology • Institute of Polymer Composites • Institute of Optical and Electronic Materials • Institute of Business Logistics and General Management • Institute of Chemical Reaction Engineering • Institute of Product Development and Mechanical Engineering • Institute of Nanoelectronics • Institute of Microsystem Technology • Institute of Materials Physics and Technology • **University of Hamburg** • Institute of Applied Physics, Institute for Technical and Macromolecular Chemistry • **Helmholtz-Zentrum Geesthacht – Centre for Materials and Coastal Research** • Institute of Polymer Research • Institute of Materials Research • **DESY** German Electron-Synchrotron Hamburg

• Information: *www.tuhh.de/lexi*

BIOCATALYSIS2021

Biocatalysis Opening New Paths

CLUSTER BIOCATALYSIS2021 – SUSTAINABLE BIOCATALYSIS OPENING NEW PATHS

Based on a joint research cooperation between industry and academia the Cluster BIOCATALYIS2021, supported by the Federal Ministry for Education and Research (BMBF), is pursuing the goal of researching systematically the enormous potential of biocatalysts from microorganisms as to their possible application in industry. To achieve that goal the Cluster combines the unique expert knowledge of the academic sector in five Federal States of Northern Germany with the economic and innovative power of globally operating companies throughout Germany. The primary goals of the Cluster are the use and application of new biocatalysts achieving novel synthetic effects by subjecting them to unconventional conditions (extreme temperatures, pressures, pH values, concentrations of salt and solvents). The enzyme systems are to be used both as final products and in subsequent processes for the production of fine chemicals and active agents. This is complemented by the development of an innovative process technology under unconventional conditions.

Biocatalysis Opening New Paths

INDUSTRIAL BIOTECHNOLOGY – INNOVATIVE SOLUTIONS FOR THE FUTURE

Biotechnology is viewed by experts as key technology offering an enormous potential for solving problems in almost all areas of life. Industrial biotechnology (white biotechnology), in particular, using the great potential of enzymes or whole cell systems for the sustainable production of fine chemicals, pharmaceutical precursors, active agents of cosmetics as well as of technical enzymes and bio fuels is playing an increasingly important part. Thus, industrial biotechnology has the function of an innovative motor giving decisive impetus to numerous fields of application. This sector of biotechnology owes its strength to the interdisciplinary cooperation of chemists, biologists and engineers.

INNOVATIONS IN THE CLUSTER – A UNIQUE CONSORTIUM

The Cluster BIOCATALYSIS2021 coordinates the expert knowledge of 15 large companies, 19 small and medium-sized companies, as well as of 27 academic research groups and 7 agencies promoting innovations and economy. Through networking of all partners the application of fundamental knowledge in the manufacture of innovative chemicals, cosmetics, foods and detergents throughout the entire value-added structure from screening to the ultimate consumers is ensured.

www.biocatalysis2021.net

BIOREFINERY2021

CLUSTER BIOREFINERY2021 – ENERGY FROM BIOMASS BIOREFINERY – DRIVING FORCE OF A NEW BIOINDUSTRY

Biomass is a sustainable alternative to fossil feedstock, which is currently used to produce fuels, chemicals and other valuable goods. Innovative technologies utilizing renewable plant-based materials are envisioned to serve as the foundation of a new sustainable bioindustry.
To date the main feedstock for biorefineries is based on starch. However, lignocellulose is a more attractive renewable resource since it is available in large quantities and does not compete with food or feed. The joint project BIOREFINERY2021, which is funded by the German Federal Ministry for Education and Research (BMBF), aims at the development of a fully integrated and sustainable biorefinery based on lignocellulose.

CONSORTIUM

BIOREFINERY2021 is a joint project between partners from academia and industry forming a unique consortium. The expertise of the partners covers all relevant fields required to develop the biorefinery of the future including microbiologists, chemists, engineers and economists.

CONCEPT

The conversion of an existing bioethanol production plant into a fully integrated biorefinery based on lignocellulose requires the following concerted action:

PROCESS OPTIMIZATION

Optimized biogas production from distillers grains and solubles. Efficient microbial communities Production of fertilizers.

