2013

MUNICH SCHOOL OF ENGINEERING
ANNUAL REPORT

Technische Universität München

Munich School of Engineering
Technische Universität München

2013

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Welcome

President´s Preface

PRESIDENT
Prof. Dr. Dr. h.c. mult.
Wolfgang A. Herrmann

Today's world faces major challenges like the climate change, an exponential growth of human population and its energy needs, urbanization and lifestyle changes. These challenges make it indispensable to focus on sustainability and resource-efficient planning and acting in all spheres of life. In this context, risks of fossil and nuclear energy gave rise to questioning established energy sources. People have recognized - not only since the Fukushima disaster - that in order to conserve the environment and to cope with the great societal challenges, renewable energies have to be promoted as much and as fast as possible.

Aware of its responsibility, TUM joined forces and developed the new format of "Integrative Research Centers". These concentrate on cross-departmental topics, both in teaching and research. The university thus makes a visible commitment for long-term focus areas that include a high and diverse scientific challenge. We are aiming at the creation of trans-disciplinary science communities tackling topics of high complexity in joint efforts. This attitude helps to master potent, interdisciplinary alliances with other universities, non-university research institutes and the industry.

The Munich School of Engineering (MSE), founded in 2010, plays a role-model function for the new Integrative Research Centers. Its research is dedicated to Energy, one of the great societal challenges, in a typical cross-faculty, trans-disciplinary approach which would never be accomplished within a specific, traditional department. Structurally, MSE thus functions as an element in a matrix organization. Round-about 100 TUM faculty from ten departments are related to energy research in one or the other way, some of them even in quite a focused approach. With MSE they share an identity-forming scientific community. Consequently, TUM's visibility in energy research has been rapidly growing ever since. To boost our competence profile even more, new chairs have been set up in the areas of Energy Storage Technology (Prof. Jossen), Carbon-Composites (Prof. Drechsler), Automotive Technology (Prof. Lienkamp), Technical Electrochemistry (Prof. Gasteiger) and Energy Efficient and Sustainable Design and Building (Prof. Lang). In its first three years MSE has already emerged as a well-functioning, well-developed center which has gained high reputation both within TUM and with external partners. The Annual Colloquia show the impressive output of experienced and young researchers. With the successful approval of external funds ranging around €40M, MSE is now enabled to conduct comprehensive research.

One of MSE's most convincing early successes is the fully electric vehicle MUTE, furnished by a community of numerous contributors from several TUM departments under the leadership of Professor Markus Lienkamp. This initiative is born out from TUM's commitment to electromobility with the associated project "Electromobility for Mega-Cities" presently being pursued at TUM Create in Singapore.

MSE is embedded in a network of cooperations and alliances to facilitate national and international collaboration. The EuroTech Universities Alliance was also initiated by the MSE vision; at this time, it comprises Danmarks Tekniske Universitet (DTU), Technische

Universiteit Eindhoven (TU/e), École Polytechnique Fédérale de Lausanne (EPFL) and Technische Universität München (TUM). EuroTech is gaining profile for the “Green Technologies”, once again with the emphasis on energy research, and with TUM playing a major role. The new Ludwig Bölkow Campus, located in the Munich Metropolitan Area, is dedicated to the field of Green Aerospace & Security; university and industry partners like EADS, IABG (Industrieanlagen-Betriebsgesellschaft mbH), the University of the Armed Forces and the University of Applied Sciences Munich as well as Bauhaus Luftfahrt and the German Aerospace Center (DLR) join their efforts.

Research is associated with teaching. To sensitize brilliant young talents for trans-disciplinary thinking and acting, MSE has established the study courses (General) Engineering Science and Industrial Biotechnology, respectively. Energy Management, as a Master Course, is going to follow soon. We are proud of smart and highly engaged students who have joined TUM particularly for these courses aimed at cultivating better interlinks between science and technology. This philosophy is strongly supported by our TUM Graduate School and, particularly, the International Graduate School of Science and Engineering.

Besides pooling competencies by establishing interdisciplinary centers and forming alliances, an important aspect is to promote the dialogue between science, industry and politics. MSE thus has become TUM’s frontier Integrative Research Center.
We gratefully acknowledge Professor Thomas Hamacher, the Director of MSE, for his efforts in shaping our energy research to become TUM’s strongest and largest center of competence.

Prof. Dr. Dr. h.c. mult. Wolfgang A. Herrmann
President

Director´s Message

DIRECTOR
Prof. Dr. Thomas Hamacher

The profession which is still best represented in the German parliament is lawyer. Engineers form a much smaller group. During the last years companies and many industry federations claimed a lack of engineers. The success of the German economy was to good fraction based on the production sector which again requires good engineers. The role of engineering combined with a very high level of craftsmanship looks still as the central basis of our economic model.

Engineering is still at the heart of our economy and necessary to master most of our societal challenges. New concepts in education and research are necessary to maintain these challenges on the long run. For the education part a couple of changes seem necessary. First, science and mathematics gain more importance, because experience-based decisions and design criteria are more and more replaced by complex simulations and calculations. Second, students need to learn from the very beginning that products need to be seen in their interplay with society. The last year demonstrated the dark sides of the new communication world. In the energy field acceptance is of prime importance and currently stops many necessary developments. Engineering education has to cover these new soft matters.

In research one of the major challenges can be seen in the systemic nature of most technical products. Cars, aircrafts, mobile phones or wind turbines are all part of rather complex systems. Research has to be able to cover the complex nature of the new products. Only new forms of interdisciplinary research can in the end lead to success. It is not possible to focus on one discipline only. Still the excellence and depth of individual research needs to be maintained.

All this demonstrates that the world of engineering became more complex in the recent past. The Munich School of Engineering (MSE) wants to be an answer to these challenges, by developing new forms of engineering education and research. The interplay between teaching and research is essential.

At the moment, MSE offers one Bachelor´s and one Master´s program. The Bachelor´s program (Bachelor of Engineering Science) is designed to bring even more science into the engineering education. More classes in physics, chemistry and mathematics are taught than usual. The first batch of these students finished in the last year. Most of them will continue in one of the Master´s programs offered at our university. MSE also developed one Master´s program in Industrial Biotechnology. More programs will follow especially to build bridges between disciplines. A special lecture in “public participation” was launched to develop the necessary soft skills.

The research focus is on energy research so far. This research is covered under the umbrella of TUM.Energy. The energy system is expected to make a major transition in the near future and is certainly one of the best examples for a field in which all the new trends in engineering can be seen. The research is grouped in four columns which represent the research focus at TUM (see figure on page 19). Two big programs were launched within MSE: EEBatt and Energy Valley Bavaria. Both interconnect researchers from many departments and different chairs. The Energy Valley Bavaria program also offers young research groups the possibility to develop new and unconventional approaches and ideas.

MSE will also build and operate a new research center called “Energy and Information”. The idea of the center is to combine both energy and information technology, which will be the basis of a future smart grid. This center will also be used to execute public participation processes.

The organization of the energy transition in Germany and especially in Bavaria is a tremendous challenge ahead of us. MSE tries to become a major actor in this transition and will demonstrate that especially universities are as well capable as reliable partners of industry and politics to organize and shape such a transition.

Even if in the future engineers also will not be better represented in parliament, it is the very goal of MSE to bring the reasoning of engineers closer to the political decision makers.

Prof. Dr. Thomas Hamacher
Director

Message
Dean for Academic Affairs

DEAN FOR ACADEMIC AFFAIRS
Prof. Dr.-Ing. Nikolaus A. Adams

The Munich School of Engineering (MSE) has been established in 2010 with two main objectives. One of these objectives is the reinforcement and focusing of energy research at TUM. The other objective is to enhance teaching programs offered through the departments of TUM by specific programs, as response to current trends in technical education at the University level, and as anticipation of future developments.

Future technological development and innovation have increasing impact on nearly all areas of life. For a society that relies almost entirely on technological creation of value, it is a necessity to sustain the education of engineers that can prevail in international competition. Engineers that can cope with future challenges need to be exposed to interdisciplinary thinking and acting at the very roots of their education. On the other hand disciplinary barriers in applications also need to be overcome, which can only be addressed by appropriate programs at the advanced level. Current and future programs at the undergraduate and at the graduate level at MSE have the purpose of addressing these needs.

The 6-semester, two-language (German, English) Bachelor's Program "Engineering Science" offers a challenging syllabus that emphasizes methodological and technological fundamental education. It meets the requirements for later merging into different graduate programs and for a professional career in nearly any area of technological research, development or production. The program conveys fundamental methods and engineering sciences without expressing one of the classical engineering disciplines during the first four semesters. It thus offers students the flexibility of a later professional carrier at the interface between classical engineering disciplines or in natural sciences with an engineering bias. Emphasis during the first 4 semesters is placed on mathematics, computer science, natural sciences and engineering sciences. During the last 2 semesters students extend the scope of their subjects towards later specializations in a graduate program and their anticipated professional activity.

Bridging disciplines in applications is the objective of the second program currently offered by MSE. The Master's program on "Industrial Biotechnology" addresses the need for preparing students that received their undergraduate education in engineering or natural sciences, such as chemistry or biology, to meet the interdisciplinary engineering challenges of bioprocesses and biomaterials.

In the future we expect to establish an inter-disciplinary and scientifically oriented Master Program on aerospace engineering sciences, benefiting also from the Munich Aerospace network. The program reflects the need of specialized knowledge in particular in modeling and simulation of processes and devices, spanning the wide range of specific disciplines involved in aeronautics and astronautics. Graduates of this program, however, will also earn the competencies to work or perform research in all areas of high technology.

Engineering education in the future will face the combined challenges of securing and further improving education quality, increasing the number of successful graduates, while competing with other education fields and alternative professional career paths for the brightest students. Outreach towards high-school graduates is a necessity, as there is no substitute to early familiarization and straightening preconceptions about engineering. MSE develops modern programs for aiding prospective students during their transition between school and university.

Engineering offers the unique possibility to combine scientific challenge with art, craft, and creativity. MSE heralds the motto of engineering, coined by the late Hans W. Liepmann, Emeritus Professor of the California Institute of Technology, and former director of their Graduate Aeronautical Laboratories, during a commencement speech in 1982:
To Know. To Understand. To Do.

Prof. Dr.-Ing. Nikolaus A. Adams
Dean for Academic Affairs

MSE at a glance

MSE Facts & Figures

MUNICH SCHOOL OF ENGINEERING

Bachelor Engineering Science

STUDENTS

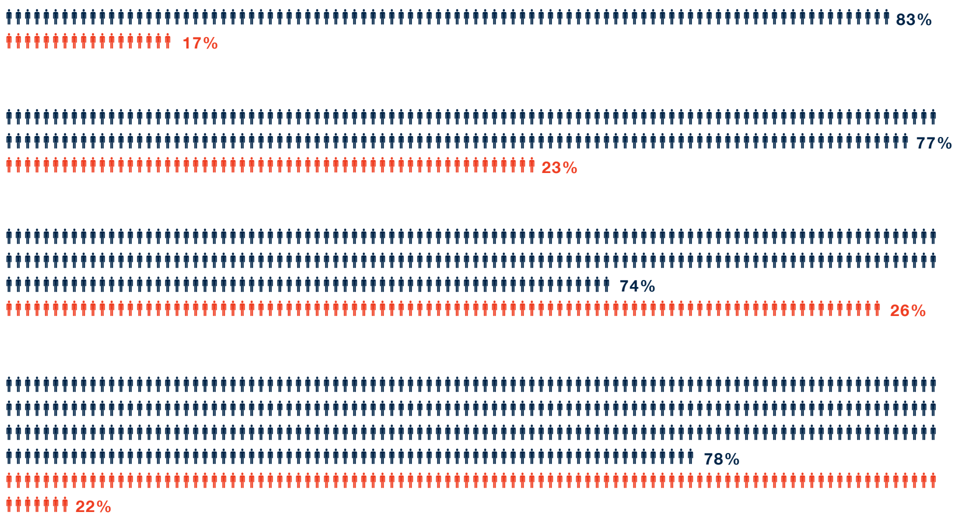
male student *female student*

WINTER TERM 10/11
114 students
(incl. 7 international students)

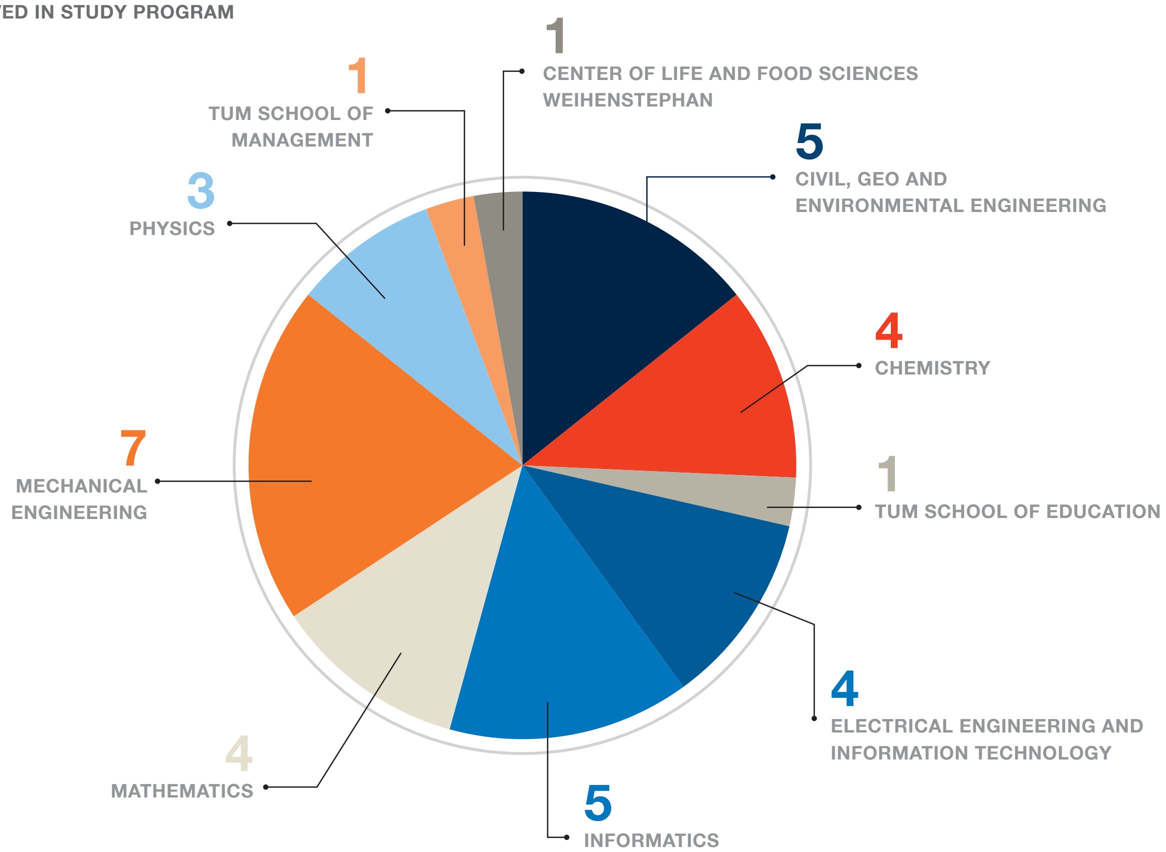
WINTER TERM 11/12
250 students
(incl. 13 international students)

WINTER TERM 12/13
359 students
(incl. 29 international students)

WINTER TERM 13/14
481 students
(incl. 39 international students)



PROFESSORS
INVOLVED IN STUDY PROGRAM



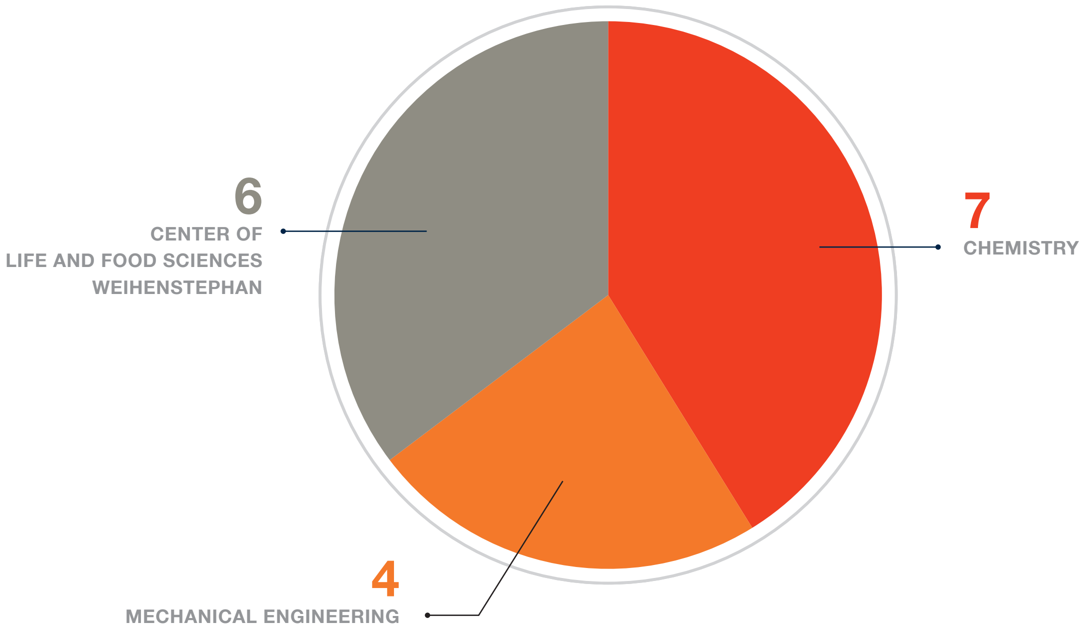
Master Industrial Biotechnology

STUDENTS

male student · *female student*

Term	Male student	Female student
WINTER TERM 10/11 *17 students*	41%	59%
WINTER TERM 11/12 *27 students* *(incl. 1 international student)*	52%	48%
WINTER TERM 12/13 *40 students* *(incl. 3 international students)*	57%	43%
WINTER TERM 13/14 *48 students* *(incl. 7 international students)*	62%	38%

PROFESSORS
INVOLVED IN STUDY PROGRAM

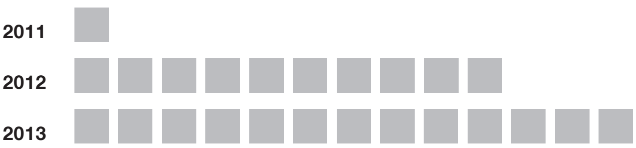


Facts & Figures

MUNICH SCHOOL OF ENGINEERING

OUTGOING STUDENTS 2013
BY DESTINATION

SCHOLARSHIPS
(DEUTSCHLANDSTIPENDIUM)



OUTGOING STUDENTS 2013
BY EXCHANGE PROGRAM

ERASMUS *14 students*

PROMOS *4 students*

TUM EXCHANGE *7 students*

NUMBERS
2013

104
RESEARCH PROJECTS

76
INDUSTRY PARTNERS

263
SCIENTISTS INVOLVED IN RESEARCH PROJECTS

51
PROFESSORS INVOLVED IN RESEARCH PROJECTS

49
INVOLVED CHAIRS & INSTITUTES

24
AWARDS

17,432,200
RESEARCH EXPENDITURES (IN EURO)

13
DELEGATIONS DISPATCHED

30
DELEGATIONS RECEIVED

175
PUBLICATIONS

112
GUEST LECTURES

173
LECTURES FOR EXTERNAL PARTNERS

32
PATENTS

31,872,600
THIRD PARTY FUNDING (IN EURO)

Structures

MSE WITHIN TUM: INTEGRATIVE RESEARCH CENTER

TUM developed the new format of Integrative Research Centers (IRCs) to answer the growing demand for interdisciplinary research and teaching. Today's societal challenges in the fields of energy, climate, natural resources or health and nutrition can only be tackled when disciplines work together and grow beyond their traditional borders. Integrative Research Centers bring together scientists from different scientific cultures in topic-specific education and research centers, to focus on these societal challenges and to make use of TUM's unique range of subjects. Just like regular departments, IRCs consist of the two pillars research and teaching. But IRCs are not intended to be additional pared-down versions of departments or to be rivals to the existing departmental structures - IRCs offer a complementary issue-focused and interdisciplinary approach and trigger synergies and added value for all partners at TUM. Integrative Research Centers are flexible platforms and networking hubs for specific research and teaching issues. For example, MSE integrates roughly 100 professors from ten departments to work on energy related topics. Therefore, IRCs need to have flexible structures to be able to react quickly on changing challenges. All these points can hardly be handled within the traditional departmental structures. This integrative, result-oriented approach allows TUM to fully synergize its vast academic portfolio. TUM's portfolio is outstanding in the European academic space, successfully combining natural sciences and engineering with medicine, life sciences and business studies.

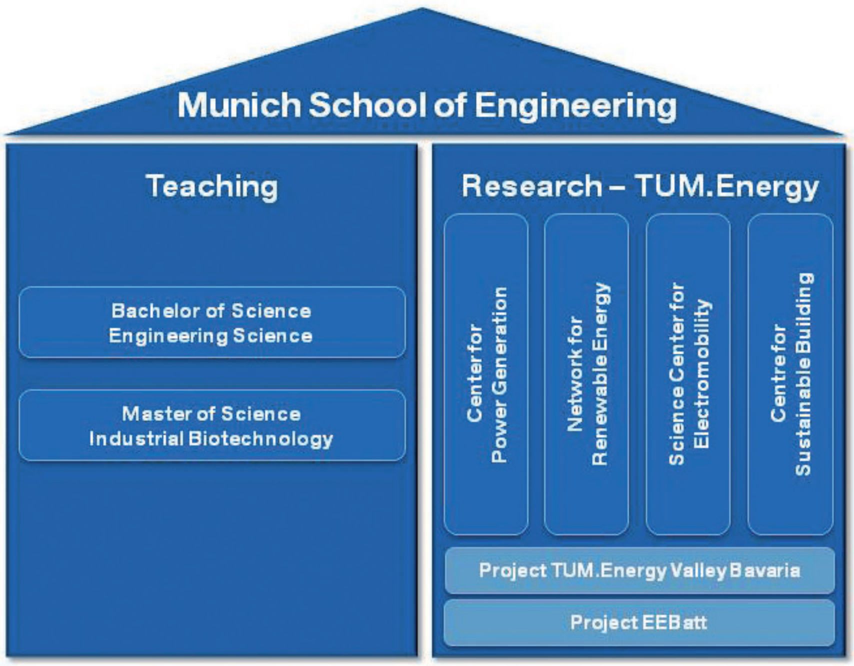
■ *Integrative Research Centers at TUM*

The Munich School of Engineering combines interdisciplinary research with cross-faculty teaching for tomorrow's top engineers. The TUM.Energy research project bundles the various facets of energy research and "green" technologies with the aim of finding a sustainable energy supply for the future. In addition, MSE offers two completely newly set up interdisciplinary engineering courses – the Engineering Science BSc course and the Industrial Biotechnology Master's program.

To attract young researchers and to be able to conduct independent research, Integrative Research Centers have the right to award doctorates – on a par with departments.

The first PhD students started in summer 2013. To support the PhD students and to offer them a structured PhD program within the framework of the TUM Graduate School, the MSE Graduate Center is in the course of formation.

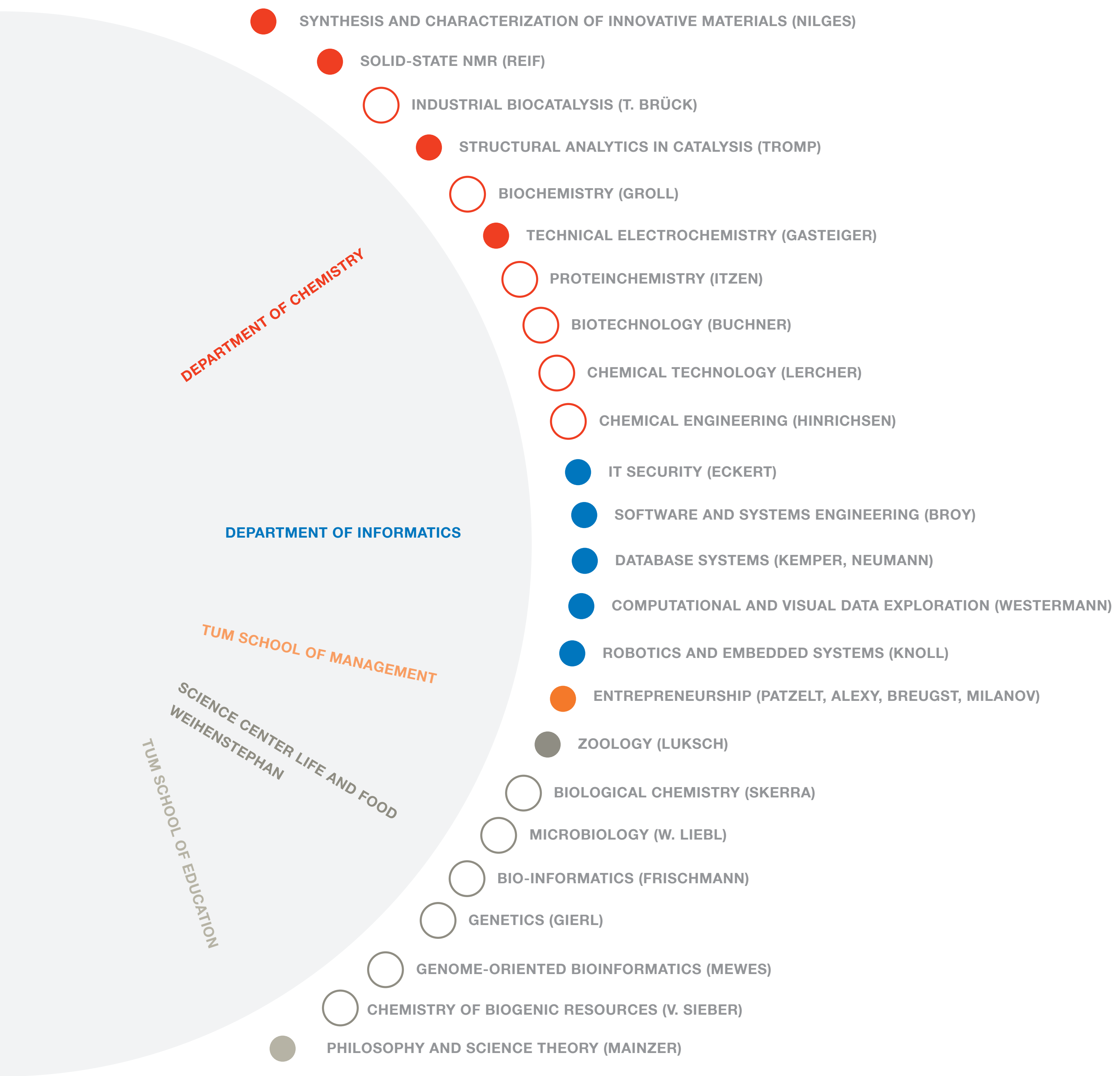
To protect the unique structure of MSE, "TUM Munich School of Engineering" is a registered trademark at the German Patent and Trademark Office (Nr. 302010041142) since Nov. 3rd 2010.