LIGNOCELLULOSIC FEEDSTOCK

Thermal processes for biomass pretreatment. Robust enzymes (extremozymes) for the efficient conversion of biopolymers. Novel yeasts for the fermentation of C6 and C5 sugars.

HIGH VALUE PRODUCTS FROM LIGNOCELLULOSE

Phenols from pyrolysis of lignin. Gasification of lignin for the production of synthesis gas. Biocatalytic synthesis of cellulosics.

INTEGRATED CONCEPTS

Development of economically feasible biorefinery concept. Economical and ecological evaluation of the integrated biorefinery Commercialization.

www.biorefinery2021.com

TUTECH INNOVATION GMBH
KNOWLEDGE . TECHNOLOGY . MARKETS

Collaboration and exchange with industry belong to the characteristics of Hamburg University of Technology (TUHH). In order to strengthen its knowledge transfer TUHH has outsourced the organization and the management of transfer processes into an own company TuTech Innovation GmbH (TuTech).

TuTech is a private company with a public mission to promote effective transfer and exploitation of knowledge, especially by sharing and using science and technology for wealth creation and the benefit of society. For almost two decades TuTech has been helping businesses work with Hamburg University of Technology.

TuTech offers a range of services to support knowledge transfer:
- R&D collaboration and cluster management
- International cooperation and EU office
- Business start-ups and innovation funding
- Open innovation and social media
- Patenting and licensing
- Training and continuing professional development
- PR and "Science and Society" communication
- IT and web design
- Conferences and workshop organization
- Project controlling support

TuTech is at home in various disciplines; topics range from participatory democracy to aircraft construction. As strategic partner TuTech supports the research centers and institutes of TUHH in bilateral collaborations as well as in the development and coordination of national or European network and cluster projects with partners from science, economy and government. In Germany TuTech is responsible for two major biotechnology clusters and a flagship project on climate change.

BIOCATALYSIS2021 – Sustainable Biocatalysis Opening New Paths

Based on a joint research cooperation between industry and academia the cluster BIOCATALYIS2021, supported by the BMBF, is pursuing the goal of researching systematically the enormous potential of biocatalysts from microorganisms as to their possible application in industry. The primary goals of the Cluster are the use and application of new biocatalysts achieving novel synthetic effects by subjecting them to unconventional conditions (extreme temperatures, pressures, pH values, concentrations of salt and solvents). The enzyme systems are to be used both as final products and in subsequent processes for the production of fine chemicals and active agents.

Consortium

The cluster BIOCATALYSIS2021 coordinates the expert knowledge of 15 large companies, 19 small and medium-sized companies, as well as of 27 academic research groups and 7 agencies promoting innovations and economy.

BIOREFINERY2021 – New Approaches towards the Biorefinery of the Future

Biomass is a sustainable alternative to fossil feedstock, which is currently used to produce fuels, chemicals and other valuable goods. Innovative technologies utilizing renewable plant-based materials are envisioned to serve as the foundation of a new sustainable bioindustry. To date the main feedstock for biorefineries is based on starch. However, lignocellulose is a more attractive renewable resource since it is available in large quantities and does not compete with food or feed. The joint project BIOREFINERY2021, which is funded by the German Federal Ministry for Education and Research (BMBF), aims at the development of a fully integrated and sustainable bioindustry based on lignocellulose.

Consortium

The cluster is a joint project between 9 partners from academia and 7 partners from industry forming a unique consortium. The expertise of the partners covers all relevant fields required to develop the biorefinery of the future including microbiologists, chemists, engineers and economists.

KLIMZUG-NORD – Strategic Approaches to Climate Change Adaptation in the Hamburg Metropolitan Region

Within the research priority "KLIMZUG" the KLIMZUG-NORD project works with regional partners from 6 universities, 6 research centers, 10 offices related to city affairs, and 11 companies. The objective is to develop innovative strategies for adaptation to climate change and related regional weather extremes. The focus of this research is on three main topics concerning the impacts of climate change and how these can be dealt with: a) estuary river management, b) integrated urban development and c) sustainable cultivated environment.