■ *MSE Structure*

Structures

MSE TEACHING: PARTICIPATING INSTITUTIONS


SYNTHESIS AND CHARACTERIZATION OF INNOVATIVE MATERIALS (NILGES)
SOLID-STATE NMR (REIF)
INDUSTRIAL BIOCATALYSIS (T. BRÜCK)
STRUCTURAL ANALYTICS IN CATALYSIS (TROMP)
BIOCHEMISTRY (GROLL)
TECHNICAL ELECTROCHEMISTRY (GASTEIGER)
PROTEINCHEMISTRY (ITZEN)
BIOTECHNOLOGY (BUCHNER)
CHEMICAL TECHNOLOGY (LERCHER)
CHEMICAL ENGINEERING (HINRICHSEN)
DEPARTMENT OF CHEMISTRY
IT SECURITY (ECKERT)
SOFTWARE AND SYSTEMS ENGINEERING (BROY)
DATABASE SYSTEMS (KEMPER, NEUMANN)
COMPUTATIONAL AND VISUAL DATA EXPLORATION (WESTERMANN)
ROBOTICS AND EMBEDDED SYSTEMS (KNOLL)
DEPARTMENT OF INFORMATICS
ENTREPRENEURSHIP (PATZELT, ALEXY, BREUGST, MILANOV)
TUM SCHOOL OF MANAGEMENT
ZOOLOGY (LUKSCH)
BIOLOGICAL CHEMISTRY (SKERRA)
MICROBIOLOGY (W. LIEBL)
BIO-INFORMATICS (FRISCHMANN)
GENETICS (GIERL)
GENOME-ORIENTED BIOINFORMATICS (MEWES)
CHEMISTRY OF BIOGENIC RESOURCES (V. SIEBER)
SCIENCE CENTER LIFE AND FOOD WEIHENSTEPHAN
PHILOSOPHY AND SCIENCE THEORY (MAINZER)
TUM SCHOOL OF EDUCATION

Structures

MSE RESEARCH: PARTICIPATING INSTITUTIONS

NETWORK FOR RENEWABLE ENERGY

- CHEMICAL ENGINEERING (HINRICHSEN)
- STRUCTURAL ANALYTICS IN CATALYSIS (TROMP)
- PHYSICAL CHEMISTRY (HEIZ)
- ORGANIC CHEMISTRY I (BACH)
- THEORETICAL CHEMISTRY (REUTER)
- INORGANIC CHEMISTRY WITH FOCUS ON NOVEL MATERIALS (FÄSSLER)
- CHEMICAL TECHNOLOGY II (LERCHER)
- ANALYTICAL CHEMISTRY (NIESSNER)
- MOLECULAR CATALYSIS (KÜHN)
- MACROMOLECULAR CHEMISTRY (RIEGER)
- TECHNICAL ELECTROCHEMISTRY (GASTEIGER)
- SYNTHESIS AND CHARACTERIZATION OF INNOVATIVE MATERIALS (NILGES)
- POWER TRANSMISSION SYSTEMS (WITZMANN)
- RENEWABLE AND SUSTAINABLE ENERGY SYSTEMS (HAMACHER)
- NANOELECTRONICS (LUGLI)

SCIENCE CENTER FOR ELECTROMOBILITY

- RENEWABLE AND SUSTAINABLE ENERGY SYSTEMS (HAMACHER)
- ELECTRICAL DRIVE SYSTEMS AND POWER ELECTRONICS (KENNEL)
- ENERGY CONVERSION TECHNOLOGY (HERZOG)
- REAL-TIME COMPUTER SYSTEMS (CHAKRABORTY)
- ELECTRICAL ENERGY STORAGE TECHNOLOGY (JOSSEN)
- INTEGRATED SYSTEMS (HERKERSDORF)
- TRAFFIC ENGINEERING AND CONTROL (BUSCH)
- TECHNICAL ELECTROCHEMISTRY (GASTEIGER)
- INDUSTRIAL DESIGN (FRENKLER)
- SOFTWARE AND SYSTEMS ENGINEERING (BROY)
- APPLICATION AND MIDDLEWARE SYSTEMS (JACOBSEN)
- AERODYNAMICS AND FLUID MECHANICS (ADAMS)
- AUTOMOTIVE TECHNOLOGY (LIENKAMP)
- MACHINE ELEMENTS (STAHL)
- ERGONOMICS (BENGLER)
- MACHINE TOOLS AND INDUSTRIAL MANAGEMENT (REINHART, ZÄH)
- AIRCRAFT DESIGN (HORNUNG)
- THERMODYNAMICS (SATTELMAYER, POLIFKE)

DEPARTMENT OF MATHEMATICS
DEPARTMENT OF PHYSICS
DEPARTMENT OF ELECTRICAL ENGINEERING AND INFORMATION TECHNOLOGY
DEPARTMENT OF MECHANICAL ENGINEERING
DEPARTMENT OF CIVIL, GEO AND ENVIRONMENTAL ENGINEERING
DEPARTMENT OF CHEMISTRY
DEPARTMENT OF INFORMATICS
TUM SCHOOL OF MANAGEMENT
SCIENCE CENTER LIFE AND FOOD WEIHENSTEPHAN
TUM SCHOOL OF EDUCATION
DEPARTMENT OF ARCHITECTURE
PART OF SEVERAL RESEARCH CENTERS

- ROBOTICS AND EMBEDDED SYSTEMS (SCHNEIDER)
- THERMODYNAMICS (SATTELMAYER, POLIFKE)
- COMPUTATIONAL MECHANICS (WALL, GEE)
- FLUID MECHANICS (SCHILLING)
- PLANT AND PROCESS TECHNOLOGY (H. KLEIN)
- ENERGY SYSTEMS (SPLIETHOFF)
- INTERNAL COMBUSTION ENGINES (WACHTMEISTER)
- BIOELECTRONICS (SIMMEL)
- INTERFACES AND ENERGY CONVERSION (KUNZE)
- EXPERIMENTAL SEMICONDUCTOR PHYSICS (STUTZMANN)
- FUNCTIONAL MATERIALS (MÜLLER-BUSCHBAUM)
- NONEQUILIBRIUM CHEMICAL PHYSICS (KRISCHER)
- AGRICULTURAL PRODUCTION AND RESOURCE ECONOMICS (SAUER, HEISSENHUBER)
- RESOURCE AND ENERGY TECHNOLOGY (MAYER)
- MICROBIOLOGY (W. LIEBL)

CENTER FOR SUSTAINABLE BUILDING

- RENEWABLE AND SUSTAINABLE ENERGY SYSTEMS (HAMACHER)
- BUILDING CLIMATOLOGY AND BUILDING SERVICES (LANG)
- ENERGY EFFICIENT AND SUSTAINABLE DESIGN AND BUILDING (LANG)
- BUILDING PHYSICS (HAUSER)

CENTER FOR POWER GENERATION

- CHEMICAL ENGINEERING (HINRICHSEN)
- ELECTRICAL ENERGY STORAGE TECHNOLOGY (JOSSEN)
- POWER TRANSMISSION SYSTEMS (WITZMANN)
- RENEWABLE AND SUSTAINABLE ENERGY SYSTEMS (HAMACHER)
- HIGH VOLTAGE ENGINEERING AND SWITCHGEAR TECHNOLOGY (KINDERSBERGER)
- AUTOMATION AND INFORMATION SYSTEMS (VOGEL-HEUSER)
- PLANT AND PROCESS TECHNOLOGY (H. KLEIN)
- ENERGY SYSTEMS (SPLIETHOFF)
- FLIGHT PROPULSION (O. HAIDN)
- THERMODYNAMICS (SATTELMAYER, POLIFKE)
- NUCLEAR ENGINEERING (MACIÁN-JUAN)
- INTERNAL COMBUSTION ENGINES (WACHTMEISTER)

Calendar of Events 2013

EVENTS & LECTURES

** location: Garching, if not stated otherwise*

JANUARY	
15	7 Deutschlandstipendien awarded to MSE students
FEBRUARY	
01-02	Presentation of MSE at “Einstieg“ (graduate fair) in Cologne
07	Presentation of MSE at “TUM Schülertag“
08	Presentation of MSE at “TUM Unitag“
25	Colloquium Science Center for Electromobility (inhouse)
MARCH	
13-14	MSE-exhibition stall at “Forum Life Science” by Bayern Innovativ
APRIL	
11-13	Solar Technologies go Hybrid Workshop, Kloster Banz
12	Visitation of Prof. Carlos Pereira, Universidade Federal do Rio Grande do Sul (Escola de Engenharia), Porto Alegre/Brazil
12-14	Training for teachers “Physik von Zukunftsmaterialien“, Zwiesel
18	Presentation of MSE and exhibition stall during the “Energie Innovativ – Forschung und Innovationen für den Energieumstieg“ conference (Nuremberg)
MAY	
02	TUM Applied Technology Forum: Review Meeting of first Call for Applications
10	First graduation ceremony Master´s Program “Industrial Biotechnology“
17	Opening event “TUM.Energy Valley Bavaria“ (Vorhoelzer Forum, Munich)
JUNE	
10	Project Leader Training within the EuroTech Green Tech Initiative
26-28	IGSSE Forum with EuroTech TUM students, Raitenhaslach



JULY	
04	Third MSE-Colloquium “Research Towards Innovative Energy Systems and Materials”
09	Delegation visit from Academy of Sciences Malaysia (ASM)
12	Delegation visit of Managers from Russian oil and gas industry, Petroleum Business Institute (Moscow/Russia)
16-18	PhD students meeting for ISPV EuroTech Partners at TUM
22	Colloquium Science Center for Electromobility with participation of industry advisory board
24-26	„Nanosystems for Solar Energy Conversion“ SolTech & NIM joint symposium, Munich
AUGUST	
02	MSE summer festival and “Welcome Day”
SEPTEMBER	
03	Delegation visit from Universidad Tecnica Federico Santa Maria (UTFSM, Valparaiso/Chile)
30	Training for teachers „Energiewandlung und Energiespeicherung“, Leitershofen
OCTOBER	
01-02	Training for teachers „Energiewandlung und Energiespeicherung“, Leitershofen
09	Delegation visit from CEA (CEA: French Commissariat for Nuclear and Alternative Energy)
NOVEMBER	
06	MSE-exhibition stall at “TUM-Mastermesse“
06-07	two-day workshop at TU Graz on mobility, energy technology, battery research and techno-economics (participation of nine TUM-Professors), Graz/Austria
16	MSE-exhibition stall and lecture series at “Tag der offenen Tür Garching“
DECEMBER	
03	Eurotech Alliance Meeting

Teaching


INFORS

Studying at MSE

BACHELOR ENGINEERING SCIENCES
MASTER INDUSTRIAL BIOTECHNOLOGY
FUTURE PROGRAM STUDIUM MINT
MSE STUDENT COUNCIL FACHSCHAFT MSE

The Munich School of Engineering (MSE) was founded in 2010 in order to pool activities and competencies in both research and teaching because of the growing demand for scientists being able to work together beyond the borders of traditional scientific disciplines. It is institutionalized as an Integrative Research Center with doctorate-granting rights, so MSE-students can complete their university education from Bachelor to PhD.

In the field of teaching, MSE offers research-oriented study programs that focus on engineering sciences with a specific interdisciplinary approach: Professors and lecturers from diverse departments representing a wide range of subjects contribute to both study programs, bringing in the corresponding perspective of each discipline. Young talents keen on mathematics and sciences in general have the opportunity to examine in detail the results of basic research and the entrepreneurial viability of new technologies. This opens up exciting professional opportunities in the interdisciplinary fields of the future.

Since Winter Semester 2010/11, the Munich School of Engineering provides the Engineering Science Bachelor's Program and the Industrial Biotechnology Master's Program. From that time on, the number of participants in both MSE programs has been increasing, as shown in the "Facts and Figures" part.

The Engineering Science program offers students broad basic scientific training in the first four semesters. The focus at this stage is on mathematics and science subjects. In the fifth and sixth semester, the program concept allows students to individually create their personalized specialization within engineering oriented at the envisioned Master´s Course. The first graduates of the Bachelor´s Program are already enrolled in different Master´s Programs both at TUM as well as foreign universities.

The Industrial Biotechnology Program qualifies graduates from different Bachelor's Programs in science and engineering for the interdisciplinary field of industrial biotechnology. Over a four-semester period, the subjects covered include biotechnology, food science, process engineering, chemistry, physics, agricultural science, robotics and information technology. This program is the answer to the increasing demand for engineers who are experts in this field of biotechnology. In 2013, the first graduates from the Master´s Program Industrial Biotechnology received their degrees and subsequently started their professional or scientific careers.

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■ *Students Master Industrial Biotechnology*

Engineering Sciences

BACHELOR OF SCIENCE

WEB
www.engineering.mse.tum.de

BACHELOR´S PROGRAM ENGINEERING SCIENCE – ONE PROGRAM, ALL OPPORTUNITIES

Employment prospects are excellent within the field of engineering, but just as large is the range for specialization as well. With the Engineering Science Program, TUM is preparing junior engineers for this increasing diversity of career options available in market economy.

The Bachelor's Program Engineering Science is a truly interdisciplinary and research-oriented program with a strongly enhanced focus on mathematics, natural sciences and life sciences. It started in Winter Semester 2010/11 and is aimed at university applicants who are looking for a broad, method-based, basic scientific training without having to commit to one of the traditional engineering disciplines when they begin their studies. This is of particular interest for those who wish to enter the engineering profession at the interfaces of traditional engineering and scientific disciplines. Examples of a future profession are in the areas of mechatronics, process engineering (chemical, biotechnological, pharmaceutical), medical technology, material science, material technology and software engineering. Most important, however, students who graduate with a degree from the Bachelor's Program Engineering Science have the option of continuing their studies at TUM and pursuing a Master's Program in Mechanical Engineering, Electrical Engineering and Information Technology or even Civil, Geo and Environmental Engineering.

STUDY PROGRAM PROFILE

Engineering Science is aimed particularly at technically and scientifically gifted high school graduates and individuals who have the necessary qualifications for university admission. This intensive study program comprises 210 ECTS points (instead of 180 ECTS) and includes a mentoring program starting at the very beginning. Engineering Science features the strictest admission criteria at TUM (average Abitur grade of accepted students: 1.4). During the program, exclusive and newly designed lectures and lab courses (e.g. Material Science jointly conducted by the Physics, Chemistry and Engineering Departments) are in use.

Engineering Science also offers the possibility to complete a four months research internship within a TUM research group.

After having completed the challenging basic scientific training during the first four semesters, participants can structure individual curricula during the focus phase (fifth and sixth semester) and thus prepare themselves for a broad range of potential subsequent Master's Programs at TUM and other universities. These components make the Bachelor's Program Engineering science an absolutely unique program in Germany.

The first graduates from the Engineering Science Program commenced Master's Programs in different departments, as shown in the figure below. The variety of specialization possibilities during the Bachelor's Program is reflected by the chosen Master's Programs reaching from Computational Mechanics over Aerospace Engineering to Medicine.

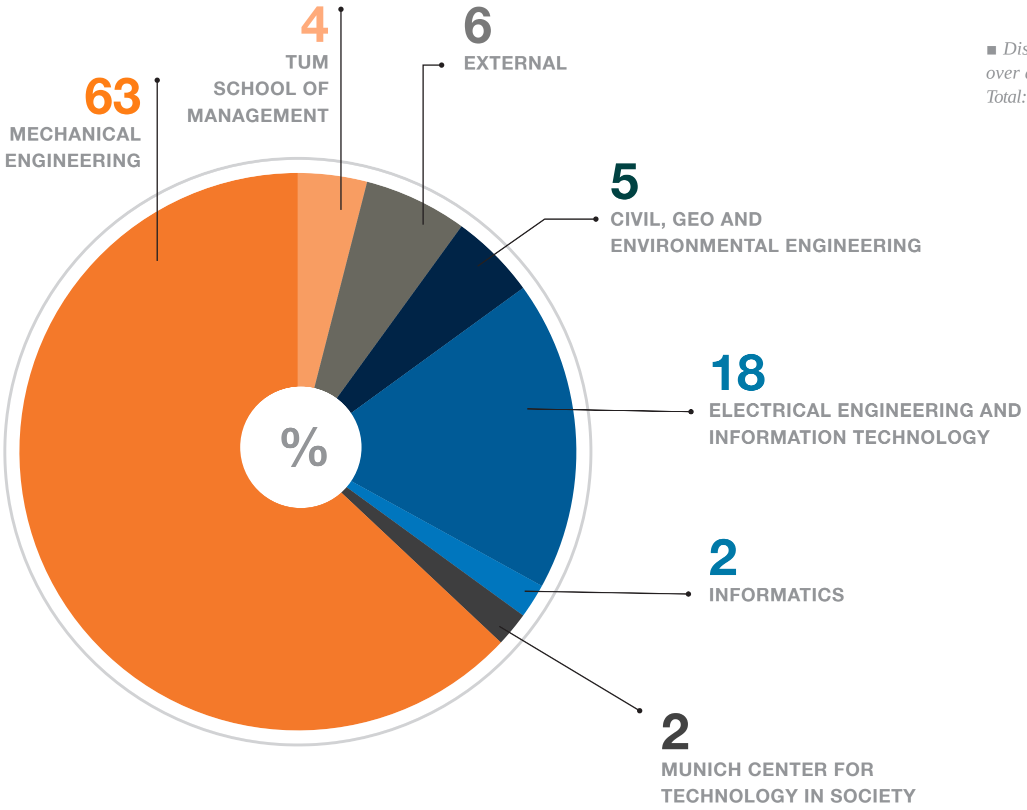
STUDENTS´ VIEWS

"We learn ways of approaching problems from different points of view from professors of various disciplines. This is challenging - and an ideal preparation for interdisciplinary professions." Katharina Kollenda (Germany) - Academic year 2011/12

"... I have benefited from outstanding teaching and a flexible course structure. After having acquired the necessary mathematical, scientific and engineering knowledge base, I could set my own accent within the program and develop my skills according to my personal inclination. Due to the flexibility of the program in particular, I was able to customize my studies with practical relevance and thus gain contacts with companies already from the 3rd semester on." Eskander Kebsi (Tunisia) – Academic year 2010/11

„The broad scientific and engineering fundamentals, the individual focus in the fifth and sixth semester as well as the numerous choices concerning Master's Programs were impressing. (...) Personally, I would take the same decision again at any time!"

Johannes Liebertseder (Germany) – Academic year 2010/11



■ *Distribution of Bachelor graduates over different departments in %*
Total: 54 graduates. (Master´s Programs)

Industrial Biotechnology

MASTER OF SCIENCE

The demand for outstanding individuals who can work across a number of disciplines and have a broad applicable expert knowledge of bioscience and process engineering is continually rising: The MSE is meeting this increased demand by offering an interdisciplinary Master's program in Industrial Biotechnology (IBT) that is unique in Germany and one of its first kind in Europe. This master program qualifies for a transition to a PhD, for example in the TUM Research Center for White Biotechnology, or alternatively for challenging careers in the area of IBT.

The Master's Program IBT first started in winter semester 2010-2011 and attracts an increasing number of students from the TUM as well as from external universities, both domestic and foreign. Currently 48 students are registered in the program.

PROFESSIONAL PROSPECTS

After graduation in Industrial Biotechnology a wide variety of challenging occupations are offered in Research and Development, Production and Manufacturing, Plant and Equipment Engineering as well as in Consulting and Management. The demand for well-trained engineers with a broad skills spectrum and the appropriate specialist knowledge in the interdisciplinary field of Industrial Biotechnology is increasing.

The transformation of raw materials into bio-materials for use in modern industries such as the Chemical and Pharmaceutical Industries, Biotechnology, Plant and Equipment Engineering, Process Engineering, as well as Environmental Engineering requires this fairly new profession of highly skilled Industrial Biotechnologists.

WHITE BIOTECHNOLOGY

Industrial biotechnology – also known as "white biotechnology" – involves the use of microorganisms or enzymes to create industrial products. These include specialty and fine chemicals, foodstuffs and food additives, agricultural and pharmaceutical intermediate products and process materials for the manufacturing industry. The production of bulk chemical products and fuels is increasing. By concentrating on the chemical industry, which has been undergoing a radical paradigm shift recently, industrial biotechnology focuses on renewable raw materials and aims to transform these selectively using biological catalysts into refined chemical products.

As a highly interdisciplinary science, industrial biotechnology covers the areas of molecular biology, biochemistry, microbiology and bioinformatics to create new biocatalysts – enzymes and production organisms. Both chemical engineering and technical chemistry methods are equally important in exploiting the technological and industrial potential of the new biocatalysts and implementing new biological production processes on an industrial scale.

■ *Pilot Plant for White Biotechnology*

STUDY PROGRAM PROFILE

The Master's Program IBT aims for graduates with very good bachelor´s degrees in science or engineering. Interdisciplinary fundamentals, based on a specially tailored curriculum, are taught in the first two semesters to prepare the students for their future work environment. The program continues with scientific training in enzyme engineering, metabolic engineering, bioprocess engineering and bio separation engineering. The lectures are complemented by research practices and a mentoring program is offered during the whole time of studies

RESEARCH PRACTICE

With the Research Center for White Biotechnology the TUM has established a strong, interdisciplinary research and training unit. For students in the Master's Program IBT a research practice at this center is obligatory and presents one of the highlights within the program.

The technical facilities for research, teaching and technology transfer at the Research Center for White Biotechnology include a screening lab in Weihnenstephan and a pilot plant for White Biotechnology in Garching. The plant, unique in the international academic landscape, offers researchers access to new biocatalysts and bioproducts and provides students with practical training in the area. Fermenters with a capacity of up to 1,000 liters and the relevant facilities for the reprocessing of products allow researchers to examine the scaling up for processes form laboratory to pilot scale.
Alongside the research internship students can benefit from the plant if research work for their Master´s Thesis is required.

WEB

www.biotech.mse.tum.de

■ *Master Students*

Future Program

STUDIUM MINT

TUM ORIENTATION PROGRAM
FOR MATHEMATICS, ENGINEERING AND NATURAL SCIENCES

The age at which pupils have to decide on a study program for their professional careers has fallen in recent years due to the shortened period of schooling on one hand and abolition of mandatory military service on the other. At the same time, the number of available study programs is constantly growing. It is a big challenge for young people to choose the most suitable option from the wide range of offers – and they often fail in this decision as shown by dropout rates. In addition, many graduates would like to complete an internship abroad or voluntary social service before they start university.

For this reason, an orientation program for those interested in STEM/MINT* disciplines will be launched in summer semester 2014. Coordinated by the Munich School of Engineering, seven departments participate in this program (Civil, Geo and Environmental Engineering; Chemistry; Electrical Engineering and Information Technology; Informatics; Mechanical Engineering; Mathematics; and Physics). The objective of the program is to provide participants with a solid information and knowledge fundament for their study and career choice by allowing them to get in touch with different scientific disciplines and thus find out where their individual interests and strengths lie before enrolling in a certain study program. Moreover, they obtain important personal and learning skills very early during the program, making study entry significantly easier.

Participants visit selected lectures provided by partnering departments and thus improve their expertise in these areas. The individual courses are assigned to five basic elements (here referred to as modules) according to their purpose:
The basic module is used for acquisition, expansion and repetition of mathematical and physical fundamentals that are needed in all STEM/MINT study programs alike, supplemented by specific knowledge in computer science.
The navigation module serves as an opportunity to get an insight into various study courses as well as an impression of being student in different departments and get to know accompanying chairs, professors, lecturers and students.
The navigation module is complemented by the perspectives module which aims to build bridges between study programs and subsequent potential employment fields.
In addition, promotion of long-lived key competences is included in the main components of studium MINT.

Finally, participants discover basics of project management and learn about interconnections between different disciplines during independent study projects within the project module.

The learning process is supported by tutorials and counseling services in which participants´ needs can be addressed in particular.
studium MINT offers additional course counseling in due time before the application deadline for the subsequent winter semester. Program participants are already enrolled at TUM and thus receive certain student benefits. ECTS acquired during the program may be accepted in part, depending on the Bachelor´s Program participants choose after having completed studium MINT.

WEB
www.tum.de/studium-mint

** the use of the acronym MINT (Mathematik, Informatik, Naturwissenschaft, Technik) is common in Germany whereas STEM (science, technology, engineering, mathematics) is used internationally with a similar meaning*

MSE Student Council

FACHSCHAFT MSE

WEB
www.fs.mse.tum.de

The Student Council of the Munich School of Engineering (Fachschaft MSE) was founded December 2010 and stands in for round about 500 students. This includes the highly interdisciplinary B.Sc. of Engineering Science and the M.Sc. of Industrial Biotechnology. We organize various events, just like the introduction to university life for freshmen, parties and several more. Furthermore the Fachschaft MSE represents the students in political issues regarding the university, as well as providing scripts for all lectures. Another task is to take care of the MSE premises at the business campus in Garching-Hochbrück, including the Quantum.

All members work as volunteers enjoying to be able to move and change things concerning every aspect of student life. We all highly appreciate new members which are willing to contribute something to the development of the MSE.

MANAGEMENT OF THE FACHSCHAFT MSE
Each semester the new management department of the Fachschaft gets elected by all members of the MSE to represent and coordinate the students' interests. Another point is the struggle for continuous improvement of the studies, regarding the selection of lectures and exams. The most important task of the management nevertheless is the coordination of the single departments within the Fachschaft MSE.

DEPARTMENTS
Each department has its own leader to take care of the projects on stake.

- *Freshmen:* Organizes the freshmen days and other events for future students and also helps new students to get accustomed to university life
- *Evaluation:* Creates surveys, taken at the end of each semester, in order to improve teaching and tutorials in each subject.
- *Finances:* Cares about every aspect of money and finance (e.g. events/taxes/scripts)
- *IT:* Responsible for www.fs.mse.tum.de as well as providing a cloud system for internal data and tutorials
- *Publication and Marketing:* Tries to promote the Fachschaft MSE and writes articles for student newspapers and similar. Also creates flyers and logos.
- *Events:* Is the biggest department and organizes study trips, parties and the Fachschaftswochenende that depicts a weekend at a hut with around 30 active members of the Fachschaft MSE.
- *Scripts:* Prints and spreads the scripts for each semester.
- *Politics:* All members are elected in the FSR (legislative power of the students at TU). They work on general improvement of the university and attend special political meetings within the Fachschaft MSE.

Research


Conventional power plants
Non-domestic sector
Co-generation systems
Electromobility
Electricity grid
ICT infrastructure
Public sector
Renewable energy generation
Residential sector

General Overview

RESEARCH AT THE MUNICH SCHOOL OF ENGINEERING

Even before MSE was officially founded, the research collaboration TUM.Energy started as a bottom-up approach of different scientists to join forces in the field of energy research at TUM. In 2010 TUM began to set up the structure of the Munich School of Engineering in which TUM.Energy was incorporated and institutionalized. Four main topics were identified on which energy research at MSE should focus: Renewable Energies, Electromobility, Efficiency of Energy Supply and Transport and Efficient Use of Energy. These main topics are represented in four different but partly overlapping networks with different specialist areas: the Center for Power Generation (CPG), the Network for Renewable Energy (NRG), the Center for Sustainable Building (ZNB) and the Science Center for Electromobility (WZE).

In order to promote research in this field, new chairs were created: Energy Storage Technology (Prof. Jossen), Carbon-Composites (Prof. Drechsler), Automotive Technology (Prof. Lienkamp), Technical Electrochemistry (Prof. Gasteiger) and Energy Efficient and Sustainable Design and Building (Prof. Lang).

Within the MSE-network groups of highly motivated researchers met and developed ideas to promote the concept of the Munich School of Engineering. To apply for third-party-funding, several proposals for collaborative research projects were written. An excellent team of 25 professors joined forces to develop the cluster proposal “Electromobility Beyond 2020” within the Excellence Initiative 2012-2017. In a holistic approach, the big questions in the field of electromobility, novel energy conversion and storage technologies, innovative vehicle components and design as well as optimized energy management schemes and future mobility concepts, were addressed. Even though this promising project was not awarded funding, the collaboration continues and the developed ideas bear fruit in many different ways.

In 2012, the proposal “TUM.Energy Valley Bavaria – stage ONE”, funded with € 10 Mio by the Bavarian State Ministry of Science, Research and the Arts, was successful (see chapter “Research” p.89). In 2013, MSE was granted the project EEBatt “Dezentrale stationäre Energiespeicher zur effizienten Nutzung erneuerbarer Energien und Unterstützung der Netzstabilität”, funded with € 30 Mio by the Bavarian State Ministry of Economics (see chapter “Research” p.112).

One very visible result of the network activities at MSE is the electrical vehicle MUTE. The project demonstrates that electric mobility is also suitable for mass application in the near future. MUTE was presented at the IAA in September 2011. More than 200 Students, 60 PhDs and 21 chairs from 8 departments contributed to this project which proves our capacity for teamwork. Furthermore a Fraunhofer project group “Electrochemical Storage” was founded in March 2012.

■ *Integration of smart grids in energy efficient renovation*

Research Centers

Center for Power Generation

CENTER FOR POWER GENERATION

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HEAD
Prof. Dr.-Ing. Hartmut Spliethoff

HEAD

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Maximilian Blume

Steffen Kahlert

The Center for Power Generation (CPG) is a research cooperation established within the MSE and involving multiple TUM institutes which deal with research on energy transformation in the broader sense. Apart from efficient and innovative power plant technologies, the research spectrum also includes innovative research on transportation and storage of electricity, control systems to achieve the latter, and new, optimized technologies to reduce greenhouse gas emissions. The CPG provides an innovative environment enabling efficient collaboration across faculty borders through the exchange of knowledge and resources from several institutes of the TUM.
Furthermore, the CPG serves as a qualified contact for interested parties and potential partners, supporting the transfer and sharing of expert knowledge.

RESEARCH SCOPE OF THE CPG

Power generation comprises all methods and technologies for energy conversion on the one hand and power supply on the other. Thus, it covers all tasks and operations from fuel to socket. Furthermore it includes all processes necessary to control power plant and grid operation as well as the storage of energy.

Within the research efforts of the CPG all of the aspects of power generation are considered with a special focus on new technology development, efficiency and flexibility increase, and emissions reduction of biomass, gas and coal fired power plants. Partner institutes contribute their expert knowledge to cooperative projects. In parallel, the acquired knowledge is shared between partners on a regular basis, building a strong common knowledge base.

NEED FOR RESEARCH

Research in power generation has for decades concentrated on a continuous efficiency improvement to decrease electricity production costs. Due to the ‘Energiewende’ on the one hand, and rocketing energy demand in developing countries on the other. The objective above has been replaced by the urgent need for highly flexible, fuel efficient, ideally near-zero emission power plants. New technologies and designs provide only half of the solution, though, as investment costs are high, payback periods of existing power plants are long and the basis of decision-making for such an investment nowadays is volatile. Therefore, upgrading existing power plants became vital for meeting the new demands for efficiency, emissions and flexibility.

Although the core working principles of the technologies considered have been in the focus areas known for well over 100 years, a range of promising optimization parameters have not been given much attention by utility operators in the past due to low pressure, both with respect to cost and environmental legislation. Nevertheless, universities and research institutes have been working on new solutions and technologies, which now, in a changed political and economic environment, provide plant operators with multiple options for improving plant emission levels, cost effectiveness, and operation flexibility.

In an increasingly fast changing setting, thorough research efforts are needed in order to provide a stable electricity supply in an economic and environmentally friendly way in accordance with political demands. Within the context of MSE, the Center for Power Generation therefore provides solutions and research on technologies and strategies which meet environmental, economic and flexibility needs as a partner of the public and the private sector.

CURRENT ACTIVITIES

The center for Power Generation coordinates several projects and activities within the MSE. Please see the respective chapters for more information.

Current activities of the CPG include the coordination and scientific work on the Bavarian state funded project “Energy Valley Bavaria”, which, in a collaboration of four CPG institutes focuses on increasing the flexibility of current conventional power plants.

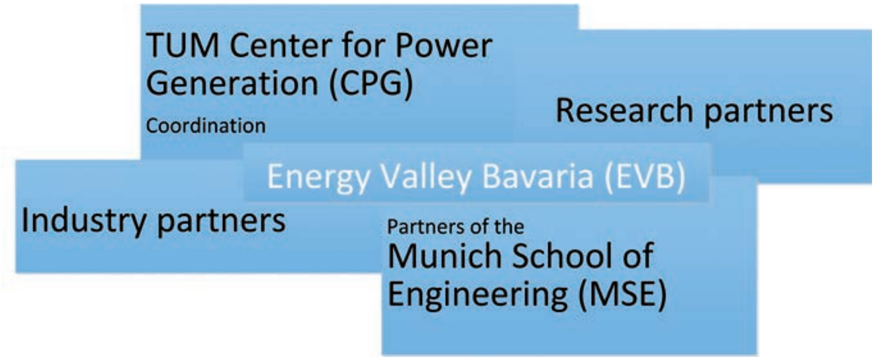
Within the seed-funding project Power-to-Gas (PtG) several partners from CPG as well as industry are aiming to bundle their expertise on the field. The aim is to establish a research platform which serves as a contact for industry as well as a project initiator.

Geothermal Energy is seen as one of the promising technologies for electricity as well as domestic heat production for the near future. CPG partners are currently putting forward an initiative for system and technology development in close cooperation with industry.

CENTER FOR POWER GENERATION

HEAD AND COORDINATOR

The Center for Power Generation is led by Prof. Dr.-Ing. Hartmut Spliethoff. He also chairs the Institute for Energy Systems, which – in the context of TUM's mechanical engineering department – scientifically focuses on efficiency improvement and emissions reduction from conventional power plants as well as development of new technologies for power generation from solid fuels. In his function as director of the CPG, Professor Spliethoff sees himself as an initiator of and contact for innovative projects among the partners of the CPG in close cooperation with external partners and governmental institutions.



■ Multidisciplinary collaborative project Energy Valley Bavaria (EVB): Research and industry partners working together under the coordination of the Center for Power Generation in the context of the Munich School of Engineering

ELECTRICITY GENERATION

Due to its unlimited convertibility into other types of energy, electricity is a high quality energy form. Furthermore, the transportation of electricity over great distances is comparatively easy and low-loss. In Germany 19% of end energy takes the form of electricity. The Center for Power Generation targets to provide solutions for highly efficient electricity generation. Primary energy sources for electricity generation may be conventional (coal, gas, oil) as well as renewable energy sources (biomass, wind, water). At present the share of renewable energy sources in the German energy mix is up to almost 25% (end of 2013). In order to achieve agreed upon targets for climate protection, the research conducted at the CPG therefore focuses on raising the efficiency of conventional technologies for electricity generation.

CONVENTIONAL POWER PLANT TECHNOLOGY

Conventional power plant technologies comprise all technologies producing electricity predominantly from fossil energy sources. The common ground of most of the technologies is the fact that they generate steam at high temperature and pressure by combusting a carbon-based fuel. Steam is then

PARTNER INSTITUTES

To date, 14 institutes from four departments are cooperating within the Center for Power Generation. The actual involvement reaches from information exchange to close research cooperation in projects. All partners are invited regularly to present new ideas for research proposals or to commit themselves to new project ideas.

Current partners are:

Chair of Chemical Engineering - Prof. Dr.-Ing. Kai-Olaf Hinrichsen

Research work is oriented along the process chain, starting from particle design, to reactor design, to process design. Topics include particle design and technology, chemical reaction engineering aspects (i.e. reaction kinetics, multiphase systems), modeling of reactive flows and chemical reactors, the design of novel reactors (i.e. adsorptive reactors, multifunctional reactors, microreactors, fluidized-bed reactors) and the optimization of entire (integrated) chemical processes. Special focus is laid on methanol chemistry and hydrogen production.

Institute for Synthesis and Characterization of Innovative Materials - Prof. Dr. Tom Nilges

The institute is occupied with the synthesis and the characterization of thermoelectrics and energy materials for high-power lithium batteries. The research focuses on developing new concepts for bulk-thermoelectrics using a targeted manipulation of the electrical structure and thermal forces by the materials. Prospective materials for electrodes depending on the 5th group of the periodic table are tested and advanced respective to their electrochemical characteristics and their potential as materials for anodes in lithium batteries.

Institute of Power Transmission Systems - Prof. Dr.-Ing. Rolf Witzmann

The field of electrical power supply grids is occupied with tasks of energy transmission and distribution and with the integration of local, renewable energy generation as well as new stochastically distributed demands like electromobility in the future.

Research topics are for example:

- Capacitance and structure of electrical power supply grids
- Effects of local renewable power generation on the distribution grids
- Conception, design and control of electrical distribution grids with a high number of local and fluctuating sources
- Integration of electro-mobility
- Local supervision and advancement of grid quality by using power electronics and new IKT technologies

Institute for Renewable and Sustainable Energy Systems - Prof. Dr. rer. nat. Thomas Hamacher

The Institute for Energy Management and Application Engineering teaches the technical-economic basics for energy supply. Therefore attention must be paid to the methodical coaction of all technologies from primary energy gain to different kinds of energy transformation to the point of final energy use. Apart from conventional energy supply systems and especially regarding the changing requirements of climate and environmental protection, technologies to gain energy from renewables or more efficient ways to deplete exhaustible sources have become more and more important. The whole field of energy application includes all types of energy demand and different ways to cover it (f.e. alternative drives in cars, new individual process heat technologies, power-heat-cogeneration with fuel cells, solar technologies, etc.)

Institute for Electrical Energy Storage Technology - Prof. Dr.-Ing. Andreas Jossen

The institute is engaged in electrical energy storage, especially rechargeable batteries. Aside from lithium batteries, also conventional systems (for example plumb batteries and alkaline systems) play a role. Furthermore future systems like metal-air, redox flow and high temperature batteries are part of the research.

Main topics are:

- Modelling of single components (thermal-electrical linked)
- Models for battery systems
- Models for linked batteries including statistical views
- Examination and modelling concerning the lifetime of batteries
- Battery management with measurement technology and interfaces for integration
- Thermal battery management
- Management for security in large battery systems
- Advanced methods for battery status determination
- New quick charge technologies
- Optimization of operating strategies to get low costs, long lifetime and high efficiency

Laboratory for High Voltage Technology and Power Transmission - Prof. Dr.-Ing. Josef Kindersberger

The main research topics of the Laboratory for High Voltage Technology and Power Transmission are to achieve efficient electrical power transmission technologies. They deal with basic questions of characteristics and the longtime behavior of high voltage insulation by plastics, the level of insulation by gas and solids in high voltage aperture, the longtime behavior of electrical compounds under load with high current and questions concerning the cable insulation in HV grids for hybrids and electro mobility. The institute holds considerable experimental devices for high voltage and high currents. There is also testing equipment for electrical matter characteristics and electrical compounds.

Institute for Systems Engineering and Process Technology - Prof. Dr.-Ing. Harald Klein

Both teaching and research by the institute concentrate on the thermal separation technique of fluid alloys (f.e. distillation, rectification, absorption). Parts of the topic are the thermodynamic basics of thermal separation (f.e. phase equilibrium, mass transport), the synthesis and optimization of complete processes and the technical design of separation devices.

expanded in a turbine. Electricity is finally generated by transforming the mechanical energy in a generator. Research on this topic is primarily concerned with efficient combustion technologies, steam generation at high pressure and temperature, power plant dynamics and control, efficient design of water/steam cycles and optimized steam turbine technologies.

ELECTRICAL POWER TRANSMISSION

Reliable grid design and development will become increasingly important in the future, especially with further increasing local electricity production from decentralized renewable energy sources.

ENERGY STORAGE

Going along with grid improvements, storage technologies will gain more importance in the future. In a few years front-end electricity generation will fully depend on weather conditions and thus cannot be controlled. Furthermore the power of conventional backup power plants cannot be modulated as quickly as those changing conditions would require. This is where storage technologies come into play. By storing surplus energy when generation from renewables exceeds energy demand and supporting electricity supply when electricity demand is high, energy storages help to stabilize the grid.

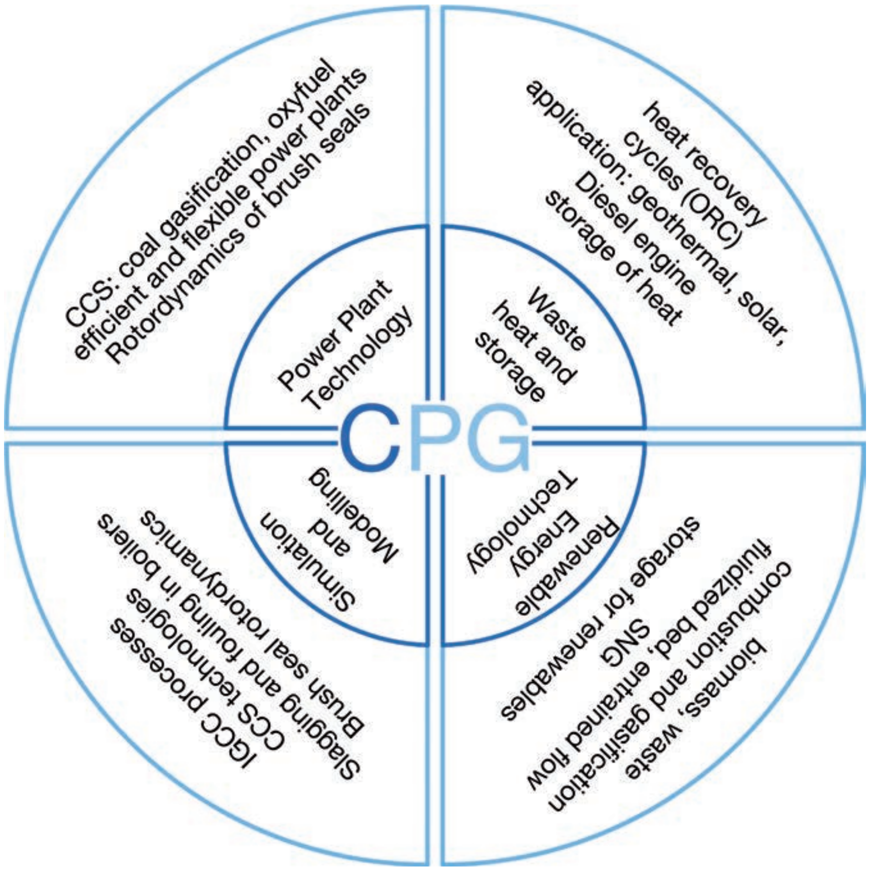
FLEXIBILITY INCREASE BY INNOVATIVE PLANT CONTROL MECHANISMS AND DEEPER UNDERSTANDING OF MATERIAL BEHAVIOR

To date, a characteristic feature of most of the existing steam power plants is their design for base load operation. Operational flexibility has often deliberately been limited to 200 cold start cycles throughout plant life time. Driven by an increased share of green (and volatile) power generation plants especially in the German grid, previous base load plants now require flexibility for frequent load changes as well as cold and warm start-ups. Plant materials have not been designed for such requirements. Especially thermal stress becomes an issue. Therefore exact knowledge of material properties and material lifetime when exposed to this new operation conditions becomes vital.

CENTER FOR POWER GENERATION

Institute of Automation and Information Systems - Prof. Dr.-Ing. Birgit Vogel-Heuser
The goal of ais, e.g. SFB 768 information systems and information technology aspects is to improve engineering, operation and maintenance, and re-engineering of hybrid systems including all three disciplines (mechanical, electrical and software engineering) to increase product and production quality and time to market.
Both research areas model-based development approaches and quality management contribute directly to increase product quality and reduce time to market. Indirectly, also improved and integrated engineering tools and more adequate support during operation, which is grouped under human factors (usability), leads to the above mentioned goals. Due to the rising complexity in engineering one measure to cope with complexity and therefore one key research topic of ais is operation distribution.

■ *Research scope of the Center for Power Generation.*



Institute for Energy Systems - Prof. Dr.-Ing. Hartmut Spliethoff
The Institute for Energy Systems focuses on current challenges in energy technology. The research is divided into four areas: Power Plants, Modelling & Simulation, Measurement Techniques and Renewable Energies. Current research addresses challenges related to solid fuel combustion, including biomass, gas, coal and waste. Activities also include regenerative energy production and energy storage. The institute is participating in several national and international research projects, in cooperation with other research institutes as well as with industrial partners.

Institute for Flight Propulsion – Prof. Dr.-Ing. O. Haidn
Mobility and Energy are the basic needs of humans. The main research focus is therefore on efficiency enhancing and pollution reducing provisions. In so doing the Institute for

Flight Propulsion benefits from its comprehensive experimental and numeric infra-structure. To advance these topics the Institute for Flight Propulsion cooperates with many industrial partners. Furthermore SCRAMJET research at the Institute for Flight Propulsion aims to advance a non-market-ready technology.

Department of Nuclear Engineering - Prof. Dr. Rafael Macián-Juan
The target of research and development at the Department of Nuclear Engineering is the improvement of the security of nuclear devices (commercial or research) in cooperation with international agencies and partners in industry. To reach this target state of the art system codes for security analysis (deterministic or stochastically) are used. Furthermore new advanced models are developed and validated with high resolution data.

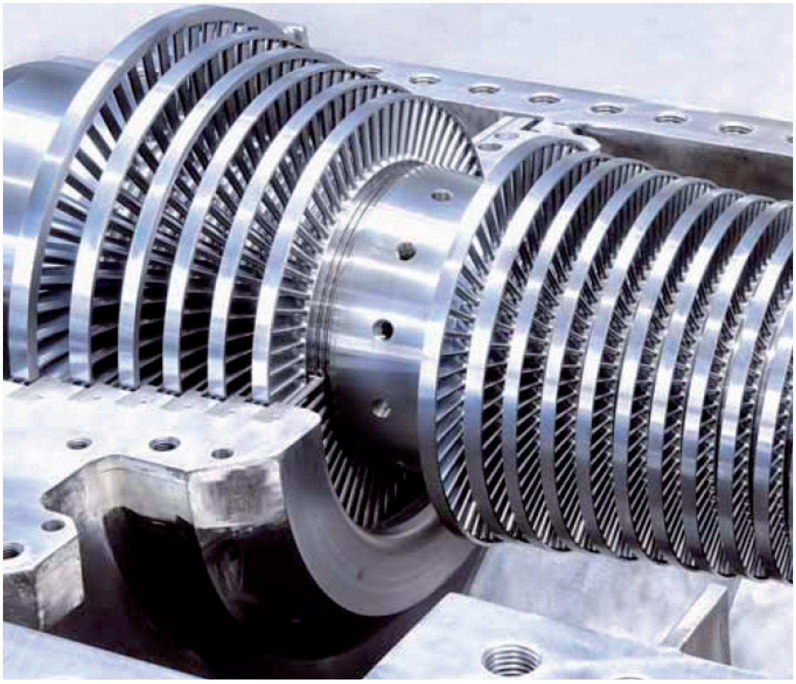
Chair for Thermodynamics - Prof. Dr.-Ing. Thomas Sattelmayer
Research at the Chair for Thermodynamics is inspired by the needs of the power generation industry. Fuel flexibility, emission reduction, stability and reliability of combustion processes (predominantly gaseous fuels) are important research topics. In particular, a broad portfolio of work on combustion instabilities has been developed, where the institute presumably is the strongest group worldwide. Additional activities in the areas of mobility, aerospace and energy efficiency are continuously being developed.

Institute of Internal Combustion Engines - Prof. Dr.-Ing. Georg Wachtmeister
The institute can provide the equipment and know-how for research projects on the development of internal combustion engines. Basic research on alternative drives and fuels is also executed. Beside this, the development of future combustion processes with our simulation tools and innovative concepts for recuperation will lead to higher efficiencies.

Chair of Functional Materials - Prof. Dr. Peter Müller-Buschbaum
The Chair of Functional Materials is concerned with polymers and their applications. One main topic is future photovoltaics. Thereby photo active semiconductors on polymer basics are used to gain electricity out of light. The research focuses on the structural characteristics which influence the efficiency of the new generation of solar cells.

■ *Compressor stage of an Alstom Gas Turbine*

■ *Turbine house of an pumped storage plant*



Network for Renewable Energy

NETWORK FOR RENEWABLE ENERGY

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www.nrg.mse.tum.de

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Institute for Functional Materials,
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Prof. Dr. Peter Müller-Buschbaum

CONTACT PERSON

Dr. Eva M. Herzig

The Network for Renewable Energy (NRG), headed by Professor Müller-Buschbaum (Chair for Functional Materials), is a network for inter-faculty research at the Technische Universität München, consisting of a multitude of different chairs at TUM which are focusing on the topic of renewable energy. It was founded within the TUM.Energy Network to create the opportunity to stem interdisciplinary, large-scale research projects and is one of the research centers that are interconnected under the umbrella of the Munich School of Engineering. Together, these centers follow the aim to achieve a sustainable energy supply of the future.

There is already an active participation of various disciplines to form the NRG: Physics, Chemistry, Mechanical Engineering, Electrical Engineering and Information Technology, Computer Science, as well as the Science Center Life and Food Weihenstephan, the Walter-Schottky-Institut and the Bavarian Center for applied Energy Research (ZAE Bayern).

Within NRG, both fundamental research in the field of new technologies and materials as well as improvement of existing technologies increasing their applicability are conducted. This research therefore has a wide range from nanoelectronics and material research, as well as microbiology and theoretical chemistry to biomass power stations, wave and solar energy systems.

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Technische Universität München
Institute for Functional Materials
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85748 Garching

TUM.SOLAR

The Solar technologies go Hybrid Research Network SolTech is an interdisciplinary project initiated by the Free State of Bavaria to explore innovative concepts for converting solar energy into electricity and non-fossil fuels. It concentrates on two areas; firstly, photovoltaics (i.e. the conversion of solar energy into electric current) and secondly techniques with which solar energy can be stored as chemical energy. The network is formed by five universities in Bayreuth, Erlangen-Nuremberg, Wurzburg and Munich. At each place well-equipped laboratories, the so-called key labs, integrated into existing internationally recognized research centers, have been set-up. TUM.solar is the key lab at the Technische Universität München.

New concepts for the controlled structuring of materials interfaces as well as the use of new materials for energy transformation and energy storage offer an enormous potential for pushing the utilization of regenerative energies into new areas in the future. The use of nanomaterials, organic-organic or organic-inorganic hybrid systems, enables completely new concepts and visions of energy transformation and energy storage.

TUM.solar is focusing on research in light-induced energy transformation and energy storage based on these nanomaterials and hybrid systems. There is a wide range of possibilities, from catalytic processes to low-cost photovoltaics. The respective basic questions refer to aspects of materials preparation and charge transfer at interfaces. For this purpose, TUM.solar combines complementary investigations by theoretical and experimental research groups in physics, chemistry, and electrical engineering.
Shape and mobility of future generations of solar cells could reach completely new dimensions by the use of new fluid-based production processes. These promise new possibilities of use, applicable in mobile entertainment electronics as well as in the power production of mega cities. Furthermore, new materials allow alternative production processes leading to considerably decreased production costs and thus promising future low-cost power production.

A completely different attempt to energy storage, far from nowadays' energy storage technologies, is offered by photocatalysis. Here the concepts are new catalysis materials and guided structuring of electrolyte interfaces which help to increase efficiency. Examples like photo-chemical reduction of carbon dioxide and water splitting are aspects which can direct to the so-called "green technologies".
Furthermore, the combination of photocatalysis and photovoltaics is expected to generate additional synergy effects. In integrated systems, the load transformation and the load storage can be directly connected on the nanoscale. The aimed optimization of symbiotical systems of photocatalysis and photovoltaics instead of individual optimization of independent singular systems is a new attempt and a central goal of TUM.solar.
Thus, research in TUM.solar covers the whole "chain of value creation" from energy transformation up to energy storage and hereby aspects of basic physical-chemical processes up to application-related questions such as the construction of prototypes. As a part of the "Network of Regenerative Energies" (NRG), TUM.solar is integrated in TUM.Energy, the faculty-general research project of Munich School of Engineering (MSE).

In 2013 the PIs working at TUM.solar were Prof Thomas Fässler (CH), Prof Katharina Krischer (PH), Prof Paolo Lugli (EI), Prof Peter Müller-Buschbaum (PH), Prof Karsten Reuter (CH); Prof Friedrich Simmel (PH) and Prof Martin Stutzmann (PH). In the ongoing projects on non-oxide semiconductor networks, CO2 conversion on silicon, nanoimprinting and coating techniques for hybrid solar cells, complex structured hybrid solar cells, theoretical optimization of organic solar cells and photocatalysis with group III-nitrides are detailed.

MORE ABOUT SOLTECH
http://www.soltech-go-hybrid.de/about-soltech/

MORE ABOUT TUM.SOLAR
http://www.tum-solar.mse.tum.de/

NETWORK FOR RENEWABLE ENERGY

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NON-OXIDE SEMICONDUCTOR NETWORKS

Ordered non-oxide semiconductor networks are auspicious materials for application in hybrid inorganic-polymer solar cells. In scope of the Bavarian research project "Solar Technologies go Hybrid" the Fässler group is developing, in close cooperation with the Fattakhova-Rohlfing group (LMU), synthetic strategies for the preparation of thin film non-oxide semiconductor networks starting from Zintl-Clusters.

For a successful buildup of a hybrid solar cell it is mandatory to level the electronic properties of both the inorganic and organic semiconducting part.[1] For the inorganic part non-oxide semiconductors offer a broader variation of optical and electronic characteristics as well as a low photooxidation activity, compared to the more frequently used metal oxides. By preparing mixed germanium/silicon materials Ge_xSi_{1-x} and introduction of dopants like phosphorus or boron, the electronic properties can be modified.[2]
Our research focuses on developing a solution based method starting from $[E_9]^{4-}$ Zintl-Clusters (E = Ge, Si) which enables the production of non-oxide semiconductor networks with defined morphology and electronic properties [1,2].

In 2013, we succeeded to set up a synthetic route for preparing germanium thin films adapting inverse opal structure, starting from $[Ge_9]^{4-}$ Zintl ions.
Close interdisciplinary cooperation with working groups, at TUM, LMU, WSI and ASCR, gave us the opportunity to characterize our germanium networks. With scanning electron microscopy (SEM), energy dispersive X-Ray analysis (EDX) (Fattakhova-Rohlfing group at LMU) and grazing incidence small angle X-ray scattering (GISAXS, in progress) (Müller-Buschbaum group) we revealed both morphology and chemical com-position of our thin films. X-Ray photo-electron spectroscopy (XPS) (Wintterlin group at LMU), Raman- and photo thermal deflection spectroscopy (PDS) (Brandt group at WSI) indicated frameworks consisting of amorphous elemental germanium. Aiming at tailored charge transport properties (Terahertz-Spectroscopy with Hynek Nìmec, ASCR) we currently work on tuning our synthetic strategies in order to prepare doped germanium/silicon networks $Ge_{1-x}Si_x$ (x = 0-1)[3,4].

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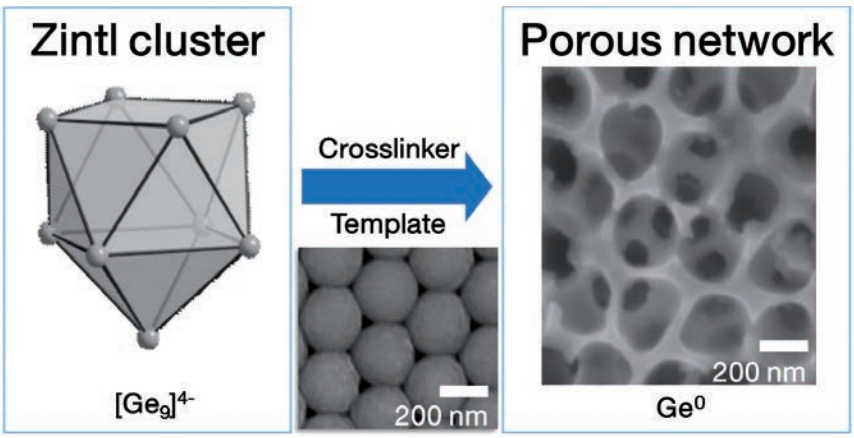

■ *Scheme of the synthetic strategy for preparation of thin film non-oxide semiconductor networks: Zintl-Cluster $[E_9]^{4-}$ are "filled" into the voids of a template structure and oxidative "crosslinked" to form elemental E. After removing reaction side products and the template structure ordered non-oxide semiconductor networks are obtained.*

CO_2 CONVERSION ON SILICON

Photovoltaic cells play an increasing role in our energy infrastructure. Despite decreasing costs and increasing efficiency this source of renewable energy poses the challenge that the energy is not produced on demand. Furthermore, the question of individual mobility in a cheap and sustainable way remains unanswered. As electrical energy is not easily stored and the energy density of existing storage devices is relatively low, a promising pathway toward a sustainable energy infrastructure lies in the energetic upgrading of CO_2 to carbon based fuels. Such fuels can then be converted into electricity on demand or used to drive cars. The research of the Krischer group is focused on the integration of suitable chemical catalysts into solar energy converters aiming at devices that, rather than producing electrical energy, directly convert solar energy into chemical fuels. As the precursor for these carbon based fuels we use CO_2. Together with existing technologies this offers a path towards a closed carbon cycle with zero net carbon emissions.

Silicon is a material ideally suited for solar energy conversion and the necessary technologies are well established and applied on a global industrial level. It is earth abundant, non-toxic and cheap. The challenge in adapting the silicon technology to chemical processes lies in the relatively poor catalytic properties of this material. The solution to this can be found by identifying a catalyst that is both compatible with silicon and active regarding the CO_2 reduction reaction. Such a catalyst can then be attached to the silicon surface modifying its chemical properties. To have the potential for industrial upscaling the catalyst should additionally be easily accessible, non-toxic and cheap. In our research we thus follow a twofold path: Firstly, the decoration of the silicon with metal nanoparticles as catalytically active reaction centers, and secondly, the attachment of aromatic molecules known to catalyze the CO_2 reduction.
For the first approach, a detailed understanding of the semiconductor|metal particle|electrolyte system is indispensable. To this end, metal arrays with different length scales and identical geometries are fabricated on silicon substrates using nanotransfer printing. These samples are then characterized regarding the size dependence of the photo-electrochemical properties and reaction product distribution. Furthermore, the composition of the metal structures themselves is varied and optimized.
The second approach focuses on two main tasks, the production of monolayers of the aromatic molecules and on the study of their catalytic properties. For this purpose, electrochemical methods like rotating ring-disk electrode measurements and surface characterization methods as e.g. x-ray photoelectron spectroscopy are employed. We already observed an increase in the catalytic activity of silicon surfaces modified this way. We aim toward a deeper understanding of the catalytic mechanism and a further optimization of the parameters for the surface preparation.
For all experiments a full quantitative analysis of the reaction products as e.g. methane, methanol, formic acid and carbon monoxide on a reasonable timescale is crucial. To this end, an electrochemical flow cell setup equipped with a differential electrochemical mass spectrometer (DEMS) and a high pressure liquid chromatograph (HPLC) was built up in our research group.

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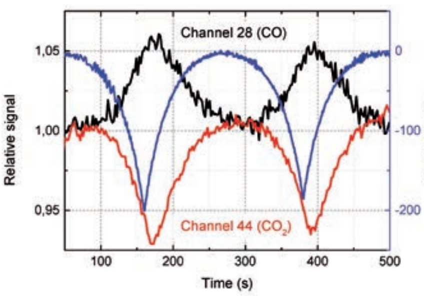

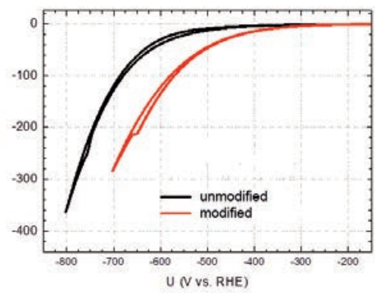

■ *Fig. left: Time resolved DEMS analysis of the CO2 conversion to CO at a gold electrode. The reduction of the amount of CO2 and the corresponding increase in CO are well visible as well as the good time resolution.*

■ *Fig. right: Decrease of the overvoltage necessary to reduce CO2 due to a surface modification with aromatic molecules.*

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M. A. Niedermeier, G. Tainter, B. Weiler, P. Lugli, P. Müller-Buschbaum
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Journal of Materials Chemistry A, Vol. 1, Issue 27, pages: 7870-7873,

■ figure left: Current-Voltage characteristics of organic solar cells with P3HT:PCBM as semiconductor fabricated with and without DIO additive

■ figure right:AFM characterization of the semiconductor layers

NANOIMPRINTING AND COATING TECHNIQUES FOR HYBRID SOLAR CELLS

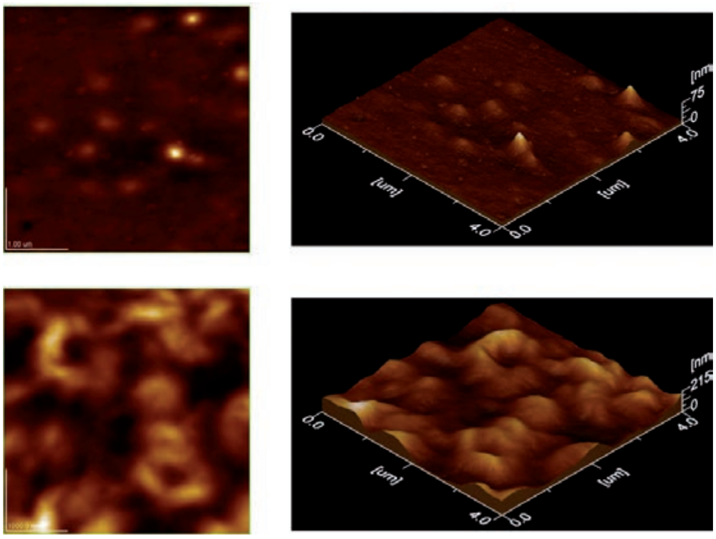
Organic solar cells have been realized using spin and spray coating techniques. The starting layout is that of the conventional bulk heterojunction with a [6,6]-phenyl-C61-butyric acid methyl ester (P3HT:PCBM) blend. The Lugli group is working on nanoimprinting and coating techniques for hybrid solar cells and has studied the effect of a 1,8-diiodooctane (DIO) processing additive.