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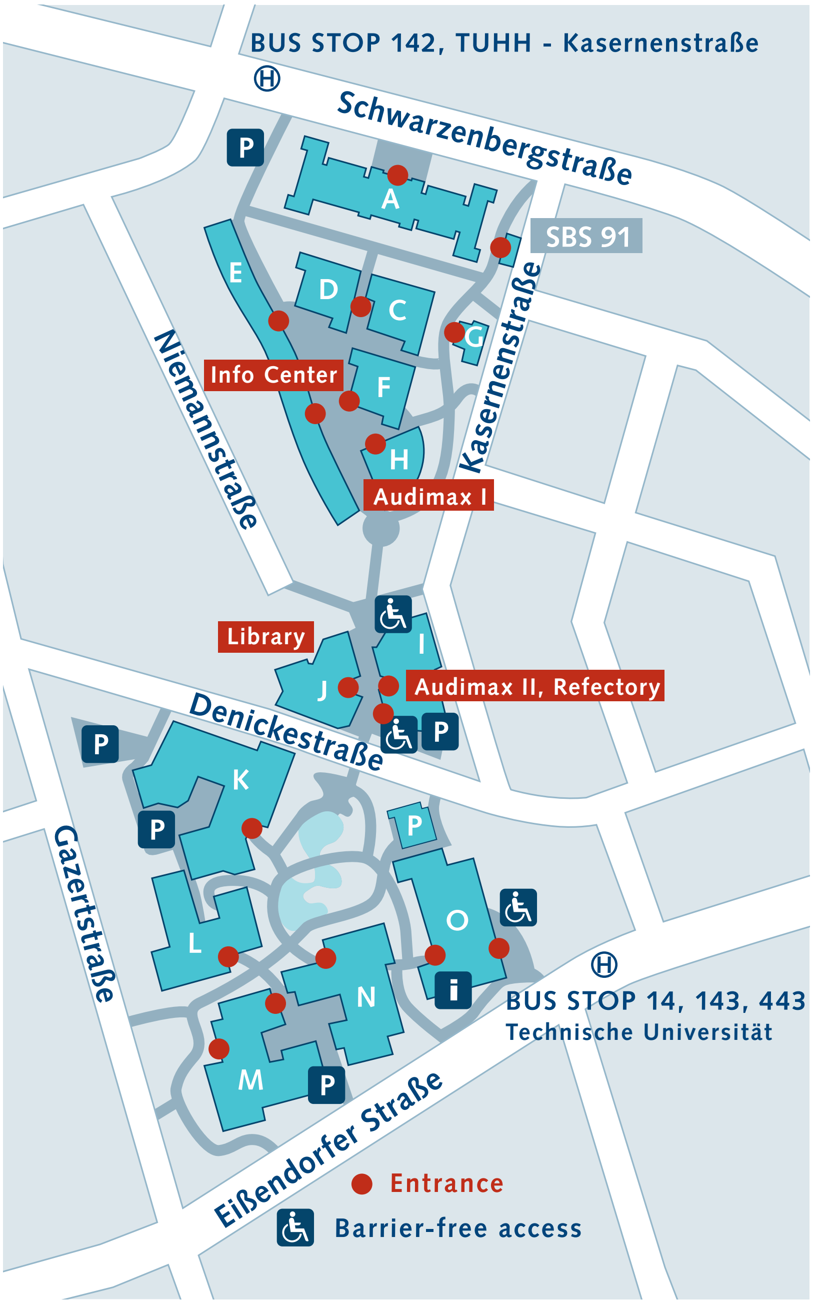

WITHIN EASY REACH

From Hamburg Airport: S1 rapid transit to Hamburg main station (Hauptbahnhof), then S31/S3 to Harburg-Rathaus or Heimfeld
By rail: Harburg is a station stop on the ICE and EC rail networks
By rapid transit: S31/S3 to Harburg-Rathaus or Heimfeld
By car from downtown Hamburg: via Elbbrücken and Wilhelmsburger Reichsstraße, Exit Hamburg-Harburg Mitte
By car: A1 autobahn (take Hamburg-Harburg exit), A7 autobahn (take Hamburg-Heimfeld exit), B75

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