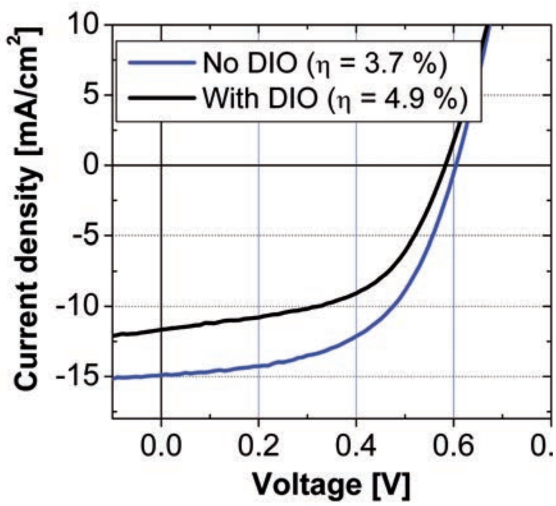
Experimental results show that the addition of a small amount of DIO to the solution (about 3% Vol.) results in a solar cell with a Power Conversion Efficiency (PCE) close to 5%. This represents an improvement of about 30 % compared to the PCE measured on a reference solar cell (Figure left).

In order to eventually be able to fabricate a whole solar cell via printing techniques, we have started the realization and characterization of electrodes via solution based materials (e.g. carbon nanotube, silver nanowires and PEDIT films). Preliminary results are very promising and indicate a full compatibility of the different processes.
The possibility to extend the spectra of the device to the Near-InfraRed (NIR) range by keeping the visible sensitivity was investigated. A low band gap material poly[2,6-(4,4-bis(2-ethylhexyl)-4H-cyclopenta [2,1-b;3,4-b0]dithiophene)-alt-4,7-(2,1,3-benzothiadiazole)] (PCBPDTB) was used. Preliminary results show that a ternary blend of P3HT:PCPDTBT:PCBM can be fabricated with an organic solvent with an extended sensitivity spectrum up to about 800 nm. Finally, we investigated the possibility to further extend the cell spectra by incorporating Si nanoparticles into the semiconductor layer. Preliminary results show that the addition of the nanoparticles to the blend results in an extra peak in the device quantum efficiency.

In addition we have used nanoimprinting techniques to realize patterns on the top surface of a solar cell (for instance in the form of electrode grating) or at any interface of a multilayer material system (for instance at the interface between bottom electrode and active layer,). By tailoring the dimension and the pitch of the grid it is possible to enhance the transmission or the trapping of light into the cell for specific wavelength.

From the simulation point of view, we have started an investigation of various solar cells (e.g.bulk heterojunction, bilayer and tandem) using a commercial drift-diffusion simulation code. In parallel, we are developing a kinetic Monte Carlo that will allow us to simulate hybrid cells and to investigate the effect of morphology.





COMPLEX STRUCTURED HYBRID SOLAR CELLS

Based on block copolymer assisted sol-gel synthesis nanostructured titania films are prepared by the Müller-Buschbaum group. Foam-like network structures are realized, with pore sizes of several tens of nanometers which are the n-type part of the hybrid solar cell. With different approaches these nanostructured titania films are superstructured. Nano-imprint lithography and wet imprinting are successfully established to create micrometer sized line gratings. Structure characterization is based on advanced scattering techniques as well as real space imagin

Today, photovoltaic devices are well established for conversion of solar energy into electricity and mostly based on silicon technology. With respect to next generation photovoltaic devices, inorganic-organic hybrid solar cells gain growing attention. These solar cells combine the advantages of the inorganic material like titania (titanium dioxide) with the advantages of organic materials, which are cheap, lightweight, easily manufactured and can be used on flexible substrates. In contrast to dye-sensitized cells no dye is necessary anymore and thus all problems related to the dye material such as photo-bleaching are ruled-out.

During the last years we have prepared different types of titania morphologies in thin films using the sol-gel technique. Sol-gel chemistry templated with a structure-directing micro-phase separation of an amphiphilc diblock copolymer solution results in a control of the structure on the nanoscale. Different morphologies are installed by the choice of the weight ratios used in the sol-gel synthesis. In particular porous nanostructures are of interest, with pore sizes of several tens of nanometers. Such foam-like titania films have high mechanical stability and provide a percolating network for charge transport.[1]

In this study, we present novel routes to obtain nanostructured titania films with additional superstructures on large areas via a combination of block copolymer assisted sol-gel processing with nanoimprint lithography and wet-imprinting.[2,3] We are able to demonstrate a successful routine for large area superstructuring with both approaches.
For demonstration purposes we fabricated a master structure of wavy, parallel channels which exhibits the typical colorful diffraction pattern of a line grating. This way we were able to add enhanced light scattering abilities to the titania film homogeneously over the full sample area in the order of several square centimeters while the bicontinuous foam-like nanomorphology with pores ranging from 25 – 45 nm in size is preserved.[3]

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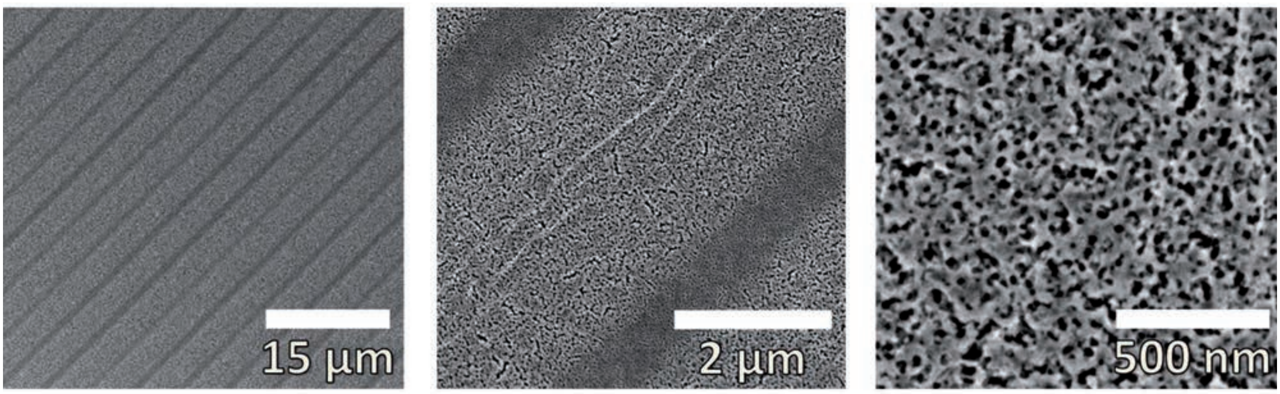

■ SEM images of super-structured titania film created via wet imprinting method. On the micrometer scale the line grating is visible and on the nanoscale the titania network is seen.

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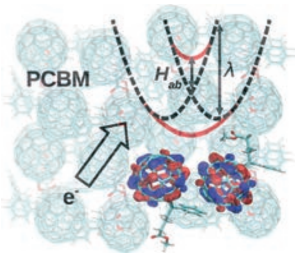
THEORETICAL OPTIMIZATION OF ORGANIC SOLAR CELLS

The Reuter group aims at systematically optimizing charge transport properties in solar cell components through a complete theoretical description of charge migration in the solar cell. In order to gain an insight on the interplay between microscopic structure and macroscopically observable charge carrier mobilities we rely on a so-called multi-scale approach based on first-principles electronic structure calculations and macroscopic charge transport models.

■ *Schematic of electron transport in a BCC PCBM crystal. Frontier orbitals participating in the transfer are depicted as blue and red surfaces. Marcus parabolae demonstrate the effect of electronic coupling Hab and reorganization energy*



The project so far has focused heavily on the development of computational and theoretical models to efficiently gauge microscopic charge transfer parameters. In collaboration with groups at University College London we first studied electron mobilities in Phenyl-C_{61}-butyric Acid Methyl Ester (PCBM) which is the electron accepting component in virtually all organic solar cells studied today. In accordance with the current state of the art in literature we first assumed a hopping model where localized electrons – so called small polarons – move from PCBM molecule to PCBM molecule via a series of discrete jumps. The site-dependent rates of the hops can then be described using Marcus theory of charge transfer or generalizations thereof.

The validity of such an approach rests entirely on the existence of a small polaron, that is in the presence of an energetic barrier for the electron transfer between molecules ($H_{ab} << \mu$). In our work [1] we could show that for all crystal structures of PCBM there is at least one axis along which that condition is not fulfilled. Our research thus clearly demonstrates that the mechanism of electron transfer in PCBM is only partially via hopping and partially via band transport. As these two mechanisms cannot easily be separated in a macroscopic description our future theoretical work will be based on the direct propagation of electrons with an effective Hamiltonian.

The central quantity of all above mentioned approaches is the Hamiltonian transition matrix element H_{ab}, which describes the coupling strength between donor and acceptor orbitals. Accurate estimates of the matrix elements are therefore absolutely necessary for every theoretical procedure, regardless of the underlying mechanisms. We therefore also put some effort into the development and improvement of computationally cheap yet accurate methods to calculate H_{ab}. We implemented [2] a highly efficient version of the Fragment Orbital- Density Functional Theory (FO-DFT) approach into the FHI-aims electronic structure package. The advantage of this new implementation is that it can make full use of the highly efficient numeric atomic orbital basis used in FHI-aims. Additionally, our new implementation profits from model chemistries beyond standard DFT such as the GW or RPT2 methods. In our FO-DFT implementation we also provide an embedding scheme based on the local electrostatic potentials of donor and acceptor, which allows us to account for polarization effects neglected in earlier versions of the method. First validations of this new approach were carried out on hole conduction in crystalline small molecule solar cells composed of pentacene and rubrene. Currently, we are working on applying the improved FO-DFT method to technically more relevant polymer cells in order to assess the connection between morphology and function.

Finally, on top of our development work we also collaborated with groups at UCL and the Karlsruhe Institute of Technology to provide a comprehensive set of benchmarks for transition matrix element calculations.[3] For a test set of small molecules, we compared our methods (FO-DFT and constrained DFT) and others (e.g. tight binding DFT) to high level quantum chemical methods. We found that overall FO-DFT yields very good accuracy yet with low enough computational cost to allow the study of large systems such as semiconducting polymers used in organic solar cells.

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PHOTOCATALYSIS WITH GROUP III-NITRIDES

The group III-nitrides GaN, InN, and AlN constitute a materials system which today is widely used and commercialized in solid state lighting as well as in high speed and high power electronics. In this project the Stutzmann group investigates possible applications of these semiconductors in electrochemistry and photocatalysis. In particular GaN and InGaN alloys have interesting properties in combination with silicon solar cells or as electronically active supports for catalytic nanoparticles.

The direct and efficient use of sunlight for electrochemical reactions such as water splitting is the fundamental requirement for artificial photosynthesis and the production of storable solar fuels such as ethanol. Three steps are necessary to achieve this goal: The transformation of solar photons into long-lived excited electronic states of a suitable absorber, the splitting of water, and the reduction of carbon dioxide to CO or C. Many optimized solutions and materials exist for each single process. For example, semiconductor solar cells can transform sunlight into electrical energy with efficiencies approaching 50%, and electrolytic water splitting with platinum electrodes has reached efficiencies of up to 80%. However, there are worldwide efforts to realize "artificial leafs", i.e. integrated devices which perform all three basic steps simultaneously in an optimal way.
In this context, we investigate the fundamental properties of the so-called group III-nitrides InN, GaN, and AlN. Of particular interest is GaN alloyed with InN (InGaN), because the optical absorption of this ternary alloy can be tuned continuously through the entire visible spectrum from the infrared (InN) to the ultraviolet radiation (GaN). This allows a good match to the solar spectrum. Samples are grown by molecular beam epitaxy either in the form of 2D thin films or as disordered and ordered arrays of nanowires, as shown below.

Thin films are used for the investigation of basic electronic and electrochemical properties, whereas nanowire arrays provide very large effective surfaces in a well controlled way. We combine the InGaN layers or nanowires in the form of heterojunctions with other materials such as silicon (for solar cells), diamond (for electrochemistry) or platinum (for catalysis).

As an example, the following paragraph shows the influence of substitutional doping of GaN on the catalytic activity of platinum nanoparticles which were deposited onto the GaN sample surface. As a test reaction we used the hydrogenation of ethene (C2H4) to ethane (C2H6). Without illumination, both n- and p-type doped GaN supports lead to the same catalytic conversion rate. Under illumination with abovebandgap light, however, platinum nanoparticles on p-type GaN exhibit a faster conversion, whereas the hydrogenation reaction for particles on n-type GaN is inhibited. Thus, the GaN support allows an electronic control of the catalytic activity of platinum nanoparticles, which can be explained by a specific electronic charge transfer between the GaN support and the nanoparticles under photoexcitation of GaN.

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The group III-nitrides have revolutionized the field of optoelectronics since 1990. This is due to the favorable electronic structure of these materials: their "direct" electronic bandgap enables strong and efficient optical transitions in the broad spectral range of light wavelengths between 1800 nm (InN) and 200 nm (AlN).

For applications in the field of photocatalysis, III-nitrides are very attractive not only because of their unique optical properties, but also because of their chemical, mechanical and electronic stability required for long-term use under varying environmental conditions.

The unique tuneability of electronic levels such as the conduction band, the valence band or the Fermi level in III-nitrides via alloying or substitutional doping makes this materials system particularly suited for heterostructures with other semiconductors or metals.

Molecular beam epitaxy (MBE) is the deposition method of choice to produce tailor-made semiconductor heterostructures with well-defined properties. In MBE, the different chemical elements such as In, Ga, or N are provided by independent high purity atomic or molecular sources, enabling full control of chemical composition on the level of atomic monolayers. In addition, a controlled variation of the growth conditions is used to determine the morphology of the deposited samples (continuous 2D films, quantum dots, or nanowires).

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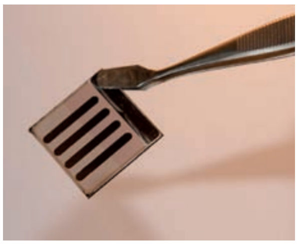
INTERFACE SCIENCE FOR PHOTOVOLTAICS - ISPV

The project Interface Science for Photovoltaics (ISPV) is one of the network projects within the Green Tech Initiative. It brings together researchers from each of the four EuroTech universities DTU, EPFL, TU/e and TUM. The initiative will focus on the development of future photovoltaic technologies and combine the knowledge from the fields of thin film and organic photovoltaics. ISPV focuses on fundamental issues within solar cell research.

The Green Tech initiative intends to guide and stimulate joint research projects under the strategic theme of Green Tech with the aim to foster research in environmentally friendly technologies and sustainable energy generation.

Thin film semiconductor solar cells, organic solar cells, and hybrids with organic and inorganic materials are among the technical options for photovoltaic technologies that will secure a continued lowering of solar cell prices; reduced materials use; and versatile design of photovoltaic systems.

Improvement of performance and lifetime are crucial issues for all the technologies when they are compared to crystalline solar cells that represent 90% of today's installations. The proposed initiative creates the basis for such improvements through understanding and characterizing the relation between structural morphology and performance and degradation in solar cells. Many important processes occur at interfaces in thin film and the even thinner organic solar cells. Transport of charge carriers; exicitons, impurities, reactive gasses – water and oxygen – are particular influenced by interfaces in the structure on both nano- and micro-scale. The photovoltaic effect itself relies on the existence of a junction between regions promoting transport of negative and positive charge carriers. Degradation mechanisms are often linked to interfacial properties. Both thin film photovoltaics and organic photovoltaics rely on materials with internal nano-scale morphology of the active materials – like nanotextured "black Silicon" and the bulk hetero junction of polymer solar cells. Likewise both technologies exploit interfacial layers for conduction and injection of charge carriers and transmission of light.



■ *Example of polymer solar cell fabricated based on conjugated polymers and electron accepting small molecules.*

The team represents two disciplines – thin film solar cells and polymer solar cells – with competences within both physics and chemistry of materials. The team will unite the experience in both disciplines and utilize the techniques and theoretical understanding of both areas. Through Ph.D. and master level exchange, through common projects and through educational activities, the team will seek to establish a lasting collaboration in the area of photovoltaics.

In 2013 the PIs working at TUM.solar were Prof. Martin Brandt (WSI), Prof Peter Müller-Buschbaum (PH) and Prof Martin Stutzmann (WSI). The projects were focusing on advanced interface engineering for silicon heterojunction solar cells, silicon heterojunction devices, polycrystalline solar cells and stability and performance of polymer solar cells, which includes objectives like exploring new material & controlling material properties, extending thin film preparation techniques, advanced interface analysis, mobility and interfacial effects under degradation, Interface states in solar cells and device physics & engineering. In the following selected examples are detailed.

SPIN-DEPENDENT PROCESSES IN ORGANIC SOLAR CELLS

Traditional magnetic resonance techniques combined with the sensitivity of an all-electric readout are used to investigate the spin dependence of charge transport processes in organic photovoltaics. The experiments might lead to a deeper understanding of the organic magnetoresistance effect and could enable a significant increase of the efficiency of organic solar cells.

The low fabrication costs of organic solar cells make them a competitive source of renewable energy. Further improvements of the efficiency of organic photovoltaics (OPV) are expected e.g. from advances in chemistry and the optimization of charge carrier transport. The latter could be achieved with the help of the natural magnetic moment possessed by electrons which are the charge carriers in organic or polymer thin films. This so-called spin has a decisive influence on the charge carrier dynamics, as for example observed in organic magnetoresistance (OMAR).

To understand the effect of magnetic fields in detail and to improve the efficiency of OPV, we study spin-dependent processes in organic solar cells using the method of pulsed electrically detected magnetic resonance (pEDMR), which has already proven to be a highly valuable tool to investigate charge transport processes in materials relevant for inorganic photovoltaics. In this experimental method, the combination of the selectivity of traditional magnetic resonance techniques and the sensitivity of an all-electric readout provides a unique insight into charge transfer and carrier recombination on a molecular level. The time resolution of pulsed in contrast to continuous wave experiments enables an investigation also of the dynamics of these processes. It is thereby possible to measure the time constants relevant for the different specific spin-selective processes such as the lifetime of spin pairs and the decoherence of spins. Moreover, this technique has an enormous potential in the investigation of the hyperfine interaction between charge carriers and their surrounding nuclei, allowing to microscopically map the wavefunctions of spin states.

Beginning with the model system of a bulk heterojunction of P3HT and PCBM we have performed pEDMR experiments in a wide temperature range from 4 K to 300 K, thus enabling a measurement of the temperature dependence of the spin dynamics. At low temperatures, we can spectroscopically distinguish positive and negative polarons and can demonstrate with experiments employing two different microwave frequencies that a spin-dependent recombination involving pairs of these polarons is monitored, identifying one of the dominant loss processes limiting the efficiency of P3HT/PCBM solar cells. Further experiments will include fast laser-excitation of charge carriers in order to increase the time resolution of the pair generation process, electron nuclear double resonance (ENDOR) experiments for the investigation of hyperfine interactions, and experiments at low magnetic fields to gain a more detailed understanding of the coupling between the spin partners. Another aim of this research will be to correlate the results of the pEDMR experiments with the findings of the group of Peter Müller-Buschbaum regarding the microscopic structure of different functional polymers and organic semiconductors.

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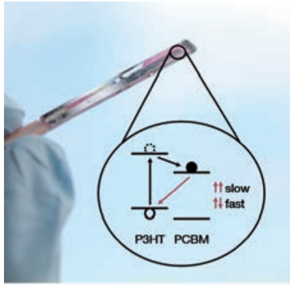

■ *An organic solar cell used for the pEDMR experiments. The inset shows a schematic depiction of the generation of positive and negative polarons via a charge transfer process. The rate of recombination of the two polarons depends on the fraction of polarons with anti-parallel spin orientation and can thus by manipulated by magnetic resonance.*

Organic magnetoresistance effect (OMAR): The conductivity of organic polymers can be tuned by the application of magnetic fields.

Pulsed electrically detected magnetic resonance (pEMDR): Spin states experience an energetic splitting called Zeeman splitting when an external magnetic field is applied. Incident microwave radiation induces transitions between these states, thus enabling or quenching charge transfer and recombination processes, which in turn are observed by a change in photoconductivity.

Solar cells used in these experiments consist of an indium tin oxide (ITO) coated glass substrate, a hole transport layer (HTL) of poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), a bulk heterojunction formed from poly(3-hexylthiophene-2,5-diyl)/[6,6]-phenyl C61 butyric acid methyl ester (P3HT/PCBM) and an aluminum top contact. The active area is approximately 5mm².

NETWORK FOR RENEWABLE ENERGY

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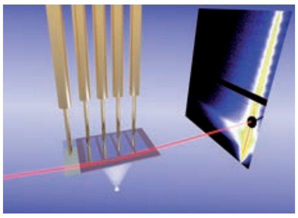
STABILITY AND PERFORMANCE OF POLYMER SOLAR CELLS

Organic solar cells, especially those based on polymers are inexpensive to produce on a large scale. Thanks to their physical flexibility, they can open up new applications of photovoltaics not possible today. Moreover, they can convert light into electricity at an efficiency of more than ten per cent and could contribute significantly to a large-scale power supply based on renewable sources. However, the efficiency of organic cells still rapidly declines and they have a shorter service life than conventional silicon cells. Thus the Müller-Buschbaum group is investigating aging and stability of polymer solar cells.

Long-term stability of organic photovoltaic (OPV) devices is still among the key problems. In principle, the stability of polymer solar cells has been thoroughly investigated. The degradation of OPV devices is mainly due to oxygen and air chemically altering the system during exposure to light and degradation of other device materials or diffusion into the active layer. However, morphological changes on the nanometer sale have not been addressed so far. As the nanometer scale structure, which is formed by the active materials used in organic bulk-heterojunction solar cells, plays a crucial role for functioning, alterations in these structures alter the solar cells performance drastically. Clearly, such changes display a pathway of polymer solar cell degradation if they occur during operation.



■ *An in-situ study of a running polymer solar cell using µGISAXS and IV tracking reveals both changes in the active layer's nano-morphology and a decay of the short-circuit current during an early stage of operation. We explain how this decay is driven by the changing morphology.*

Using standard methods like UV-Vis, PL and AFM, information on absorption and photoluminescent properties as well as on local surface structure are obtained. Further understanding is gained from various scattering techniques. X-ray reflectivity (XRR) allows the determination of film thickness, surface roughness and refractive index profiles while grazing incidence small angle x-ray scattering (GISAXS) can determine dominant domain length scales throughout large volumes of the probed OPV films. Additionally, grazing incidence wide angle x-ray scattering (GIWAXS) can resolve the arrangement within the samples on a molecular scale, giving information on the crystallisation of the involved components.

Due to the fact that semiconducting polymers conduct electricity anisotropically the arrangement of the semiconducting polymers is very important because it will directly relate to the conductivity and therefore the performance of the solar cells. Hence, GIWAXS is a very powerful tool in the analysis of function-structure relationships.

We performed an in-situ study on a model polymer-fullerene solar cell during the first hours of operation.[1] It reveals information on both, its evolving current-voltage characteristics and active layer nano-morphology. For that purpose, micro (focused) µGISAXS measurements and current-voltage (IV) tracking of an operating solar cell are performed simultaneously. Domains of pure material on nanometer scale within the device's active layer are found to grow and drift apart during operation while the short circuit-current decreases. Based on Monte-Carlo simulation, these nano-morphological changes in the active layer are found to fully explain the decrease of the short-circuit current with time.[1]

[1] C.J.Schaffer, C.M.Palumbiny, M.A.Niedermeier, C.Jendrzejewski, G.Santoro, S.V.Roth P.Müller-Buschbaum: A direct evidence of morphological degradation on a nanometer scale in polymer solar cells; Adv. Mat. 25, 6760-6764 (2013)

Science Center for Electromobility

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INTERDISCIPLINARITY AND COOPERATION

The Science Center for Electromobility is TUM's interdisciplinary research institution which addresses all relevant questions regarding electric and hybrid vehicles. Its activities cover various fields such as fundamental research on new battery chemistries, applied science including the implementation and testing of prototypes, and the development of holistic and intermodal mobility concepts.

The Science Center for Electromobility connects 18 institutes based in six departments

Department of Architecture

- Chair of Industrial Design

Department of Civil, Geo and Environmental Engineering

- Chair of Traffic Engineering and Control

Department of Chemistry

- Chair of Technical Electrochemistry

Department of Electrical Engineering and Information Technology

- Institute for Electrical Power Plants and Power Electronics
- Institute for Electrical Energy Storage Technology
- Institute of Energy Conversion Technology
- Institute for Energy Management and Application Engineering
- Institute for Integrated Systems
- Institute for Real-Time Computer Systems

Department of Informatics

- Chair of Software and Systems Engineering
- Chair for Application and Middleware Systems

Department of Mechanical Engineering

- Institute of Aerodynamics and Fluid Mechanics
- Institute of Ergonomics
- Institute of Automotive Technology
- Institute for Machine Tools and Industrial Management
- Institute for Machine Elements
- Institute of Aircraft Design
- Chair of Thermodynamics

Furthermore, vital communication exists with companies from the automotive and electronic industry sector as well as with energy suppliers. Some of these companies, namely Audi, BMW, Bosch, Daimler, E.ON, Infineon, MAN and Siemens are very close partners as they are members of the Industry Advisory Board of the Science Center for Electromobility. With these partners, research activities are coordinated in periodic colloquia and information above research progress and results is exchanged. In 2013, the colloquia were held in February for internal and in July for internal and external coordination.

Close partnerships with industries guarantee efficient and up-to-date research

SCIENCE CENTER FOR ELECTROMOBILITY

GENERAL INFORMATION AND FOCUS AREAS

As most research questions regarding electric or hybrid vehicles are interdisciplinary, the Technische Universität München founded the Science Center for Electromobility as early as 2010. In this cluster, individual research groups are connected with each other, which facilitates working successfully on projects with an integral scope.

The main goals of the Science Center for Electromobility are:

¬ It concentrates research and development activities concerning electromobility
¬ It creates additional competence teams as well as education programs for electromobility at TUM
¬ It enables fundamental research for innovative long term developments (e.g. in the field of energy storage)

Cross-departmental research for interdisciplinary research challenges

Furthermore, the Science Center for Electromobility offers a forum for the exchange of the latest research results and for general communication of all partners involved. Hence, the current complex challenges can be addressed quickly and efficiently and a common strategy can easily be coordinated.

In order to guarantee a large research scope and to effectively use possible synergies between electromobility and other relevant sectors, the Science Center for Electromobility is integrated within the TUM.Energy, research activities of the Munich School of Engineering. The research questions mentioned comprise improvements of components for electric vehicles, their integration into suitable vehicle architectures, the assessment of modern mobility needs and the integration of electric vehicles into electricity systems such as the public grid or a private household system.

VISIO.M – LIGHT, EFFICIENT, AND SAFE

Within the joint research project Visio.M well- known companies of the German automotive industry, together with scientists from the Technische Universität München, explore how the price and safety of small, efficient electric vehicles can be brought to a level enabling them to achieve a significant share of the mass market. As their test carrier the consortium partners use the electric vehicle prototype MUTE developed by the Technische Universität München to explore innovations and new technologies for vehicle safety, propulsion, energy storage, and operational concepts for implementation under the framework requirements of large-scale production.

Up to now, it has been a case of “either/or”. On the one hand, there is the typical ultra-compact, lightweight electric car, with which designers have had to compromise on safety. With larger e-cars on the other hand, the heavier frames and crumple zones come at the expense of battery runtime. The aim of the Visio.M project is to develop a mobility concept for an efficient electric vehicle, making the design as light as possible, while still delivering the best possible safety protection.

The Visio.M engineers decided in favor of an innovative monocoque body structure. Typically used in racing cars, a monocoque chassis combined with lightweight materials enables good stability while keeping overall weight to a minimum.

The lightweight design innovations may be impressive, but driver and passenger safety is still the number one priority of the Visio.M project. The sturdy carbon fiber structure will incorporate various dedicated active and passive features addressing the specific safety challenges of an ultra-compact electric car. The ideas being investigated include specially adapted seatbelts as well as other innovative concepts to minimize potential injuries in the event of an accident. By the end of the project, the researchers hope that they will have achieved the maximum possible level of safety.

An experimental vehicle has already passed the initial chassis tests. The chassis control systems, i.e. the anti-lock braking system and the torque vectoring system, have been put through their paces at a test site near Munich – marking another successful step in the move to develop a safe electric vehicle.

PROJECT PARTNERS

Participants in the Visio.M consortium are, in addition to the automotive companies BMW AG (lead manager) and Daimler AG, the Technische Universität München as a scientific partner, and Autoliv BV & Co. KG, the Federal Highway Research Institute (BAST), Continental Automotive GmbH, E.ON AG, Finepower GmbH, Hyve AG, IAV GmbH, InnoZ GmbH, Intermap Technologies GmbH, LION Smart GmbH, Amtek Tekfor Holding GmbH, Siemens AG, Texas Instruments Germany GmbH and TÜV SÜD AG as industrial partners. The project is funded under the priority program „Key Technologies for Electric Mobility - STROM“ of the Federal Ministry for Education and Research (BMBF).

■ *Experimental vehicle during chassis test*

SCIENCE CENTER FOR ELECTROMOBILITY

Teleoperated driving enables completely new mobility services

Furthermore, the researchers of the Institute of Automotive Technology have demonstrated the safe operation of the so-called teleoperated driving in public traffic. The experimental vehicle is equipped with six video cameras (five for the front and one for the back) and all vehicle functions can be controlled by a central unit. The video signals are transmitted via a secure connection to the operator workstation which is equipped with three wide-angle screens, a force-feedback steering wheel and pedals. The workstation is therefore similar to a driving simulator. Parallel to the visuals, spatially correct sound is also transferred to the operator workstation using a Dolby 5.1 system.

In case of a limited bandwidth or a complete disconnection, the vehicle is able to automatically decelerate to a full stop. Despite all technological possibilities, some legal hurdles have to be overcome in order to make this technology suitable for daily life. Nevertheless, the involved researchers of TUM are convinced that teleoperated driving might become reality within the next five to ten years. The cost is rather small as cameras and electronics are less expensive than other accessories today. The applications of the technology are plenty: from a car-sharing vehicle which is provided at the front door, to parking services in city centers, to remotely controlled electric vehicles driving to the next charging station.

■ *The experimental vehicle during teleoperated driving*

■ *EVA*
Vehicle structure made of CFRP

■ *EVA*
Integration of the battery pack in the EVA prototype

TUM CREATE: EVA - ELECTROMOBILITY FOR TROPICAL MEGACITIES

In 2011, the cooperation between TUM and the Nanyang Technological University (NTU) in Singapore started under the name “TUM CREATE”. This research program is part of the CREATE Campus (Campus for Research Excellence and Technological Enterprise) and is funded by Singapore’s National Research Foundation (NRF). Beside top-class universities such as the Massachusetts Institute of Technology, the University of California, Berkeley, Cambridge University, and the ETH Zurich, TUM was selected as another top-class research partner.

The vision and mission of all research projects within TUM CREATE is titled “Electromobility for tropical Megacities” and addresses various relevant aspects on different levels of electromobility: the slogan “from the molecule to the megacity” represents the versatile challenges ranging from fundamental research on future battery chemistries, to approaches regarding urban planning and energy optimization, to the applied sciences which aim to solve the specific technological challenges involved with electric vehicles.
The structure of this programme not only resembles that of TUM’s Science Center for Electromobility, but the existing network within the cluster significantly facilitated the acquisition of this project.

Besides numerous interesting research questions from all relevant topics, a key point in 2013 was the completion and presentation of the EVA prototype at the Tokyo Motor Show. This vehicle concept was especially developed for being used as a taxi in Singapore and considers all requirements of tropical megacities. Although taxis represent only 3 % of the vehicle fleet in Singapore, they are responsible for 15 % of the total mileage driven in the city. Hence, an effective and positive leverage effect of taxis can be used for improvements within the overall mobility sector.

EVA: charging for 200 km range within 15 minutes

However, using an electric vehicle as a taxi poses some serious challenges: these include especially the limited range related to the vehicle battery and the long charging times. For this reason, EVA is equipped with a large 50 kWh battery and a super-fast charging system was developed which facilitates charging for a distance of 200 km within only 15 minutes. The involved thermal stress on the battery can be compensated by an intelligent combination of the vehicle’s cooling system and the integration of phase change material (PCM) in the battery pack.

Lightweight CFRP vehicle structure

In order to compensate for the weight caused by the large battery, lightweight materials were used intensively. With this approach, a vehicle structure was developed that exclusively consists of carbon fiber reinforced plastic (CFRP).
Furthermore, numerous elements were integrated in the vehicle which consider a change in future mobility patterns. Assuming that the occupancy of taxis will increase in the future, individual adjustment of the air condition system and the entertainment system were made possible for each passenger via smart phone.

The completed prototype of EVA was demonstrated at the Tokyo Motor Show in November 2013. The testing of the prototype will take place in the beginning of 2014.

■ *Presentation of the EVA prototype on the Tokyo Motor Show 2013*

SCIENCE CENTER FOR ELECTROMOBILITY

Research on synergies between household and electric vehicle

SUN2CAR@GAP

This research project is part of the activities in the pilot municipality (German: Modellkommune) for electromobility in Garmisch-Partenkirchen. The Institute of Automotive Technology (Department of Mechanical Engineering) and the Chair of Traffic Engineering and Control (Department of Civil, Geo and Environmental Engineering) address the overall system, which comprises an electric vehicle and the electric system of a single family house which uses photovoltaic (PV) panels to produce electricity. This project aims at using synergies which arise from coupling the vehicle and the building and seeks to enable CO2 neutral driving or maybe even a negligible CO2 impact of the overall system. For this, the battery of the vehicle is a key element that can be used as storage whenever the PV system generates electricity.

The project was launched in 2013 and is scheduled for a period of two years. In a first step, the emissions occurring, both from driving and from the building are monitored and reduction potentials are analyzed. In order to record the driving and to estimate the related emissions, 50 test persons who are living in 20 households are equipped with a smart phone which tracks and records their mobility behavior. Later, the test persons receive suggestions of how to reduce their CO2 emissions in the future, and their willingness for behavioral adaptations is analyzed.

The project was made possible through the cooperation of both research disciplines: whereas the Institute of Automotive Technology is responsible for the modeling of the vehicle technologies and the prediction of the related emissions, the Chair of Traffic Engineering and Control has sound experience in using empirical methods. Hence, linking both disciplines is a very fruitful combination that widens the possible scope of research. Partners in this project are the Audi AG and the Forschungsstelle für Energiewirtschaft.

Virtual fleet test delivers reliable data at a minimum cost

VIRTUAL ELECTROMOBILITY FOR TAXI AND TRADE TRANSPORTATION IN MUNICH

In another interesting research project electric vehicles and their properties are simulated on a smart phone which is installed in a conventional vehicle. The sensors of the smart phone record speed and acceleration, and the electricity consumption of a virtual electric vehicle is simulated. With this approach the usability of the simulated vehicle can be tested. The goal of the project is the development of electric vehicle concepts which are suitable for a taxi and for trade transportation. Furthermore, the location of charging stations and charging technologies are tested and their influence on the infrastructure is assessed.

By using only a few real electric vehicles, the model and the simulation results can be evaluated and validated. As a large number of applications and test persons can be analyzed without requiring a high number of electric vehicles, the analysis becomes significantly cheaper than usual fleet tests with a large number of real electric vehicles.
The main results of this project are estimations regarding technical, ecological and economic aspects of electric vehicles in taxi and trade fleets.

External partners in this project are the Stadtwerke München, the Taxiverband München and the Handwerkskammer für München und Oberbayern. The project was launched in late 2012 and a great amount of data was already collected throughout 2013.

PUBLICATIONS, AWARDS AND PATENTS

Using a survey among the partners of the Science Center for Electromobility, reliable figures regarding its activities and achievements could be collected.

16 received delegations
2 sent delegations
11 publications and awards
10 patents

EXTERNAL PROJECT PARTNERS

As indicated within the earlier descriptions of the projects of the Science Center for Electromobility, there are numerous industrial project partners. These do not only comprise vehicle manufacturers and their suppliers but also various other companies such as electronic and semiconductor manufacturers and large energy suppliers. Besides, companies dealing with the overall picture of mobility, its analysis and prediction are important partners. Obviously, other research institutions working on the subject of electromobility are also suitable partners for high quality research.

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TRANSITION OF THE BUILDING SECTOR

The building sector plays a key role in the transition of the energy system. The Center for Sustainable Building faces this challenge with interdisciplinary research. The enormous technical transformation potential is simultaneously used to create livable environments. This task cannot be handled by a single actor, therefore the center uses its collaborations within the Technische Universität München and with other European partners to develop optimized solutions.

The building sector offers extensive potential to reduce the energy demand as well as to integrate renewable energies. The transformation of the sector is one of the central aspects of the energy plan of the German government and therefore high demand is placed on the transformation strategies. In recent decades, buildings have evolved into highly engineered systems whose sustainable design and use is influenced by many factors. The process for the interplay of on the one hand the actors and on the other hand the integrated building components, technologies and power systems, must be defined in the early design stage of new buildings and retrofittings. There are still numerous research questions about the individual components and their interaction, which are of central importance for selecting the right strategies. Different perspectives and levels of analysis are required to examine the function, the potential and the ability for integration of a technology.

INTERDISCIPLINARITY AND COOPERATION

At the Center for Sustainable Building, these research questions are addressed by an interdisciplinary team of engineers, architects, scientists and mathematicians. These different competences and perspectives lead to comprehensive research, by means of intensive information and knowledge exchange. Knowledge transfer and collaboration happen between the different disciplines involved in the center, along with numerous other chairs at the Technische Universität München as well as international partners. These include, as part of the EuroTech the DTU Copenhagen, the Technical University of Eindhoven and EPF Lausanne and 21 other European universities, working together in the framework of the European COST Action „Smart Energy Regions“. Research projects arise from clients from industry and municipalities, research cooperations and doctoral programs.

Interdisciplinary work on different levels provides the basis to assess the impact of policy decisions in their technical dimensions. Creating development strategies for sustainable and livable buildings, neighborhoods, cities and regions by securing the conservation of resources for future generations is the central goal of the various collaborations.

MODELING THE FUTURE

A central component of the work of the Center for Sustainable Building is the modeling of systems on different scales. Starting at the federal state level, future remediation rates, costs of building renovation and the energy demand of millions of buildings is modelled. At the urban level modeling is integrated in the conditions of the overall concept of the whole city. In collaboration with the disciplines of urban planning, spatial development, transport planning and energy economics, the impact of different city transformation strategies is assessed. At the level of the individual building, future building technology systems and building envelopes are developed by the investigations over the entire life cycle.

CENTER FOR SUSTAINABLE BUILDING

PRESENTATION OF FOCUS AREAS

A major focus of the Center for Sustainable Building is the design of sustainable, more livable and future-oriented cities. In order to provide substantive contributions to the necessary transformation to low-carbon and energy-efficient structures, the Center is working on multiple scales, from the building façade up to groups of millions of buildings. Therefore, the "EmMi" (energy modeling multi-scalar) model is developed at the Center. "EmMi's" modular structure offers the possibility to combine the different research areas of the Center for Sustainable Building and thus enables quantitative assessments of the impact of several interventions on the energy demand of the building sector. The examinations are not only taking into account technical, but also economical and sociological issues to develop applicable concepts. Finally validations are done with real buildings or building components.

Development of sustainable, future-oriented cities

The research and design of sustainable, more livable and future-oriented cities is a major focus within the Center for Sustainable Building. The necessary transformation to low-carbon and energy-efficient structures offers extensive transformation potential that can effectively contribute to the design of urban space.

In interdisciplinary collaboration among various departments of the Technische Universität München future proposals of more people focused cities are designed. On the basis of these proposals possible development paths are identified. These proposals are linked to the current stock situation and provide a specific conversion and target logic [6]. To make statements about the recommended developments in terms of energy efficiency, the energy demand and the energy supply considerations are combined in order to create a coordinated development strategy.

Scenario studies on energy-saving in construction

Local climate and energy use expand the typical architectural and engineering questions. In order to optimize the energy demand, i.e. to reduce the energy consumption, individual refurbishment strategies of the thermal envelope of the building, depending on use case, are examined and developed. In parallel, the energy supply of the building is considered with the aim of future use of renewable energy. The examined scenarios take into account not only the energy, but also the cost of building refurbishments to develop applicable concepts. In addition to the technical and economic studies, sociological issues are integrated. The motivation of the diverse users and owners is investigated, in order to make proposals to increase the refurbishment rates in Germany. In addition, the effects on the tenant structure of energy modernization of buildings are investigated and possible support instruments are developed, i.e. for hot rental neutrality.

Integration of electromobility in the building

Mobility, and perhaps in the future electromobility, plays an important role in sustainable urban and building design. The intelligent communication between the energy management system of the building and the vehicles can increase the utilization of the self-generated renewable electricity. In this context, the potential of Load and Demand Side Management is simulated and will be validated in a real building.

Building and façade

For energy generation on site, the building envelope plays a crucial role. In addition to the roof, the façade of sustainable buildings should be used to generate energy. However, the façade must still act as the interface between natural exterior and artificial interior space, providing high level comfort and at the same time minimizing the energy consumption of the building. At the Center for Sustainable Building new façades are investigated and developed in cooperation with other European research institutions and industry partners.

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Besides the investigation of the façade technology, the energy saving potential of the new building types in the urban context is analyzed, e.g. for local heating and cooling networks or seasonal storage. The investigations by the Center for Sustainable Building from façade up to city scale are not only done for the operational phase, but over the entire life cycle to ensure holistic optimization scenarios.

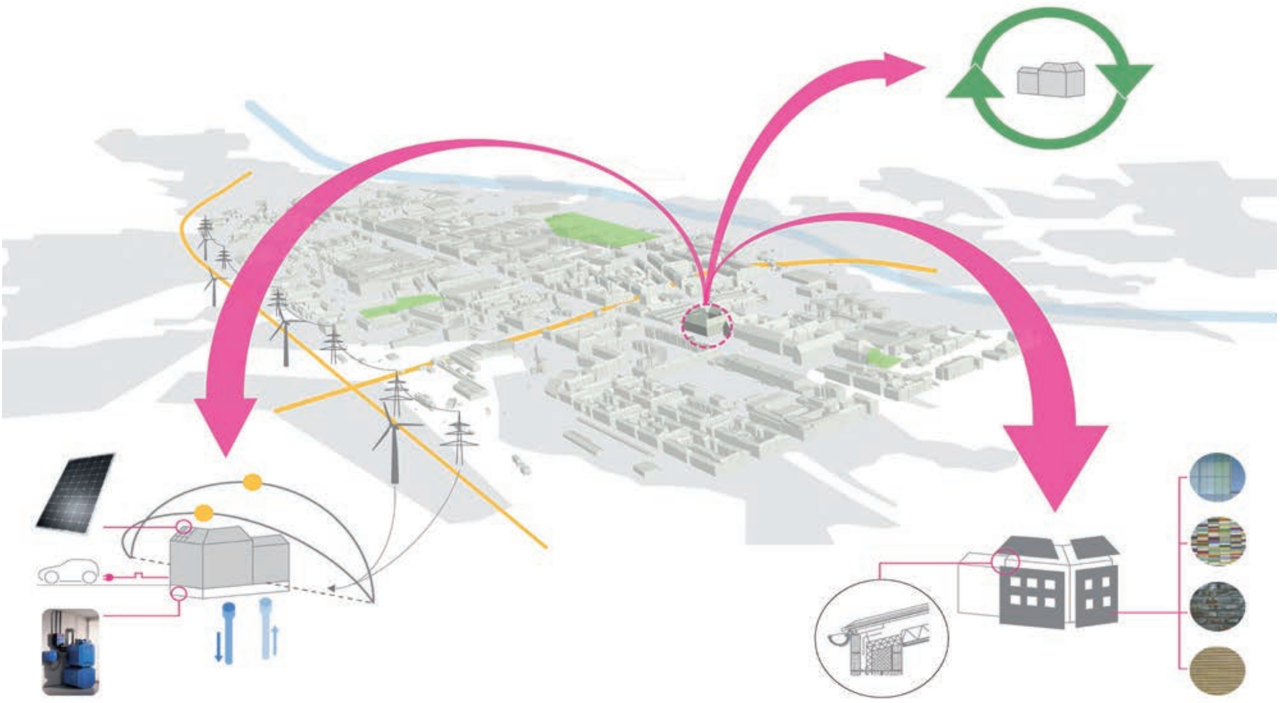
Multi-scalar energy modeling

At the Center, the "EmMi" (energy modeling multi-scalar) model is developed in order to investigate the development of the energy demand for single buildings as well as for groups of up to 3.5 m buildings. Sensitivity analyses are used to quantify the effect of energy interventions on the energy demand of the building stock. The modular structure of the model offers the possibility to combine the different research areas of the Center and thus enables quantitative assessments of the impact of several interventions on the energy demand. Furthermore, it can be expanded continuously with new elements and linked to other models which, for example, are investigating the optimization of the energy supply.

[8] P. Geyer, I. Nemeth, W. Lang, G. Wulfhorst, R. Priester, "Systems modelling considering qualities and quantities for strategies of sustainable development of a liveable urban district in Nuremberg," Proceedings of the International Workshop: Intelligent Computing in Engineering 2012, TU München, 2012.

[9] I. Nemeth, K. Elbel, M. Hoppe, M. Lindauer, P. Schneider, M. Windeknecht, „Energetische Gebäudesanierung in Bayern," im Auftrag der Vereinigung der bayerischen Wirtschaft und dem Verband der Bayerischen Metall- und Elektroindustrie e.V., Munich, 2012.

[10] W. Lang, "Sinnvolles Sanieren versus Abriss und Neubau," ibr Informationen Bau-Rationalisierung, Magazin der RG-Bau im RKW – Rationalisierungs- und Innovationszentrum der deutschen Wirtschaft e.V. Heft Nr. 5/6, 40. Jahrgang, S. 3 – 5, Dez. 2011.



CENTER FOR SUSTAINABLE BUILDING

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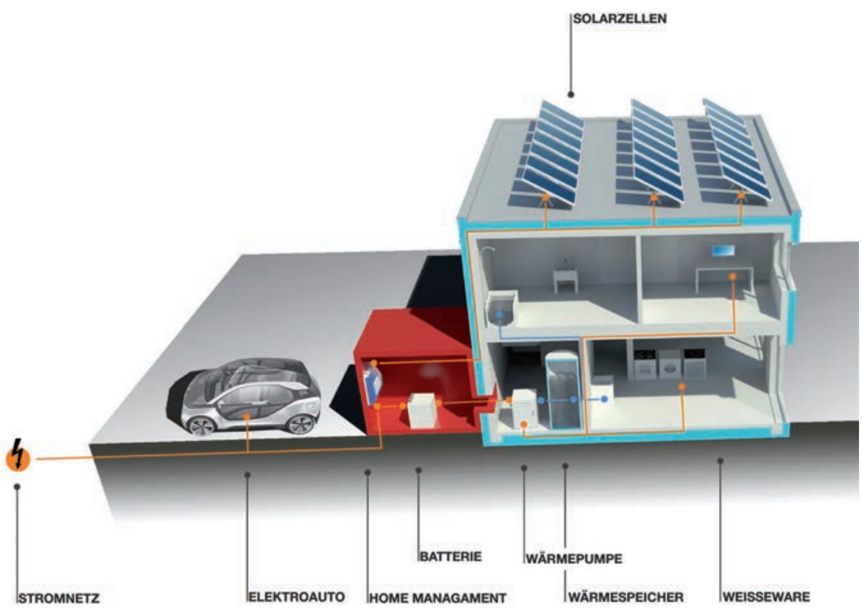
- *SMA Solar Technology AG*
- *Institute for Energy Economy and Application Technology, TUM*
- *Center for Sustainable Building, TUM*

„E-MOBILIE" – ENERGY SELF-SUFFICIENT ELECTRO MOBILITY IN THE SMART-MICRO-GRID

In the future, electromobility will become more important for the whole energy system in Germany. The project "e-MOBILie" investigates the possibilities to create an integrated energy management system, which connects buildings with electromobility and optimizes the energy utilization. The energy management system will be demonstrated in a real building in 2015.
The project follows the integrative approach to combine the energy transition and e-mobility for the user by optimally linking local regenerative energy generation and e-mobility. The target is to develop a decentralised energy management system (EMS) which controls the energy flows inside an intelligent building and to an electric vehicle (EV), simultaneously guaranteeing the best comfort for the user. The approach of this decentralised EMS is that devices of different manufacturers exchange information and interact in an energy market inside a single building in order to achieve optimal utilization of energy. The research project already determined which information should be exchanged.



■ *Schematic illustration of the involved devices: electric vehicle, wallbox, PV system, electric storage, heat pump, heat storage, hot water distribution, household applications, home management device.*

The research is not only focused on the development of the EMS, but will also analyze the economic and ecological effects of the system. To achieve this, the project is divided into the following project phases:

- ¬ Review of fundamental information linked to the topic
- ¬ Analysis of the boundary conditions for the usage of the EMS
- ¬ Creation of a simulation environment
- ¬ Installation of a hardware-in-the-loop test bench connecting the involved devices and allowing tests for the implemented interfaces
- ¬ Demonstration of the functionality in a single-family-house with privately used EVs
- ¬ Demonstration of the functionality in a parking garage with a fleet of EVs
- ¬ Assessment of the potential of the system

For the Center for Sustainable Building the main focus of the project is the application of the EMS in a single-family-house. For this demonstration, an Energy-Storage-Plus building provided by Dynahaus will be used, which, on the one hand, generates more energy than is used for heating and household applications. On the other hand, the building provides electrical and thermal storage systems, and can therefore act as a service provider for the grid.

In 2014, this building will be constructed in Hallbergmoos and equipped with a heat pump heating system, an air ventilation system, a PV system, measurement devices, an EV, and the energy management system connecting all devices. In parallel the potential of the energy management system will be investigated using a simulation environment.

In 2015 the demonstration phase of the project starts, in which a family will live in this building and test the whole system to achieve data on the real behavior of all involved systems. This data will then be used to validate the results of the simulations and to optimize the system.

■ *Dynahaus building with an electric vehicle that will be used for the demonstration phase in 2015. The building will be equipped with measurement devices to assess data on the thermal and electric behavior. A family will evaluate the functionality of the energy management system under living conditions. Source: Dynahaus*

CENTER FOR SUSTAINABLE BUILDING

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- *University of Stuttgart, Institute for Lightweight Structures and Conceptual Design (ILEK),Germany*
- *Interstate University of Applied Sciences and Technology (NTB), Switzerland*
- *Commissariat à l'énergie atomique et aux énergies alternatives (CEA-INES), France*
- *Mayer Glastechnik GmbH, Austria*
- *GlassX AG, Switzerland*
- *Hoval Aktiengesellschaft, Liech tenstein*
- *CNE Research and Innovation Center LTD (CyRIC), Cyprus*
- *ALCOA Europe Commercial SAS (KAWNEER Innovation Centre), France*
- *AMIRES s.r.o., Czech Republic*

FLUIDGLASS

The FLUIDGLASS project is developing a new and innovative concept for multifunctional solar thermal glass façade systems. The fluid glass approach turns passive glass façades into active transparent solar collectors which simultaneously are controlling the energy flow through the building envelope and providing the user with perfect comfort. It is perfectly suited for both, retrofitting of existing building stock and construction of new buildings for all climate zones.

Fluid glass unites four key functions in one integrated system:

- *Transparent solar thermal collector*
- *Transparent insulation layer*
- *Overheating protection system*
- *Heating and cooling device*

The thermal energy absorbed can be transferred to other parts of the building or, at district level, used within an energy network or collected in a seasonal storage system. Fluid glass increases the thermal performance of the whole building resulting in energy savings, while at the same time improves the comfort for the user significantly [1].

The basic concept of fluid glass is the integration of liquids and insulating glass within the transparent façade. The liquids are used for controlling the energy flows between the natural environment and the artificial interior space. The selected design consists of two liquid layers which are thermally separated. The liquid layer that is oriented to the exterior is used as a shading element and as a solar collector. The inner layer serves also as a shading device and or as a heating or cooling surface, depending on whether the circulating liquid is hot or cold [2]. To reduce the solar transmission the liquids can be colored in order to increases the absorption. For the heat transfer, the glass façade is connected to a liquid circuit which is again connected to the building service system via heat exchanger.

The Technische Universität München has been working on the research project FLUIDGLASS in collaboration with the University of Liechtenstein since 2010. During this period, simulation models were developed and validated with the results from measurements at the Technische Universität München at the Chair of Energy Management and Application Technology. The first simulation results showed significant energy saving potentials with fluid glass facades. In Munich, 20% energy savings can be achieved, in Dubai even up to about 40% for fully glazed administrative buildings with fluid glass, compared to state of the art single glass facades [3].

The Centre for Sustainable Building has been working within the EU research project FLUIDGLASS with several European partners since September 2013 [1]. The project is scheduled four years.

The Center for Sustainable Building's focus in this project is on simulations in different scales and Life Cycle Analyses (LCA). A simulation model of the fluid glass was created and will be improved within the EU-project in cooperation with the University of Liechtenstein and the Interstate University of Applied Sciences and Technology Buchs (NTB). Simulations of buildings and district energy networks in different cities will be done.

■ FLUIDGLASS prototype (Dyed) at the test facilities at the Technische Universität München at the Chair of Energy Management and Application Technology

The EU project is divided into eight work packages:

WP 1: Requirements and specifications – Defined set of functionalities for the individual components and the whole system.

WP 2/3: Collector and Façade development – Simulation, design and manufacturing of the components.

WP 4: System integration – Collector and façade components integrated and robustly connected to building automation.

WP 5: Testing of components and assembly – System ready for demonstration.

WP 6: Validation at real life conditions – Proof of applicability.

WP 7: Public awareness and exploitation (over the entire project duration)

WP 8: Management and coordination of the consortium (over the entire project duration)

[1] EU research project „FLUIDGLASS", financed by the European Commission under the seventh framework program, Grant Agreement No. 608509 (www.fluidglass.eu).

[2] Stopper J., Gstoehl D., Ritter V., (To be published), "Fluidglas – Verschattung und Raumtemperierung mit flüssigkeitsdurchströmten Glasfassaden", Detail Green, Munich, (expected to be published in Mai 2014).

[3] Stopper J., Boeing F., Gstoehl D., „Fluid Glass Facade Elements: Energy Balance of an Office Space with a Fluid Glass Façade", Sustainable Building 13, Munich, 2013.

CENTER FOR SUSTAINABLE BUILDING

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ENERGY REFURBISHMENT OF BUILDINGS IN BAVARIA

The study investigated possible scenarios for the energy demand of the building sector in Bavaria in order to reach the 2050 saving targets. A major result is that the number of refurbishment activities has to be increased while at the same time the transition to renewable energy utilization in buildings has to be accelerated. The requirements on the refurbishment quality have less influence.

Targets of the project

The central question of the study is how to realize the minimization target of the energy consumption in the building sector by 2050. Because of the ambitious aim to reduce the CO2 emissions by 80 % by 2050 a systematic and proactive approach is required to deal with the heterogeneity of the building stock and the expected social and economic changes.

The study also analyzed the potential of design strategies and instruments to resolve the lack of information of the building owners and to overcome the many existing barriers. By performing sensitivity analyses on the possible developments on the energy demand side and the energy supply structure, scenarios were investigated to reach the 2050 targets.

VARIABLE PARAMETERS:
Refurbishment quota: modest/intense
Refurbishment quality: moderate/ambitious
Share of renewable energy: conservative/renewable

Approach and boundary conditions

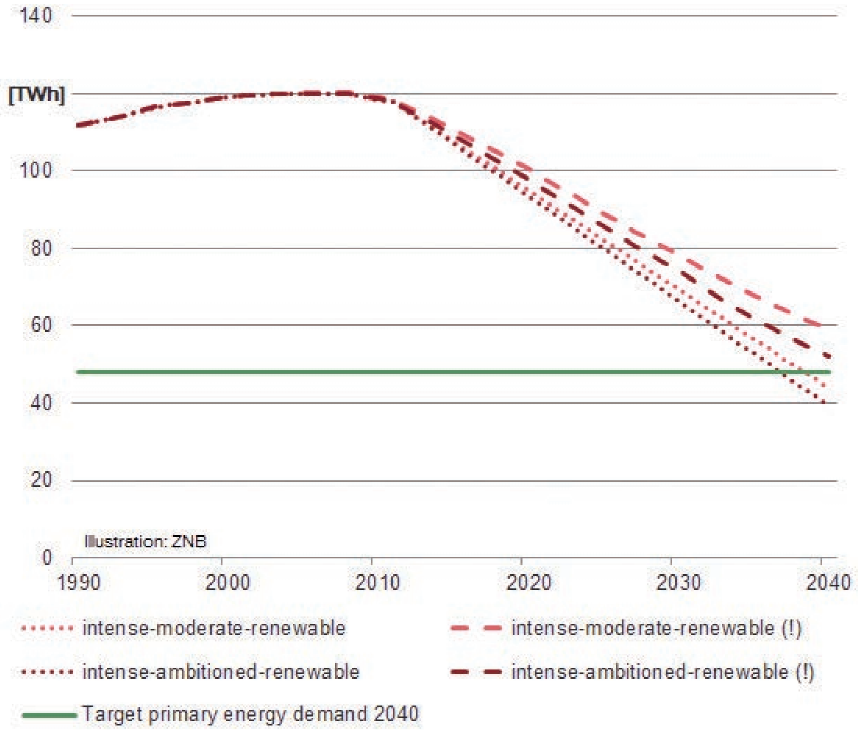
The observation horizon of the study is the year 2040.
The focus is the energy demand of the residential building stock in the future. Several developments of refurbishment activities in combination with possible developments of regulatory requirements were analyzed and evaluated. To assess the impact of demand reductions on final and primary energy consumption of residential buildings several developments in the energy supply were examined. These were taken from the study „Model Deutschland – Klimaschutz bis 2050. Vom Ziel her denken“ [Kirchner et al. 2009] and adapted to Bavarian conditions. The verification of the applicability of the adapted energy source structure was not included in the present study.

Results

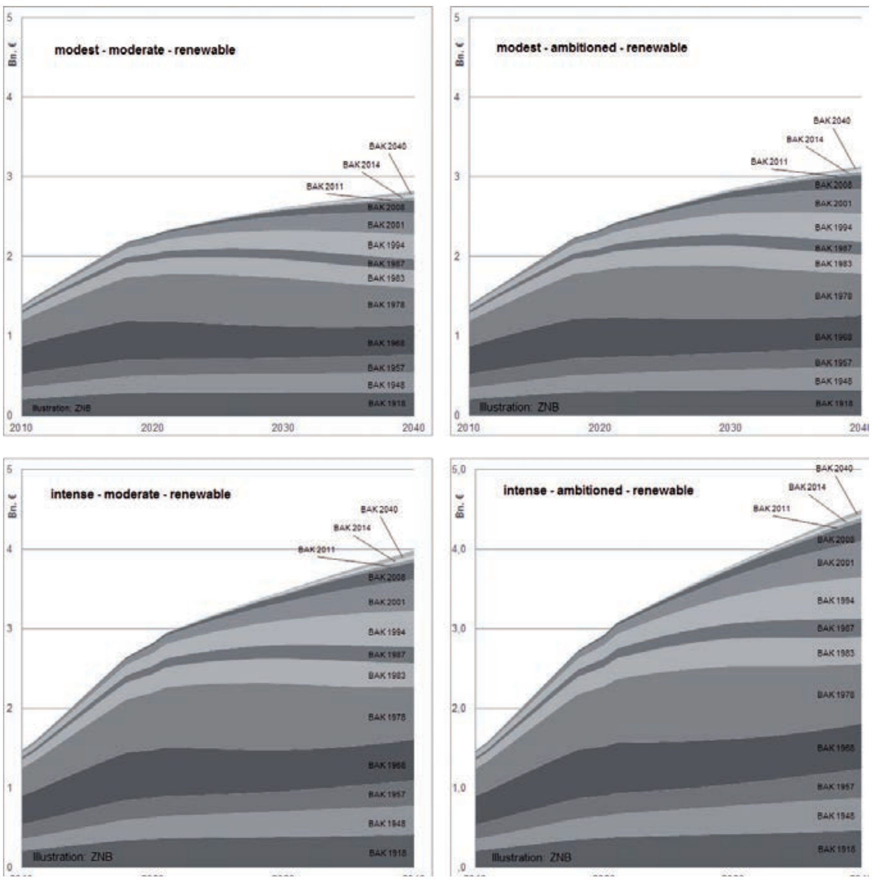
The simulation of different scenarios shows that increasing the refurbishment activities provides greater energy-saving potential than further raising the energy requirements for the building envelope. Nevertheless, the portion of refurbished buildings as well as the refurbishment quality have to be improved to achieve the defined goals.
The large share of buildings from the 1960s and 1970s immediately requires a targeted activation of the owners of these buildings. For these mostly run-down buildings a high refurbishment potential could be achieved by pending changes of ownership.

The scenarios for the development of primary energy clarify the need for the transition towards renewable energy sources for covering the energy demand for heating and domestic hot water. The reduction of primary energy demand by 60 percent by the year 2040 compared to the year 2008 will only be possible with a rapidly increasing share of renewable energy sources.

The cost for the renovation of the building envelopes of all Bavarian residential buildings varies significantly in the considered scenarios depending on the volume of renovations and energy requirements. For the renovation of the building envelopes annual costs of €1.4 billion in the least ambitious scenario were calculated. In the most ambitious scenario the annual costs rise to €4.4 billion.



■ Progress of primary energy demand in different scenarios
The targeted primary energy demand for 2040 can only be reached using renewable energy. But if the usage of solar thermal energy generation will be reduced to small buildings (scenarios with (!)), the target won't be reached in time. In the definition of the scenarios "moderate" means, that the requirements on the quality of energy refurbishments won't change compared to the requirements in 2011. "Ambitioned" means, that the requirements will be increased step by step.



■ annual costs for refurbishment measures
Annual costs for building envelope refurbishments in the four renewable scenarios, split for various building age classes.

CENTER FOR SUSTAINABLE BUILDING

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STADTLABOR NÜRNBERGER WESTSTADT

The tremendous economic, social and ecological changes of the recent years have altered fundamentally the framework for urban development initiatives. The increasingly complex conditions raise questions about the sustainability of our cities, which can only be answered with a long term orientated and interdisciplinary approach. The strengths and weaknesses of cities must be analyzed to assess their transformation potential in the direction of "livable cities" with a sustainable environment for living, working, and leisure.

Task
In the City of Nuremberg the structural changes are quite apparent. The displacement of area intensive industrial uses created large plots of vacant land and caused the loss of local jobs. A reinterpretation of the urban structures as well as the adaptation and optimization of infrastructure and building stock is required. Energy efficient refurbishment and a sustainable energy supply are needed for the transition towards a low-carbon, energy-efficient and livable city for coming generations.

In the project "Urban Lab Nuremberg West" an interdisciplinary team of six departments of three departments of TUM cooperated with the goal of describing a sustainable refurbishment of the district Nuremberg West by 2050. Hence, an approach was developed allowing collaboration across the different specialists' areas of urban, regional, and landscape planning and energy efficiency as well as mobility.

Approach
The project is divided into two main parts: definition and analysis, and projection. In the definition and analysis phase, the objectives of sustainable development for the various technical issues and for the overall project are defined. In the projection phase possible future developments are derived and presented. In three steps, key statements and considerations about limits and potential for future development were bundled together.

Step 1: Energy effciency and the integration of renewable energies are very important for all scale levels of the investigation. Therefore the analysis of these two issues was done in the first step in order to assess the potential for further development. Basic lines of development are described, and the main influencing parameters are varied. Apart from the urban and spatial development, the limits and possibilities of emission reduction were assessed.

Step 2: Sub-spaces and individual sites: In spatial considerations, the transformation possibilities of the quarter were formulated for seven strategic locations. Feasible development scenarios show the necessities, the transition potential, and the impact of interventions. With the knowledge of key drivers and dependencies, the possibilities for transition can be conceived and represented in functional chains.

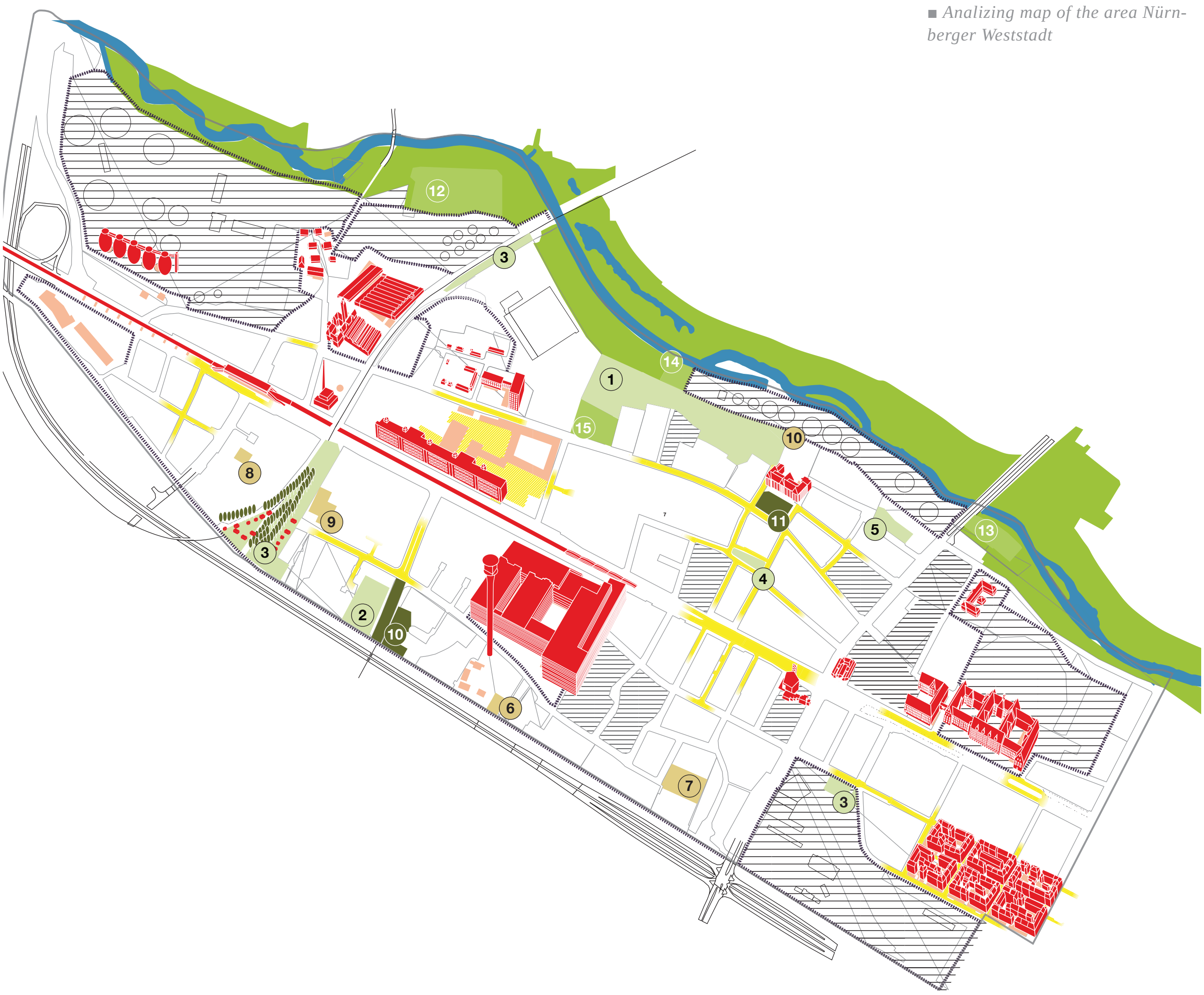
Future Alternatives: Three specific visions of the quarter show possible developments in relation to the main influences. The future situation of the quarter is drawn and the paths to achieving the development are shown. Dependencies, temporal, and spatial conditions as well as the process of change are defined.

Results

The Nürnberger Weststadt offers a number of possibilities to deal with resources in a sustainable way. A massive increase of energy efficiency is needed to comply with the objectives of the German "Energiekonzept" in order to tackle the shift of our energy system. Long term strategies to implement retrofitting of infrastructure and buildings have to be initiated promptly, but they offer a high potential for strengthening the transformation of the quarter towards a sustainable city. The study describes both, generic influences on the transformation of the quarter and particular ways to tackle the transformation process. The municipality of Nuremberg should therefore lead the way with their own real estate and act as an advocate for the transition process.

Awards

Distinction for innovative interdisciplinary research approach in the research project „Stadtlabor Nürnberger Weststadt" within the competition „Historische Stadtkerne – integriert denken und handeln" tenderd by the German government. Berlin, August 2013.



■ *Analizing map of the area Nürnberger Weststadt*

Center for Energy and Information

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HEAD

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The Center for Energy and Information is a research initiative within MSE mainly led by the Department of Electrical Engineering and Information Technology. This initiative will be based in a newly to be build center at Garching research campus. The new building will also offer office and lab space for other MSE activities like the Junior Research Groups and the new chair for Renewable and Sustainable Energy Systems. The building should also become a center for public participation in Bavaria.

Research of the center will focus on the new design of the electricity system under the assumption that a large fraction of power will be supplied by intermittent renewable sources. These challenges can be summarized as follows: the power produced in remote sites under ideal conditions for wind and solar power needs to be transported to the demand centers and the temporal mismatch between production and demand needs to be balanced. Different approaches are proposed to overcome these challenges: Energy storage like batteries, large power networks, flexible demand or the introduction of new energy carriers like hydrogen are the most prominent ones.

The name of the center implies that a new paradigm in energy and information research should be pursued. This kind of research will bring together classical energy researchers and groups that are stronger in information and communication technologies. A new design of the power system needs to be developed. A first and very central question is regarding the control philosophy of the system: control is by now mainly guaranteed by synchronous generators which react in a natural way to changes in the frequency of the power system which indicate a mismatch between production and consumption.

In the future, power will be more and more fed into the system by power electronics and here mainly by invertors which did either convert the dc-voltage from PV generators or curtailed the ac-voltage of wind turbines to match the frequency of the power grid. The simple and natural control philosophy of the former system gets lost. This requires a change in the control philosophy and means in most cases that much more information about the status of the systems needs to be available.

Another complication will arise when the demand becomes more flexible than today. This higher degree of freedom offers certainly more possibilities to control the system but it does also challenge the stability. Will households, office buildings and companies in the service or the production sector change in a way that the demand can be curtailed according to requests from the power production side? Many individual investigations are done to study the potential of flexible demand and which try to show how these potentials could then be applied. Technical, economic and many regulatory hurdles need to be overcome to make this a technical reality. Electromobility could be one of the key technologies for flexible demand as could be also power-to-heat.

The center will address these questions on a theoretical and simulation level. The currently developed power grid model of the ENTSOE will serve as a starting point. Besides this, a micro-grid laboratory will be designed and set-up to verify simulations and to make more refined hardware in the loop simulations with the micro-grid as hardware component. The micro-grid will be rather flexible and will include generation technologies like PV, micro-wind and micro-chp plants as well as storage technologies mainly batteries and flexible demands, here especially the HVAC system of the building itself. Parallel to the power grid an information grid will be designed and constructed to demonstrate various possibilities to serve the new information needs of the new power grid. The combination of a micro-grid and the building itself will be an important research tool.

To make this happen, a research project will soon be launched to study options for flexible demand within the building itself. The building design process will be accompanied by serious simulations. A refined sensor network based on energy harvesting technology will be established from the very beginning to analyze the exact state of the building at any moment in time. Since all construction details will be available it will be possible to bring all these details into the simulation. In combination with a refined sensor network it will then be possible to verify simulation technologies with the building.

One major issue will be the future design of the system on the urban level. The urban or sub-urban level makes it possible to investigate the coupling of power systems to other energy sectors like the heating sector and the traffic sector. These couplings require new infrastructure on the energy and the information side. Since the federal and state government intent to extend the information infrastructure in the coming years by setting up a fast communication network based on broadband communication technologies. The planning and design of these networks can be harmonized with the planning and design of new power. Already existing district heating networks and the newly installed communication network can also be used to serve the needs of a future smart grid.

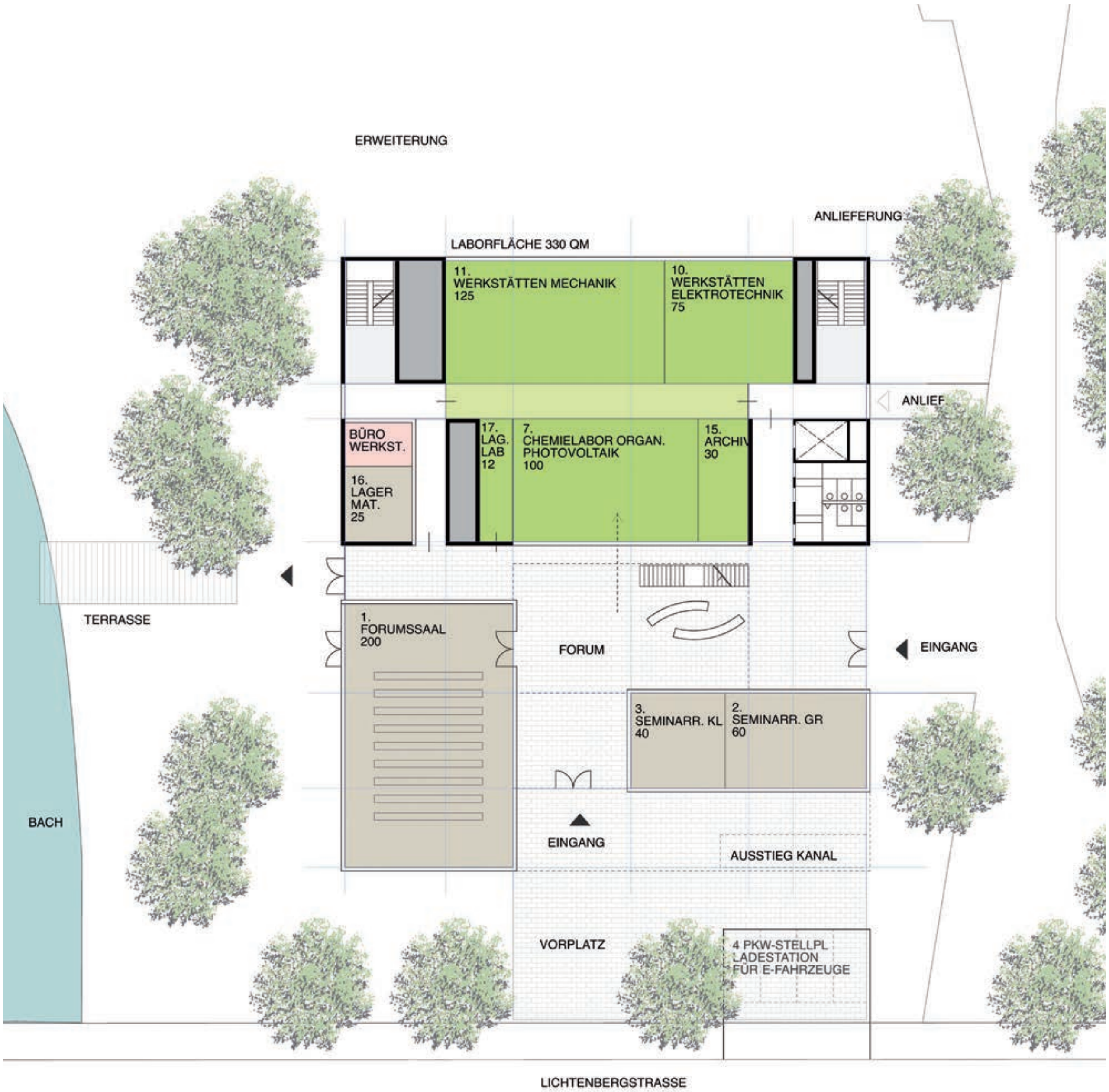
The center will also be used to strengthen activities in the field of public participation. This will be done in a threefold way: first, it will enhance education activities in this respect at university. Second, it will establish a new tenure track position for public participation most likely in close collaboration with the Munich Center for Technology and Society. And third, it will become a center for public participation processes within Bavaria which will be mainly concerned with questions around the energy transformation process.

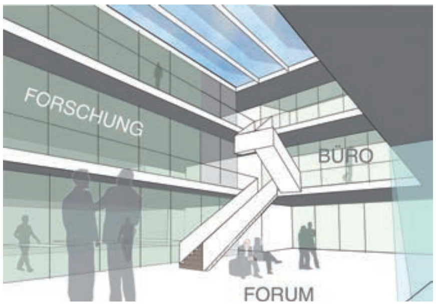
CENTER FOR ENERGY AND INFORMATION

One of the first major questions here will be related to the future wind energy extension. MSE already started with a dedicated course on public participation in winter semester 2013/14. This course was meant as a pilot project. The analysis of the course will help to define more in detail the teaching concept necessary to help engineers in becoming more familiar with these concepts. It seems rather likely that engineering needs to establish these concepts in an early planning stage. Only if people can really participate in design processes with a realistic chance on impact if and how a project will be realized in the end, it is likely that some of the major hurdles we see in infrastructure projects can be overcome in the long term.

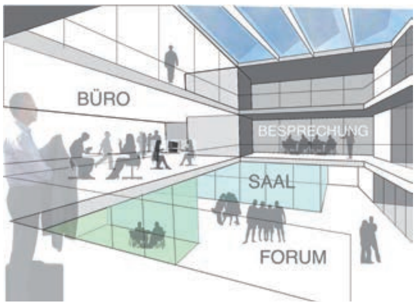
Design concept by Fritsch+Tschaidse Architekten GmbH, as per April 2014

■ *floor plan ground floor*

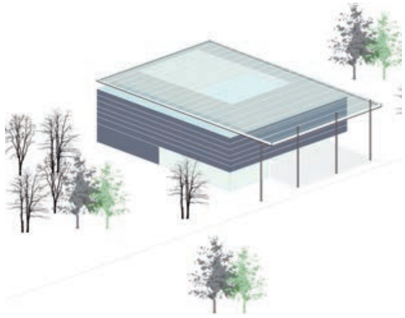




■ *atrium ground floor*

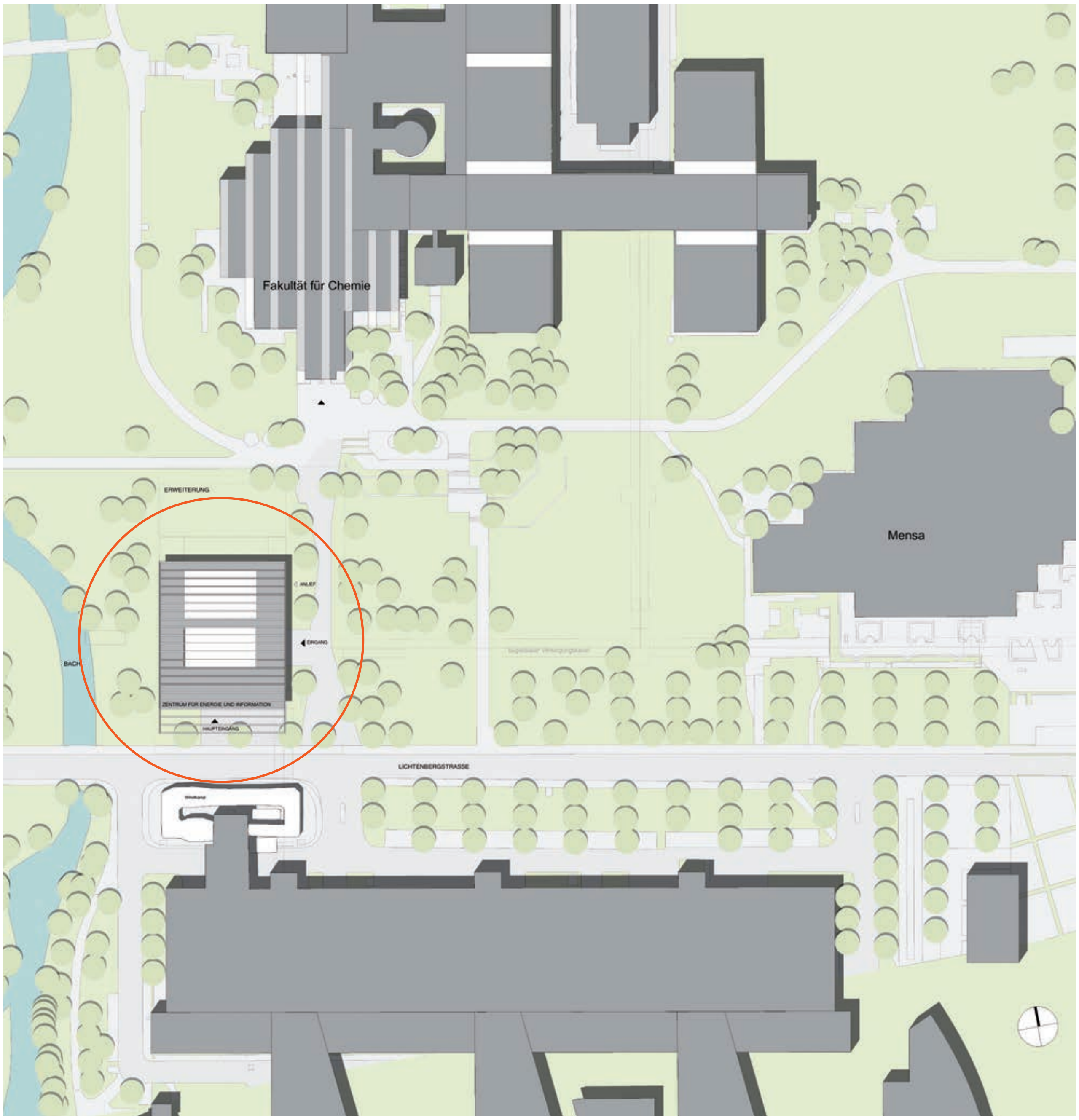


■ *atrium 1st floor*

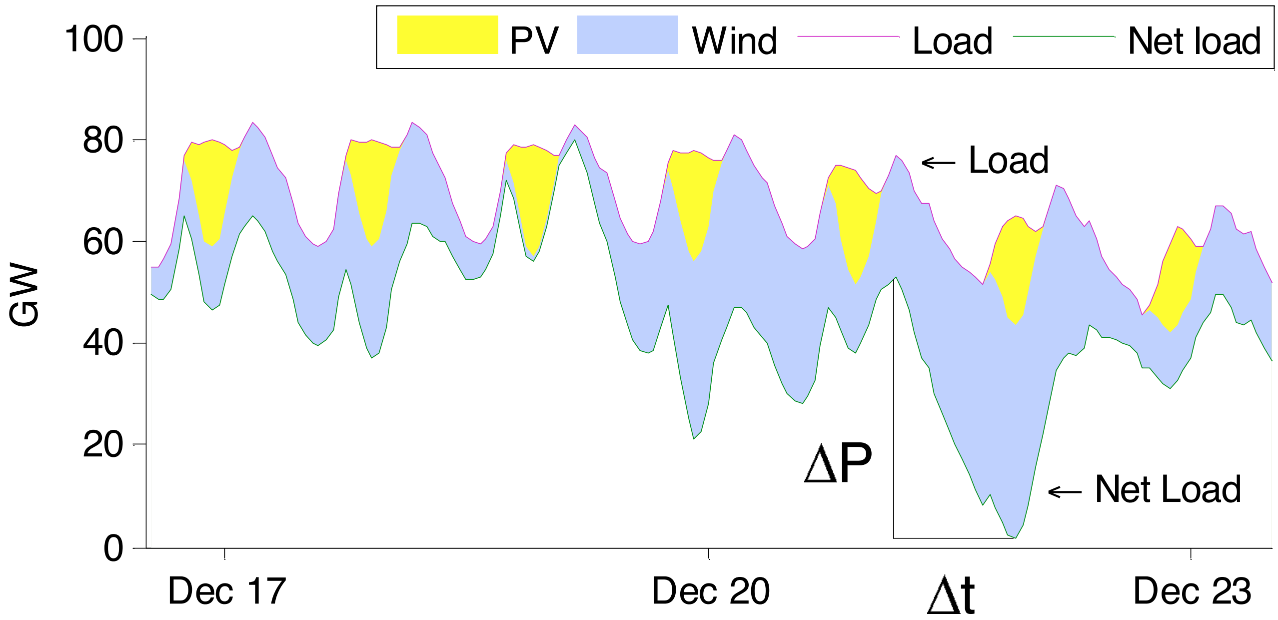


■ *view of the building*

■ *location plan*



Research Projects



■ *Illustration of net load ramps in a power system with high shares of wind and solar power*

Huber, M.; Dimkova, D. & Hamacher, T.: Integration of Wind and Solar Power in Europe: Assessment of Flexibility Requirements. Energy, 2014

TUM.Energy Valley Bavaria (EVB)

In 2012, in the aftermath of the nuclear accident in Fukushima, the Bavarian government increased its efforts to promote research in the field of energy transition with additional 500 Mio Euro. MSE was successful with its proposed program „Energy Valley Bavaria" which is funded with 10 Mio Euro for the period of five years (2012-2016).
Energy Valley Bavaria aims at simplifying the integration of renewable energies in the electricity market by making the electricity system more flexible through new power plants, new storage facilities and more flexible loads.

Three different tools were developed to address the challenges: projects between departments, junior research groups and seed funding projects.

In the project flexible power plants mechanical and electrical engineers investigate the possibilities to redesign conventional power plants so that they can help to integrate fluctuating renewable energies without major compromises in lifetime and economics.

Three junior research groups could be established in so diverse fields like organic pv, control of wind turbines and energy efficient and smart cities.

The seed funding money helped to initiate projects in many fields and turns out to be a very strong tool to bring researchers together from various departments and institutions.
A detailed description of the projects is given in the following pages.

DURATION
01.06.2012 – 31.12.2016/18

PROJECT COORDINATION
Prof. Gasteiger
Prof. Hamacher
Prof. Wall

FUNDING
10 Mio. €
by Bavarian State Ministry of Education, Science and the Arts

Bavarian State Ministry of
Education, Science and the Arts

Flexible Power Plants

FLEXIBLE POWER PLANTS
www.evb.mse.tum.de

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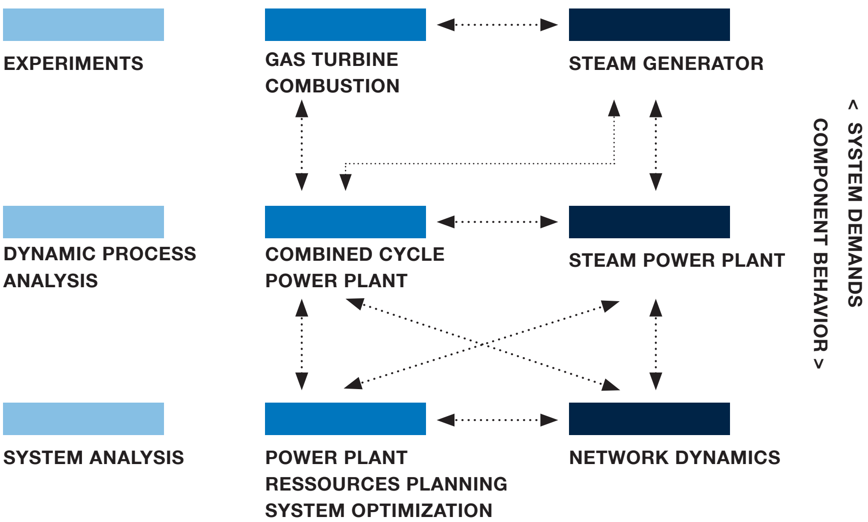
The integration of a rising share of renewable energy poses a challenge for the conventional generators in the power system. In the past, thermal power plants were mostly operated statically. Because of a high capacity utilization and only a few load changes, the power plants were designed for maximum efficiency at nominal load. Today these power plants produce the energy that cannot be generated by renewable sources. In addition to high efficiency they have to provide short start up times, fast load-change gradients and low minimum loads. To ensure a cost-efficient and stable supply system, changes in the conventional power plant technology and network infrastructure are essential.

The interdisciplinary project „Flexible Power Plants“ aims to bridge the gap between power generation and the electrical network. Measures for flexibility improvements are analyzed both experimentally and through simulations. The experiments investigate the limitations of power plants' flexibility and improvement potential. The results can be used in superordinate simulations. To investigate the effects on the stability of power grids and to optimize the interaction of generation and distribution of energy, models are developed that describe the Bavarian (and overall German) energy landscape.

The goal is to define measures that will help to adapt today's generation system to the needs of the future and to enable the transition to cleaner energy without risking the security of supply.



■ *flexible power plants: In the experimental works, gas turbine combustion and steam generation are analyzed in detail. The results are used as input data for dynamic process simulations of combined cycle and steam power plants, providing the required data for the simulation of the grid and of the overall energy system.*

FLEXIBLE POWER PLANTS

MODELING THE EUROPEAN POWER-SYSTEM

The large-scale expansion of intermittent renewable generation will require higher ramp rates and more frequent cycling of thermal power plants. Current generators cannot accommodate this demand flexibility and so flexible generator technologies are being developed. The impact of these generator concepts on the wider power system must be evaluated.

The integration of renewables will also challenge the existing control system. It is unclear whether the present control scheme can maintain stability under future system expansion scenarios. To evaluate these questions, a detailed computational model of the European electricity generation/transmission system is under development. The model will be used to simulate future scenarios with high shares of renewable generation and thereby assess the implications of new flexible power plant designs for the stability of the future power system.

The modeling work is divided in two parts: Setting up a techno-economic unit commitment (UC) and economic dispatch (ED) model, and building a dynamic power system model for load flow and stability analysis.

Techno-Economic Modeling

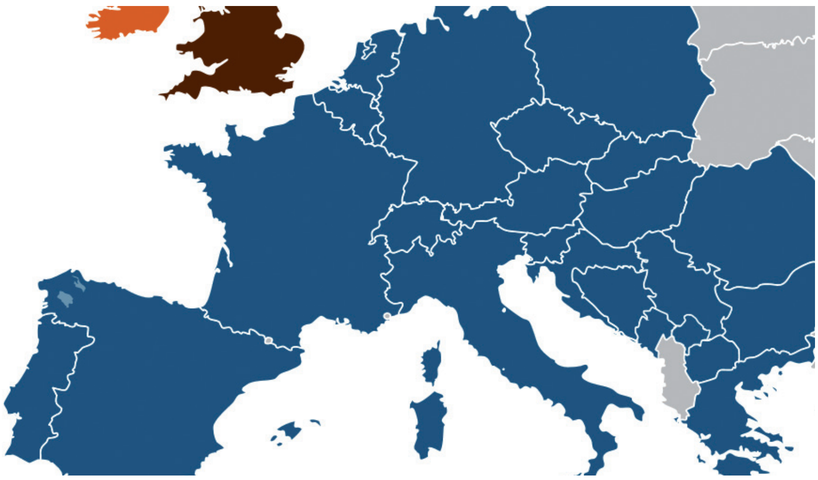
The UC and ED model are used to evaluate different scenarios of flexibility enhancement within power system. In order to analyze the impacts on the power plant behavior in detail, a state-of-the-art detailed representation of thermal power plants is used during the modeling process.

Dynamic Power System Modeling

The dynamic model is combined with comprehensive weather data to calculate power flows in the interconnected European system under various renewable power-infeed scenarios. Critical scenarios for power flow fluctuations are identified, particularly for cross border transmission. Further, potential mitigation of residual load fluctuation through network reinforcement is explored. Critical transmission corridors and loop flows are studied and optimal future network expansions (for reduction of residual load fluctuation) are calculated.

Due to the closely interconnected nature of Europe's electrical power system, the impact of any local change must be evaluated in the context of the wider system.

The system's dynamic stability is studied under the critical network scenarios identified. The impact of the flexible generator concepts on grid stability is evaluated, and suitable control schemes developed. Further, optimal specification and geographical location for flexible power plants are considered.
Through detailed techno-economic and dynamic modeling, the project will provide a thorough analysis of flexible power plant concepts in the context of the developing European power system.



■ *European Grid Map*

DYNAMIC PROCESS SIMULATION

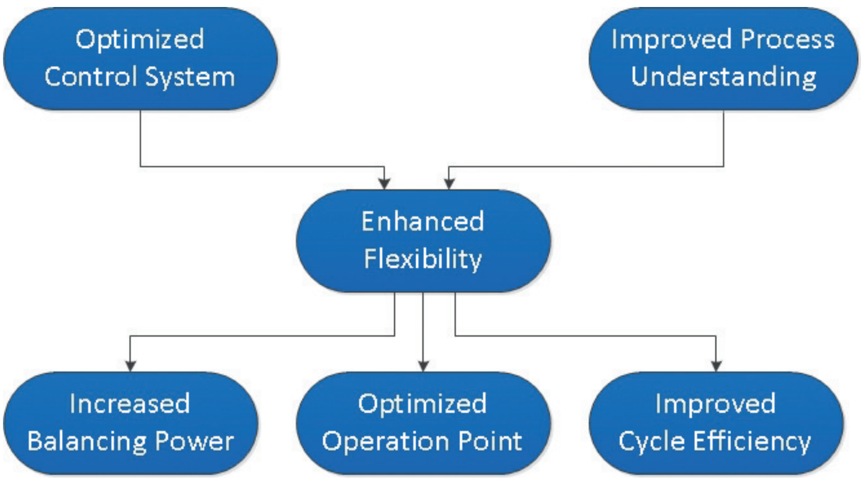
In the context of dynamic process simulation, the interaction of the power plant processes at flexible operation are investigated. Not only the efficiency of the overall process plays an important role, but also the transient behavior. The simulation software APROS is used which allows dynamic modeling of the power plant performance including automation. Thus, complex procedures such as start-up/shut-down and load cycles can be analyzed. An improved process understanding helps to develop better operating strategies and optimized power plant configurations.

Regarding the combined cycle power plants, the cogeneration plant München Süd has been chosen as a reference plant. It is a unit with a capacity of 420 MW, which both produces electricity and provides district heating. Especially during summer, the power plant has a low utilization and a dynamic operation is required. In order to include the automation in the model, the most important details of the start-up sequence and the control loops have to be taken from the control system. In addition, the lifetime calculation of thick-walled components according to DIN EN 12952 has been integrated into the model. The validation yielded good results. The next step is to investigate how to introduce changes to the control system to minimize the negative effects of dynamic operation on the power plant components.

Combined cycle power plants are meant to play an important role in the future's energy system due to the "clean" fuel and the high efficiency.

With regard to a coal-fired power plant, the influence of a more flexible plant operation on the share of lifetime consumption by fatigue was investigated. To do so, the reduction of the share of fatigue in the thick-walled components of a forced circulation steam generator by an electrical surface heating system has been simulated. The necessary models for the steam drum, the high-pressure and the intermediate superheater headers were created using reference data of a power plant with appropriate materials and dimensions. In order to reduce the thermal stress contribution to the total stress range of a load cycle, a heating strategy for the critical components has been developed. This is also useful to limit the thermal stress during accelerated cold start-ups. Due to a possible acceleration of start processes with respect to the thick-walled component, savings in fuel consumption lead to a significant reduction of start-up costs. To better address the need of controllability in power generation, the next step is to improve the control strategy of coal-fired boilers using dynamic simulation. The aim is to increase the control performance in consideration of the lifetime consumption of critical components.

Coal fired steam power plants continue to have a large market share due to the cheaper fuel.



■ The dynamic process simulation is used as a tool to optimize power plant operation.

4

RESEARCH PROJECTS EVB

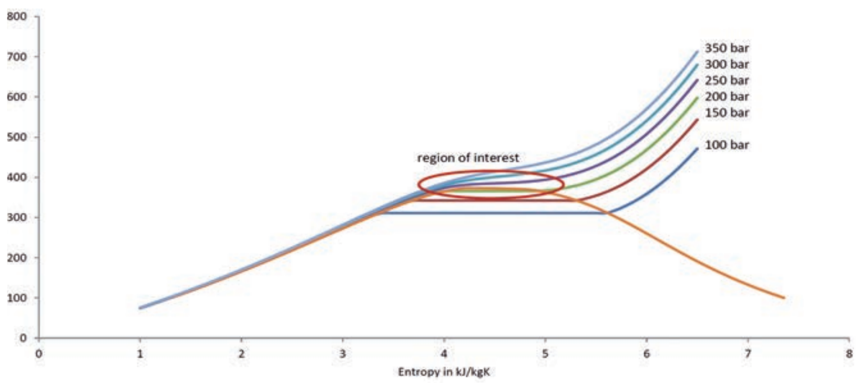
FLEXIBLE POWER PLANTS

HIGH PRESSURE EVAPORATION TEST RIG

The components of flexible power plants are strongly affected by increased plant dynamics, especially the steam generator. It will be exposed to transient loads and more frequent operation at minimum load. It is desirable to understand the operational behavior of steam generation under these circumstances. The evaporation test rig in conception at the Institute for Energy Systems aims to provide some insight into evaporation processes in flexible power plants.

In the past year, the goals were to identify the knowledge gaps regarding evaporation processes in power plants and to complete the basic engineering of the evaporator test rig. The tubes in the evaporator section of a steam generator in a conventional power plant are subject to four main independent thermohydraulic parameters: The inlet temperature, the pressure, the mass flux density and the tube wall heat flux density. These can each experience a transient variation. The secondary independent parameters are the tube geometry and the inclination of the tube. The main features of interest to be investigated with regards to the independent parameters are the wall temperature profile, the local heat transfer coefficient, the enthalpy increase, the pressure decrease and the flow patterns of the working fluid. The entire experimental space is defined by all possible permutations of the independent parameters. This has been narrowed down to the experimental space representing conditions in flexible power plants, and the experimental space that has not been covered sufficiently in previous studies. In a state of the art power plant operating in sliding pressure control mode, evaporation during stationary and transient part load operation occurs at near-critical and subcritical pressures. Past experimental studies were not yet able to adequately describe and quantify the heat transfer phenomena at near-critical pressures, as the physical properties of the working fluid are subject to significant variations of temperature. Thus, the near-critical region has been identified as the region of interest for investigation from both a practical and scientific point of view.

The rig is customized to perform experiments in the identified interesting experimental space. It is designed to cover temperatures up to 580°C, pressures up to 350 bar, mass flux densities up to 2500 kg/m²s, and tube wall heat flux densities up to 800 kW/m². The thermal power is supplied by applying a direct current through the evaporator tube. The pressure and mass flow are provided by a reciprocating feed water pump. Valves at the exit of the evaporator allow backpressure control. Tubes of variable geometry can be installed in a modular fashion, and the angle of tube inclination can be varied.
The experiments are to be accompanied by CFD simulations in order to gain some insight into the 3- dimensional behavior of the evaporation process. The experimental data are to be used for validating the results of the simulations.
Currently, the detailed engineering of the rig and its components is in progress. In 2014, the goal is to finish the detailed engineering stage and to proceed with the acquisition of components and the construction of the plant. Moreover, specific experiments have to be designed within the interesting experimental space.



■ *T-s Diagram indicating the region of interest for high pressure evaporation experiments.*

WATER INJECTION INTO GAS TURBINE COMBUSTORS

Due to its positive influence on the power output and the pollutant formation, water injection in gas turbine combustion chambers has found industrial applications in various gas turbine cycles. Practical examples are the HAT (Humidified Air Turbine) cycle or the Cheng cycle. The reasons for the water or steam injection are similar for all the different applications:

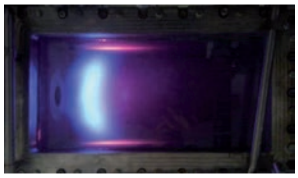
- Reduction in NOx- and CO emissions
- Increase in power generation
- Increase in engine efficiency

The presence of water in the fuel mixture primarily increases the heat capacity of the overall mixture. Consequently the temperature of the combustion products is significantly lower compared to combustion without the presence of water (if the same amount of fuel is used). The lower peak temperatures of the process influence the cycle in various ways. First of all lower peak temperatures increase the lifetime of the engine, as thermo-mechanical stresses are significantly reduced. Furthermore water/steam injection increases the volume flow through the turbine, which drastically increases the power generated and improves the overall engine efficiency.

Water injection combines an increase in power output with a decrease in emission formation

Besides these efficiency related improvements pollutant emissions can be drastically cut down. Especially the NOX- and the CO-emissions are lowered to a fraction of their original value. The reduction of the CO emissions can mainly be correlated with the decrease in temperature in the combustion chamber. Besides this physical effect, research states that a chemical effect of the steam and water injection could be found. In order to clarify the extent of the influence of water injection, further investigations are carried out at the Chair of Thermodynamics.

At the beginning fundamental research on the processes occurring during the combustion of natural gas with humidified air is done. These investigations are conducted using experimental methods on a combustor test rig. In a second step the impact of water addition on the thermoacoustic behavior of combustion systems is clarified using the results of the fundamental research done before. Finally design rules for future gas turbine combustors are developed based on the experimental investigations.



■ Lean premixed natural gas flame at the combustion test rig.

IMPROVEMENT OF THE DYNAMICS OF COMBINED CYCLE POWER PLANTS BY FUEL PROCESSING

A premixed, lean combustion is usually conducted in modern, stationary gas turbines running on natural gas. The advantages are low flame temperatures and therefore an increased engine life and reduced emissions. However the high air excess ratio at the operating point does not hold much potential for a load reduction by means of a decrease of fuel injection due to stability problems and lean blow out (LBO). Syngas (blend of mainly carbon monoxide and hydrogen) has a higher LBO limit and could be used as fuel in the part load regime. The addition of even a small share of syngas to the main fuel thus enhances stability and holds the potential for leaner combustion, which is crucial for extending the operational range to lower loads. For efficiency reasons the syngas needs to be produced in the gas turbine process by the conversion of natural gas. This integration goes along with certain constraints for the reactor, like low residence times, low pressure drop and, to ensure safe premixing, low temperatures. The auto-thermal reforming (ATR) of natural gas with air and water seems to fit these conditions.

A higher air excess ratio usually goes along with higher CO emissions.

A production of syngas elsewhere and a subsequent compression for injection is economically inefficient.

In the scope of the project an ATR reactor, which is suited to being integrated in a gas turbine process, will be built and tested. The possibility of the syngas production with the aforementioned constraints will be shown in a first step. By the integration of the ATR reactor in a combustion test rig premixing of syngas and air without prompt ignition or flashback and the potential for a higher lean blow limit by means of syngas injection in the combustion stage will be shown. Another interesting aspect of the staged process might be the CO burn out, which could be improved significantly.

The conversion of 50% of the fuel for the main stage will be possible.

FLEXIBLE POWER PLANTS

SCIENTIFIC STAFF

The Flexible Power Plants research group embodies the interdisciplinary orientation of the Munich School of Engineering. This group forms a bridge between the Department of Electronic Engineering and the Department of Mechanical Engineering. 4 chairs bring their specific expertise into innovative solutions. Including 9 young researchers, the research group is the largest in the project "Energy Valley Bavaria".

Ms. Julia Hentschel started her work at the Department of Energy System as a research assistant and is going to deal with the dynamic simulation of coal power plants. The goal is to achieve an optimization of the control system. Previously she did her master studies at the TUM and finished with her thesis „Optimization of a conventional power plant startup process by heating of thick-walled components." During her previous studies of Mechanical Engineering she has been preoccupied with the thermal hydraulic simulation of nuclear power plants in terms of accidents.

Mr. Dominic Hewes studied Electrical & Electronic Engineering at Imperial College London. As part of an RWE scholarship program, he gained experience in the field of wind power grid integration. Since October 2013, Mr. Hewes has worked as a doctoral researcher at the Institute of Power Transmission Systems with a research focus on the dynamic behavior of the European transmission system.

Mr. Max Baumgärtner obtained a diploma degree in Mechanical Engineering from the RWTH Aachen university in 2012. He joined the Flexible Power Plants team in January 2013. His research at the Chair of Thermodynamics focuses on the expansion of the part load regime of gas turbines by means of fuel reforming.

Mr. Matthias Huber obtained a Master's Degree (Dipl.-Ing.) in Mechanical Engineering from TUM and a B.Sc. in Economics from LMU, both in 2010. His research focuses on the modeling and valuation of flexible power plants within the European power system.

Mr. Nicolai Stadlmair studied Mechanical Engineering with the focus on thermofluiddynamics and renewable energy systems at TUM and graduated with a Diploma in 2012. He joined the Energy Valley Bavaria Team in 2013 and his research concentrates particularly on the flame dynamics in gas turbine combustors.

Mr. Stephan Lellek studied Mechanical Engineering with the focus on thermofluiddynamics, aero engines and gas turbines at TUM and graduated in 2013. He joined the Energy Valley Bavaria team in 2013 and his research concentrates particularly on the operational limits of gas turbine combustors.

Mr. Andreas Kohlhepp studied Mechanical Engineering at the UAS Würzburg-Schweinfurt. Before he joined the EVB-Project at TUM, he worked at E.On Kernkraft GmbH, taking care of different aspects of power plant condition monitoring for nearly four years. During this time he did part-time postgraduate studies at TU Dresden to obtain a university diploma for power engineering which is going to be finished successfully soon.

Mr. Steffen Kahlert joined the team in October 2012. He obtained his diploma in Mechanical Engineering with a focus on waste heat recovery and turbo machinery from Leibniz Universität Hannover and came to TUM because of the fascinating challenges in energy production.

Mr. Gerrit A. Schatte is involved in the project since April 2013. His previous studies at TUM focused on sustainable energy systems and fluid process engineering. For his diploma thesis, he investigated the catalytic conversion of syngas to liquid fuels in microreactors at the MIT chemical engineering department. His interest in energy conversion and future energy systems sparked his initiative to join the EVB team.

Julia Hentschel

Dominic Hewes

Max Baumgärtner

Matthias Huber

Nicolai Stadlmair

Stephan Lellek

Andreas Kohlhepp

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Organic Photovoltaics

DR. EVA M. HERZIG

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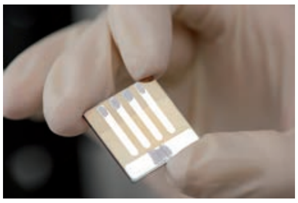
The Herzig Group is one of the three research groups established at the MSE within the framework of the Energy Valley Bavaria project. The research focus of this group is on organic photovoltaic systems, i.e. solar cells based on organic compounds like polymers or small molecules. These highly absorbing materials are promising candidates for a cheap and versatile technology to convert sunlight into electricity. A strong research effort over the last years all over the world has led to continuously rising efficiencies fueling the interest in organic solar cell devices.

Organic photovoltaics is based on highly absorbing organic molecules. These types of materials usually have a mass density close to one. In combination this allows the production of solar cells with active layer thicknesses in the range of 100 nm resulting in very light weight devices. Furthermore, since these materials can be processed from solutions, various substrates can be coated. However, the high sensitivity to and lack of defined control over the nano-morphology of such systems make large scale production and long term stability an open challenge. In the Herzig Group we aim to use the information gained from structural characterization of organic photovoltaic systems to ultimately establish controllable thin film production routes useful for industrial application.



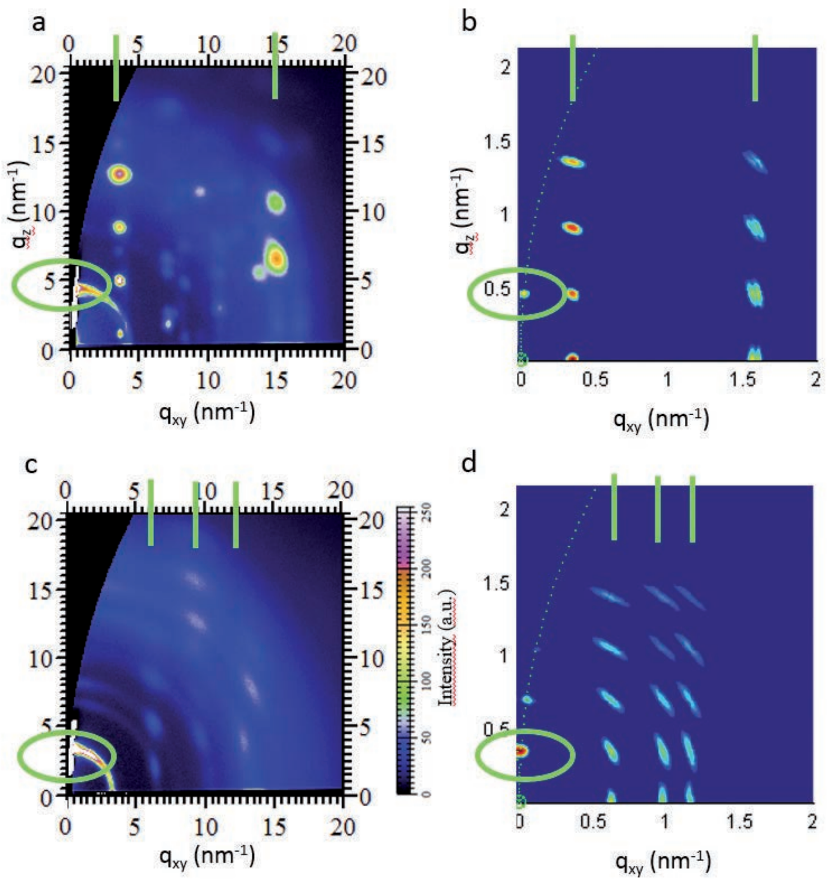
■ *Conversion of solar energy into electricity: lab scale organic photovoltaic cell*

An example of how to control the nano-morphology of the photo-active layer in organic solar cell devices is to directly manipulate the involved material. The synthesis of organic molecules offers a wide range of possibilities. This allows to tune molecular properties, for example the range in which the molecules absorb, implying that organic photovoltaics offers the possibility of tailoring devices to the field of application [1].

However, altering the molecular architecture also influences the packing of the molecules and the nano-morphology of the composite films. These morphological properties in turn are closely related to how efficiently charges are transported through the material which is directly linked to the efficiency of the devices.

Microscopy methods like atomic force microscopy are powerful to gain information on the nanoscale at local spots of the thin films. However, this information is often limited to the surface and restricted to areas of a few square microns. In contrast, grazing incidence scattering methods can be used to probe the full depth of an organic film with a surface area in the range of square millimeters depending on the beam size. This allows to obtain information with good statistics on sample areas similar to the test devices. It is important to note, that the information obtained from scattering methods is a combination of scattering events recorded in fourier space, making the analysis challenging for many systems. Therefore a powerful approach is to simulate the experimental data to compare the assumed model to the observed measurement.

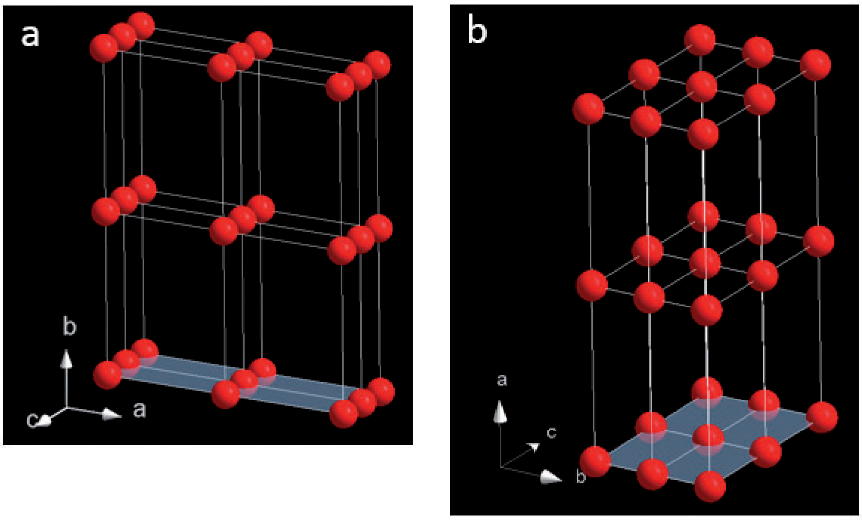
For example, grazing wide angle x-ray scattering (GIWAXS) can be used to analyze the packing and orientation of organic molecules. This method yields information on regular atomic separations and their orientation towards the substrate, thereby giving information on the arrangement of the examined molecules. Since charge transport in organic materials is often anisotropic, such information is vital for understanding device performance. To show how powerful the combination of experiment and simulation is, the study carried out in collaboration with the Müller-Buschbaum Group (TUM) and the Janssen Group (TU Eindhoven) is a nice example. In this work a custom synthesized small molecule system was examined by us with GIWAXS at the Deutsches Elektronensynchrotron (Desy) in Hamburg. These measurements were complemented with various other techniques allowing a full characterization of these systems [2]. π-conjugated molecules based on diketopyrrolopyrrole and bithiophene (DPP2T) were synthesized in such a way that only the alkyl side chain positions at the final thiophene rings were varied. However, the solar cells built from these materials in combination with PC70BM ([6,6] phenyl-C71-butyric acid methyl ester) vary significantly in performance.



■ *Figure 1: 2D experimental GIWXAS data in the left and the corresponding simulated data in the right column. Pure DPP2T-4 films are shown in the top row with DPP2T-5 in the bottom row.*

JUNIOR RESEARCH GROUPS: ORGANIC PHOTOVOLTAICS

The investigation shows that although the absorption properties of the individual DPP2Ts are not altered much in solution, significant changes occur once a dry film is formed. Several spectroscopy techniques confirm that the molecular arrangement changes with side chain position. Using an analytic comparison of 2D GIWAXS data with simulated scattering patterns obtained via simulation of the arrangement of these molecules [3], it was possible to quantify how the molecules are predominantly arranged on the substrate.



■ *Figure 2: The unit cells used in the simulation of the 2D GIWAXS data for (a) DPP2T-4 and (b) DPP2T-5.*

Figure 1 shows how well the simulated data agrees with the experimental data of the pure DPP2T-4 (a) and DPP2T-5 (b) film while figure 2 shows how strongly the unit cells differ, quantifying the clear changes in the packing.
Once PC70BM is added to form the basis for a working solar cell, the interaction of the PC70BM with the DPP2T units also varies with the side chain position. In combination with the other characterization methods, we were able to show that the device performance depends on an intricate combination of crystallinity, crystal orientation and nanomorphology. To be able to build high efficiency, large scale devices an understanding of this intricate interplay will be essential and an exciting task for the research to come.

[1] E. M. Herzig, P. Müller-Buschbaum: Organic photovoltaic cells for space applications; Acta Futura 6, 17-24 (2013)

[2] V. S. Gevaerts, E. M. Herzig, M. Kirkus, K. H. Hendriks, M. M. Wienk, J. Perlich, P. Müller-Buschbaum, and R. A. J. Janssen: Influence of the Position of the Side Chain on Crystallization and Solar Cell Performance of DPP-Based Small Molecules; Chem. Mater., 26 916-926 (2014)

[3] D. W. Breiby, O. Bunk, J. W. Andreasen, H. T. Lemke and M. M. Nielsen, Simulating X-ray Diffraction of Textured Films; J. Appl. Cryst. 41 262-271 (2008)

ABOUT THE TEAM

The team members of the Herzig group carry out research on Organic Photovoltaics focusing on structure function relationships during solar cell processing. Working in an interdisciplinary team the group members aim to merge their different expertise to bring their innovative ideas to this exciting field of research and to gain fundamental understanding of the energy converting processes involved.

■ *from left to right: Dr. Eva M. Herzig, Felipe Martinez, Leonhard Hofbauer, Stephan Pröller and Mihael Čorić*

Group leader Eva Herzig has done her PhD in Soft Matter Physics at the University of Edinburgh, Scotland before working on the development of fuel cells and in organic photovoltaic research in Germany. The newly established group currently consists of two doctoral candidates Stephan Pröller and Mihael Čorić, as well as of two Bachelor students, Leonhard Hofbauer and Manuela Heiß, and a Master student, Felipe Martinez. Their academic backgrounds range from Engineering and Physics to Chemistry. The interdisciplinary nature of their research is also visible in the collaborations of the group. The Bachelor's and Master's theses are carried out in collaboration with different chairs at the TUM; with Prof. Müller-Buschbaum in Physics and Dr. Harald Oberhofer from the Reuter group in Chemistry as well as with the Technical University of Denmark.

Energy Efficient and Smart Cities

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The "Energy Efficient and Smart Cities" research group aims to explore ways to make our cities more energy-efficient and carbon neutral. This subject is particularly timely and relevant to us in the context of climate change and the need for a clean energy revolution.

Cities cover about 1% of the Earth's surface but are home to more than 50% of the world's population. They together consume 75% of the world's energy and are responsible for 80% of the global greenhouse gas emissions. The concentrated human activities in these urban agglomerates have an unequivocal influence on the climate system which is reflected in warming of the atmosphere and the ocean. Cities are recognized as one of the major contributors to climate change but yet the rate of growth and change in cities offer great opportunities for climate mitigation measures.

In Germany, the government's plan to phase out nuclear power requires a fundamental transformation of the nation's energy landscape. The strategic "Energy Concept" set out by the German Government establishes renewable energies as a cornerstone of its future energy supply. The integration of a large share of intermittent renewable energy sources poses significant challenges to the operation of the existing energy infrastructures. In order to ensure a reliable power supply with an increasing amount of renewable sources, an intelligent and flexible electrical grid that allows for new ways of monitoring and managing power flows is needed. The recent development of smart grids opens up an exciting field of study that requires a substantial contribution of new knowledge from the scientific communities.

Human influence on the climate system is clear. This is evident in most regions of the globe, the latest assessment by the Intergovernmental Panel on Climate Change (IPCC) concludes. According to the UN, the level of greenhouse gases is rising rapidly and far greater global efforts are needed to tackle the issue. Around 80 percent of all greenhouse gas emissions from human activities are produced in cities. It is clear that in order to mitigate climate change, responsive actions are needed to decarbonize our cities.

Along with supply-side measures, demand-side management are as crucial in terms of improving the overall efficiency of our cities. An in-depth understanding of the energy consumptions and use patterns in existing towns and cities can help policy-makers to identify areas for interventions and to formulate effective energy strategies. The unprecedented availability of data on urban structures and energy use today enables valuable insight into the energy flows in cities at high spatial and temporal resolution. This removes the long existing limitations in urban energy research and uncovers new possibilities to examine our cities.

Through analyzing the existing urban energy systems, the "Energy Efficient and Smart Cities" group seeks to address the techno-economic challenges facing the global green energy agenda. The research interests of the group are centered on integrated urban energy planning and their work includes energy efficiency of the built environment, coordination of heat and electricity in urban areas, and application of smart grids. The ultimate goal of their research is to develop the evidence base for actions that can help to shape a sustainable and low carbon energy future.

EXAMPLE: SUSTAINABLE ENERGY PLANNING FOR MUNICH

With supports from the city's Planning Department and the Survey Office, the "Energy Efficient and Smart Cities" group is undertaking a study to understand the energy use patterns in the metropolitan area of Munich. The work aims to help the city to develop an effective energy planning that will pave way for a sustainable future growth.

As the capital of Bavaria, Munich is one of the most vibrant and fastest growing cities in Germany. Its service and manufacturing industries combined contribute nearly a fifth of Bavaria's gross domestic product (GDP). The prosperity of the city, however, relies heavily on the burning of fossil fuels which account for over three quarters of the city's primary energy consumption.

In order to respond to the pressing issues of climate protection and to remain competitive in the global economy, the City of Munich is committed to the Europe 2020 strategy which promotes a smart, sustainable and inclusive growth in the region. Munich is set to increase the share of renewables to 20% and to improve energy efficiency by 20% by 2020. It has a target to achieve a 50% reduction in carbon dioxide emissions per capita compared to the 1990 baseline by 2030.

■ *Munich is one of the most vibrant and prosperous cities in Europe. In order to sustain its economic success in the face of climate change, it is important that the city shifts its energy supply from heavily fossil-based to low carbon sources.*

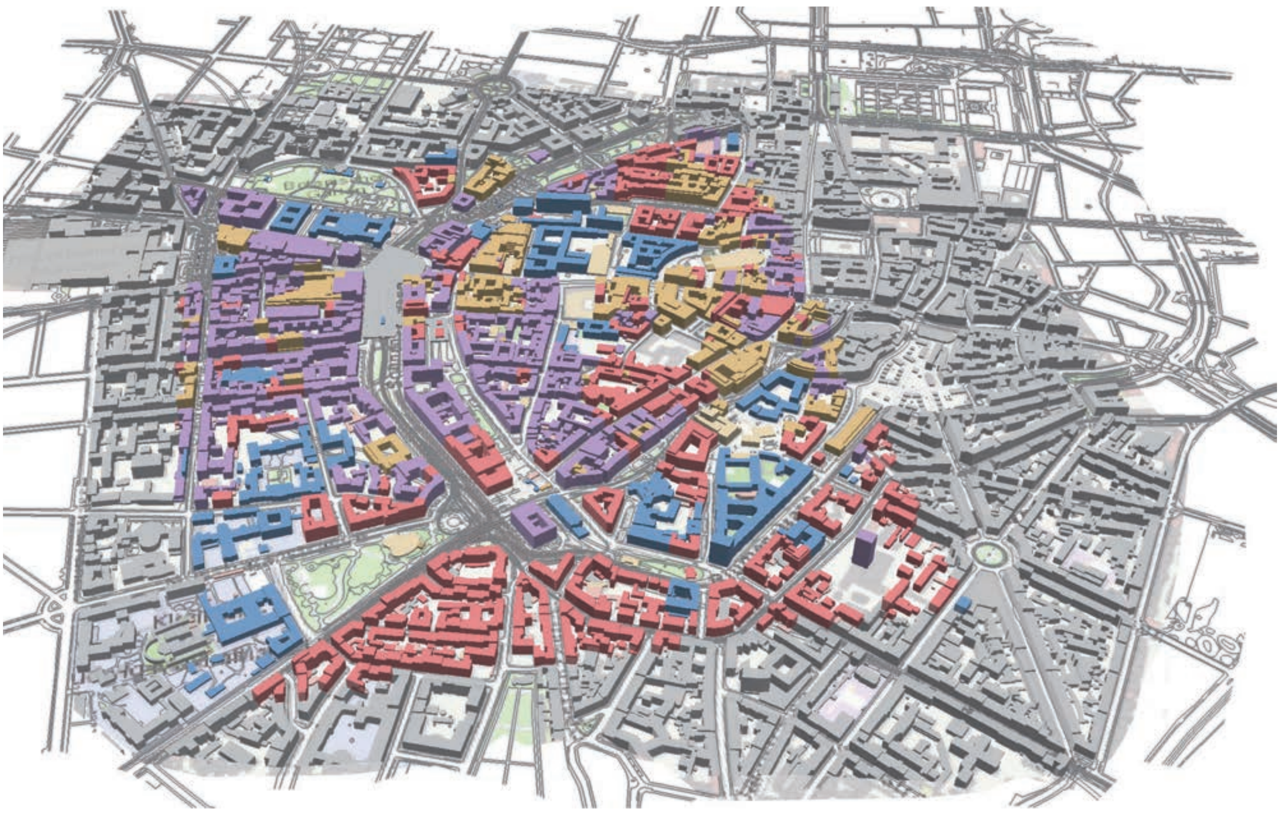
JUNIOR RESEARCH GROUPS: ENERGY EFFICIENT AND SMART CITIES

Most existing urban energy models use an archetype approach that produce annual (or sometime monthly) average energy demands based on predefined building type categories. Due to the lack of spatial reference and temporal details, these models can be used in conceptual planning at an aggregate level but they cannot cope with the intermittent nature and increased location dependency that characterize the future energy systems.

Using GIS data detailing urban structures and land use, the "Energy Efficient and Smart Cities" team aims to develop a computer model for simulating the heat and electricity demands of the metropolitan area of Munich in fine spatial and temporal resolution. The team will employ an innovative bottom-up approach which takes into account the contribution of energy components at building level and examines their use profiles in disaggregated time intervals. The model will allow a profound understanding of the existing energy patterns in the city. Moreover, it can be used to test future scenarios (e.g. technological changes) and to evaluate different policy options (e.g. land use planning).

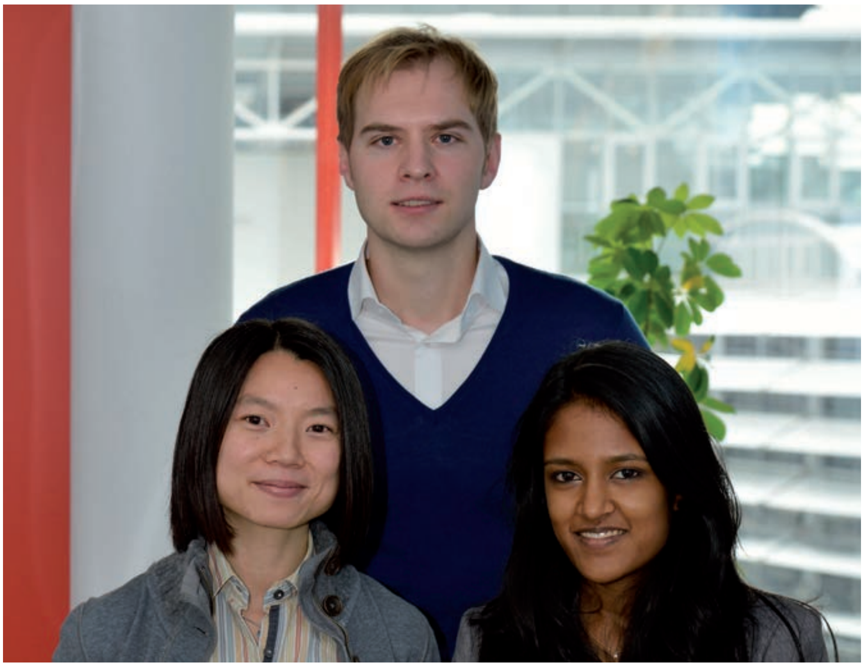
The main objective of this work is to facilitate a citywide coordination of energy use and infrastructure planning so as to ensure a sustainable security of supply in the future.

■ *Detailed spatial data of the City of Munich showing different land uses and building functions (GIS data provided by Städtisches Vermessungsamt München)*



PROJECT LEADER: DR. CHENG

Dr. Vicky Cheng obtained a BEng(Hons) in Building Services Engineering and an MPhil in Environmental Architecture in Hong Kong. She was awarded a Cambridge Overseas Trust scholarship to study at the University of Cambridge where she obtained a PhD. She has published, as well as served as a reviewer in major international peer-reviewed journals. Vicky has engaged in a number of government consultancy projects in which she applied her research findings into practice. She became an Associate of the Cambridge Architectural Research Limited in 2009. With CAR, she has developed energy models for the UK Government to evaluate energy consumptions and carbon emissions from UK homes. Her work has contributed to the annual housing energy reports published by the UK Government. The reports provide valuable information that can help the government shape policy on housing and climate change.



■ *The "Energy Efficient and Smart Cities" team: Dr. Vicky Cheng (front left), Ms. Akhila Jambagi (front right) and Mr. Michael Kramer (back).*

TEAM: ENERGY EFFICIENT AND SMART CITIES

The "Energy Efficient and Smart Cities" research group consists of a young and energetic team led by Dr. Vicky Cheng. Initially trained as a building services engineer, Vicky has worked in architecture departments in Hong Kong and the UK researching in the field of urban environmental performance. The key motivation of her work has been to bridge building physics research with urban planning through integrated understanding of the environmental, technological, economic and social dimensions of the urban systems. Her team places strong emphasis in multilateral and interdisciplinary research and they are keen to facilitate joint efforts between different research units in TUM to tackle the energy and climate change challenges.

Ms. Akhila Jambagi and Mr. Michael Kramer joined the team as doctoral students in December 2013. Akhila obtained an MEng in Electrical and Electronic Engineering with Management from Imperial College London and Michael holds an MSc in Industrial Engineering specialized in Electrical Engineering from Technische Universität Darmstadt. They both take part in the work of developing a sustainable energy planning for Munich within which they explore their research interests and develop their thesis.
This is an exciting start and the "Energy Efficient and Smart Cities" team is looking forward to a progressive year ahead.

Control of Renewable Energy Systems

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The research group "Control of Renewable Energy Systems" – starting 1st January 2014 – will initially focus on the control of wind turbine systems. In close collaboration with Prof. Carlo Bottasso (Wind Energy Institute, TUM), a holistic approach for modeling and control of wind turbine systems is favoured to combine expertise in aerodynamical, mechanical and electrical systems. The initial goal is to improve the reliability to the overall wind turbine system.

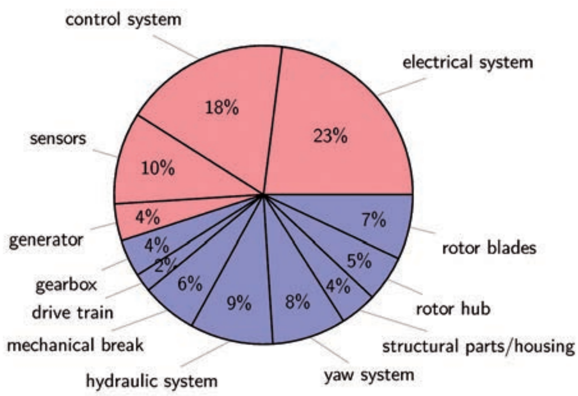
MOTIVATION: RELIABILITY OF WIND TURBINE SYSTEMS

Currently, wind turbine systems have an average lifetime of 20 years. Frequent maintenance assures an average availability of 98% per year with an average downtime of seven days per year (see [1]).
Malfunctions of the overall system are mainly due to failures in the electrical system (23%), the control system (18%) and the sensors (10%), whereas the generator and the mechanical components–such as gearbox, rotor or housing–play a minor role (see Fig. 1). During the lifetime of 20 years, the expected downtime due to failures in the control system and the electrical system is 16.7 and 18.9 days, respectively—relatively high compared to downtimes of 13.6 days due to failures in the gearbox (see Fig. 2).
Moreover, large-scale wind turbines with power ratings higher than 1 MW have high annual failure rates during their first seven years in operation (compared to small-scale wind turbines, see Fig. 1 in [1]). Therefore, in particular "[...] offshore wind turbines should be subject to more rigorous reliability improvement measures [such as tests and simulations ...] to eliminate early failures. The early focus should be on converters and generators" (see [2], a study based on data collected during 11 years in Denmark and Germany). More fault-tolerant control systems are essential to overcome the "lack of quality control" (see Tab. 2 in [3]) and to improve the reliability of wind turbine systems.

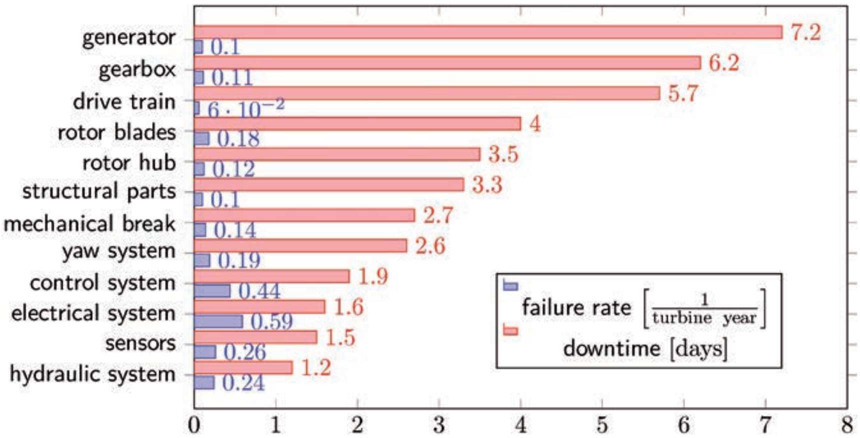
RESEARCH FOCI

The activities of the research group "Control of Renewable Energy Systems" will initially focus on the improvement of the reliability of wind turbine systems by

- holistic system modeling including aerodynamics, mechanics and electrical components,
- holistic controller design combined with stability analysis and
- fault detection and condition monitoring.



■ *Figure 1: Malfunction due to different kinds of failures in subassemblies of a wind turbine (based on Fig. 2 in [1]).*



■ *Figure 2: Average failure rate and average down time per failure of sub-components (based on Fig. 3 in [1]).*

PROJECT LEADER: DR.-ING. CHRISTOPH HACKL

Christoph Hackl received the Dr.-Ing. (Ph.D.) from the Technische Universität München (TUM) in 2012. His interdisciplinary Ph.D. project "non-identifier based adaptive control in mechatronics" was supervised by Prof. Dierk Schröder (Institute for Electrical Drive Systems, TUM) and Prof. Achim Ilchmann (Institute of Mathematics, TU Ilmenau). After a Post-Doc phase at the Institute for Electrical Drive Systems and Power Electronics, TUM (Prof. Ralph Kennel), he was appointed Junior Research Fellow of the group "Control of Renewable Energy Systems" at the Munich School of Engineering, TUM in 2014. His main research interests are nonlinear, adaptive and optimal control of mechatronic and renewable energy systems.

TEAM

Mr. Christian Dirscherl and Mr. Korbinian Schechner joined the research group „Control of renewable energy systems" as doctoral students in January 2014. Both hold a B.Sc. and a M.Sc. in Electrical Engineering and Information Technology from the Technische Universität München (TUM). With their specialization in power engineering and electrical drives they will take part in the work of developing new control strategies for wind turbine systems.

[1] B. Hahn, M. Durstewitz, and K. Rohrig, "Reliability of wind turbines, experiences of 15 years with 1500 WTs," in Wind Energy (J. Peinke, P. Schaumann, and S. Barth, eds.), Proceedings of the Euromech Colloquium, pp. 329–332, Berlin: Springer-Verlag, 2007.

[2] F. Spinato, P. Tavner, G. van Bussel, and E. Koutoulakos, "Reliability of wind turbine subassemblies," IET Renewable Power Generation, vol. 3, no. 4, pp. 1–15, 2009.

[3] Z. Hameed, Y. Hong, Y. Cho, S. Ahn, and C. Song, "Condition monitoring and fault detection of wind turbines and related algorithms: A review," Renewable and Sustainable Energy Reviews, vol. 13, pp. 1–39, 2009

■ *from left to right: Dr.-Ing. Christoph Hackl, Christian Dirscherl, Korbinian Schechner*

Seed Funding

Electrical engineering is traditionally divided in information technology and energy technology. This division becomes questionable after new information technology is necessary to make a power system relying mainly on renewable power sources possible. This seed funding project is intended to bring researchers from information technologies closer to the energy side. A new working group on energy and information is established within the department of electrical engineering and information technology. Three doctoral or postdoctoral students will be financed for one year to set up new projects in the following fields: new controls for power systems, advanced optimization methods for scheduling as well as combined development and planning of information and energy infrastructure. The three candidates will work closely together and will especially strengthen the collaboration with colleagues from the Energy Valley Bavaria and EEBatt projects. The goal is to prepare possible experimental and theoretical work in the center. This will be regarding the design of a micro-grid lab, new control philosophies for a smart and potential European super grid. An early emphasis will be put on the development of new energy and information infrastructure. Federal and Bavarian government put a strong accent on the development of fast information networks. Connecting this with the buildup of new energy infrastructure might not only save money but also time and reduce overall construction times.

PROJECTS

CONTACT
Prof. Dr. Carlo L. Bottasso
Institute for Wind Energy

Prof. Dr. Nikolaus A. Adams
Institute of Aerodynamics and Fluid Mechanics

Integrating active and passive load mitigation in wind turbines

One of the major trends in wind energy is the increase of the wind turbine size, as this has the potential for a better exploitation of wind resources, improved logistics and deeper water installation. However, up-scaling can be beneficial only if one can beat the cubic growth law, and this must be achieved by technological leaps forward with respect to the current state of the art. In addition to improvements in aerodynamics, materials, generator technology and many other areas of technological innovation, a decrease of the cost of energy can be obtained by load mitigation. In fact the reduction of loads can have a major effect on the design of the whole machine, with large potential pay-offs. However, the mitigation of loads on wind turbines is an extremely challenging endeavor: it requires the ability to simultaneously reduce extreme loads and fatigue damage, while limiting the activity and effort of the actuators and guaranteeing high reliability of the components, to ensure an elevated availability of the machine. These are contrasting goals that are in direct competition most of the times.

The present project investigates the design of advanced rotor concepts that try to optimally marry the contrasting requirements of full-range load mitigation with limited actuator activity, low maintenance and high availability. This can be achieved by integrating full-span individual blade pitch control (therefore avoiding the complexities of active distributed control) with passive blades. Furthermore, advanced new rotor concepts employing morphing structures with passive load alleviation are evaluated with respect to their potential in particular for wind harvesting areas with highly variable wind directions and intensities.

Scaled wind farm models

The understanding of the energy conversion process at the wind farm level is the focus of intense research, as it allows moving beyond the classical wind-turbine-centered approach. In fact, many problems and applications can benefit from a deeper knowledge of the wind farm system. Such knowledge has large potential pay-offs, as it may be applicable not only to new wind farms, but also to already existing ones. For example, the implementation in the field of better control algorithms that can improve the power output of a wind farm, or that can lead to a better distribution of the fatigue loading throughout the various machines, in some cases could be as simple as a software upgrade of the existing controllers. The study of wind farm dynamics, however, implies important challenges in various scientific domains, including among others the modeling and understanding of the lower atmosphere dynamics, turbulence, the dynamics of wakes, etc.

The present project investigates the development of a new experimental facility for scaled wind farm testing in boundary layer wind tunnels. The new experimental equipment is designed so as to support not only research in wind farm aerodynamics, but it also allows the testing of wind farm control laws for the first time. This capability closes a significant gap that is currently hindering the development of wind farm controllers. In fact, such controllers can only be tested using over-simplified wind farm models at the moment, or with very computationally demanding LES simulators that are still impractical even on modern high-performance computing clusters; there is in fact the need for running extensive studies in different conditions, configurations and settings for significant numbers of interacting wind turbines.

CONTACT
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Tailored tco nanostructures for pv applications

In this project, the Müller-Buschbaum group aims to fabricate and investigate extremely well organized and controlled morphologies eg. nanorods, inverted-nanorods and network structures of transparent conducting oxides (TCO's) such as zinc oxide (ZnO). These tailored TCO nanostructures will be used in combination with different n- and p-type organic materials (small molecules and polymers) towards achieving efficient and cheap tailored TCO nanostructure-based hybrid solar cells. Using low-temperature solution based methods will allow for the preparation on flexible substrates and thus give a significant contribution to flexible hybrid solar cells.

ZnO is one of the promising TCOs because it has a large direct band gap of 3.3 eV (at room temperature). Therefore it is transparent to visible light. Due to its high binding energy excitons (60 meV) it is a promising material for efficient light emitting diodes (LEDs) and hybrid solar cells. ZnO is easily available, inexpensive, environmentally friendly and nontoxic. Single-crystal ZnO nanorods have fewer defects in thin layers, which renders them an ideal material for opto-electronic components. As a consequence, ZnO nanorods have attracted enormous research interest in recent years. However, this research was focused primarily on the electronic and optoelectronic properties.

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4

RESEARCH PROJECTS EVB

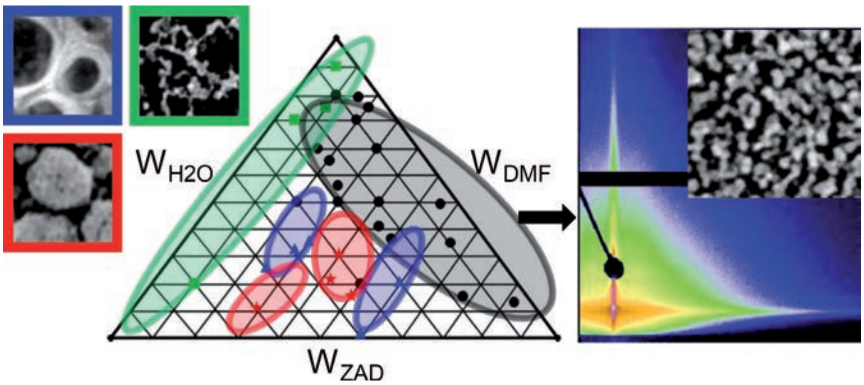
1. K.Sarkar, M.Rawolle, E.M.Herzig, W.Wang, A.Buffet, S.V.Roth, P.Müller-Buschbaum: Custom-made morphologies of ZnO nanostructured films templated by a P(S-b-EO) diblock copolymer via sol-gel technique; ChemSusChem 6, 1414-1424 (2013)

SEED FUNDING

So far, ZnO nanorods are used in dye sensitized solar cells (DSSCs or Grätzel cells) and ETA solar cells (ETA: extremely thin absorber). In DSSCs the nanorods are used as working electrode, while serving in the ETA-cells to increase the effective surface area. ZnO nano-rod arrays have a sub-wavelength structure, which makes them suitable as anti-reflection coatings which function via the Moth-eye effect. Moreover, ZnO is perfectly suited for the development of anti-reflective coatings for solar cells.

In addition, hybrid solar cells also started to use ZnO, which acts as the electron transport material in the device. Such devices have potential for low-cost roll-to-roll processing and for scalable solar power conversion systems. However, whereas TiO2 based solar cells have been extensively studied and achieved reasonable efficiencies, similar progress in ZnO based solar cells is still lacking. Very recent studies in both foam-like as well as ZnO nanorods morphology conclude that a high level of control of the morphology of the ZnO nanorods is the crucial factor to effectively tune the performance of the device. Ordered nanostructures offer the advantage of directed charge transport and controlled phase separation between donor and acceptor materials

Aim is to set up an interdisciplinary joint project which combines expertise in nanomorphology control, advanced structure characterization, electro-optical characterization and state-of-the-art device fabrication and characterization. Central part is the synthesis of tailored TCO nanostructures such as nanorods, inverted nanorods and network structures which allow for a high level of structural control and therefore device optimization beyond today's approaches. A new synthesis approach is based on the use of well defined block copolymer templates.1 Being wet-chemical and using only low temperatures this route is easy to allow for upscale and of potential low costs.



■ *Ternary phase diagram of ZnO morphologies obtained after calcinating zinc oxide-copolymer hybrid films. Different morphologies (foam-like structures, worm-like aggregates, circular vesicles, and spherical granules) are observed with SEM and GISAXS*

Chemical storage of excess electrical power

The increasing feed-in of electricity from fluctuating renewable energy sources such as wind and solar puts storage solutions in Germany on top of the to-do list for research and industry. Being one of the most promising and realistic options for long-term and seasonal storage, chemical storage technologies are of special interest and supposed to become an inherent part of future energy systems. The “power-to-gas” concept addresses the specific needs of the future German and European energy systems. Excess electricity from renewables is used in this concept for hydrogen production via electrolysis. The hydrogen is then converted with carbon dioxide for example from biogas plants to synthetic natural gas (SNG) which can be injected, distributed and stored in the natural gas infrastructure.

This concept requires an interdisciplinary approach due to the diversity of skills required along the process chain from excess electrical power to storable SNG. Electrical engineers, chemical engineers and mechanical engineers as well as physicists, mathematicians and economists have to work together and share their know-how to tackle this elaborate interdisciplinary puzzle and bring the technology to market.

The goal of the Seed Funding project is to bring these professions together, network and start collaboration within TUM to show existing overlaps, carve out synergy effects and bundle and enhance public relations efforts within and beyond TUM. This also includes identifying possible industry partners and explore possibilities for further funding proposals. The project partners (LES, APT, TC1, LfE and TEC) therefore want to establish a new interdisciplinary research platform.

Thematic key aspects are superordinate system considerations and the two main technologies - electrolysis and synthesis. System considerations include the investigation and modelling of future energy systems focusing on power, heat, gas and hydrogen markets in Bavaria, Germany and Europe and their linking. Furthermore, studies on stationary and dynamic storage technology concepts are required to investigate the potential for chemical excess power storage.

Electrolysis technologies are evaluated and investigated focusing on fundamentals as well as specific key aspects such as kinetics and permeability of hydrogen and oxygen or efficiency increase of the electrolysis unit through utilization of innovative materials. Also commercial stacks, e.g. PEM and alkali electrolysis units are evaluated and tested with respect to their dynamic behavior.

Research on chemical synthesis of storage media starts with fundamentals such as the reaction kinetics of CO and CO2 methanation at stationary and dynamic conditions. These basics are then applied to small-scale test facilities and elaborate system modeling and employed to assess the scale-up potential of the technology as well as chemical engineering and reactor design challenges. Heat removal of the exothermal reaction for example plays an important role for later implementation in real world applications. In the end, this research leads to a fundamental understanding of dependencies and key aspects, further research demands and the reproduction of the integrated design process from the chemical basics to the industry-scale application.

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EEBatt

PROJECT COORDINATION
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Institute for Technical Electro-chemistry

Prof. Dr.-Ing Andreas Jossen
Institute for Electrical Energy Storage Technology, Department of Electrical Engineering

PROJECT LEADER
Marcus Müller M.sc.
Institute for Electrical Energy Storage Technology, Department of Electrical Engineering

DURATION
01.01.2013 – 31.12.2016

FUNDING
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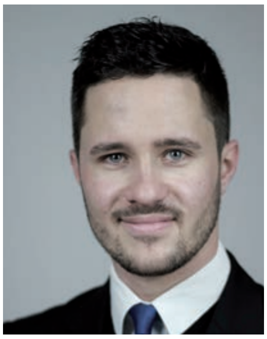
Bavarian Ministry of
Economic Affairs and Media,
Energy and Technology

HEADS

Prof. Dr. Hubert A. Gasteiger

Prof. Dr.-Ing Andreas Jossen

PROJECT LEADER



Marcus Müller

MEMBERS & PARTNERS

As an interdisciplinary project of the Munich School of Engineering, EEBatt extends over 14 chairs and departments of the TUM. Participating chairs are the following:

Prof. Dr.-Ing. Andreas Jossen
Institute for Electrical Energy Storage Technology

Prof. Dr. Hubert Gasteiger
Institute for Technical Electrochemistry

Prof. Dr.-Ing. Wolfgang A. Wall
Institute for Computational Mechanics

Prof. Dr. Thomas Hamacher
Institute for Renewable and Sustainable Energy Systems

Prof. Dr.-Ing. Rolf Witzmann
Institute of Power Transmission Systems

Prof. Dr.-Ing. Hans-Georg Herzog
Institute of Energy Conversion Technology

Prof. Dr. Samarjit Chakraborty
Institute for Real-Time Computer Systems

Prof. Dr.-Ing. Markus Lienkamp
Institute of Automotive Technology

Prof. Dr. Isabell M Welpe
Chair for Strategy and Organization

Prof. Dr.-Ing. Michael Zäh, Prof. Dr.-Ing. Reinhart Gunther
Institute for Machine Tools and Industrial Management

Prof. Dr. Moniek Tromp
Institute for Catalyst Characterisation

Dr. habil. Ralph Gilles
Heinz Maier-Leibnitz Zentrum – FRM II Neutron Research

Prof. Dr. Jutta Roosen
Department of Marketing and Consumer Research

4

RESEARCH PROJECTS EEBATT

The Research Project EEBatt "Distributed stationary battery storage systems for the efficient use of renewable energies and support of grid stability" is a multidisciplinary project run by the TUM's Munich School of Engineering (MSE).

Combining the strength of 14 chairs and departments of TUM and VARTA storage as a strong industrial partner, 51 researchers work together on a wide range of issues concerning stationary storage of electrical energy. Driven by the current evolution in the energy market, the main project goal is to investigate, develop and produce a decentralized battery energy storage *device, which ensures that locally generated electrical power can be consumed locally. Based on the actual and expected results for lithium ion technologies, EEBatt uses Lithium Iron Phosphate (LFP), and Lithium Titanate Oxide (LTO) chemistry for the setup.*

The MSE project EEBatt, led by the Chair of Electrical Energy Storage Technology, was launched in April 2013. In several subprojects, scientists at TUM and VARTA Storage GmbH examine interdisciplinary issues concerning stationary energy storage technologies. Under the umbrella of MSE there are several departments of TUM involved. Fundamental research topics range from the inner core of lithium ion cells all the way through system design and evaluation up to thoughts on new business models and political framework analysis of electrical energy storage for today and in the future. The focus of EEBatt is to explore the future market impact of such systems.

Funded by the Bavarian State Ministry for Economic Affairs, Infrastructure, Transport and Technology, topics from the fields of mechanical engineering, electrical engineering and information technology, operating economics and chemistry are combined, such that a profound and comprehensive scientific processing of distributed stationary energy storage is possible. In first publications and presentations, market analysis and market research were shown and provided a basis to choose the boundary conditions of the EEBatt system. Under the participation of the industrial partner VARTA Storage GmbH, the storage experts at VARTA add important content to the overall project.

In addition, new concepts for a thermal design of a storage system are evolved and developed by the ZAE division in Garching. Together with the partners, in late 2015 a first setup of all field test components will start.

Planned field test in mid 2015.

Particularly important in the future is the integration of renewable energy via intermediate storage devices in the overall program of energy efficiency in Germany. With powerful electrochemical storage systems, the cycle life should extend up to 20 years and sufficiently meet the challenges mentioned above. As the share of renewable energies will continue to increase in the future, the problem becomes more acute. For this reason, technologies providing economical and environmentally sustainable solutions must be developed. The system to be developed within this project is not yet available on the market. Therefore the project aims to demonstrate the basic concept and determine how it can effectively compete in the market.
During the project, basic knowledge will be developed, coordinated through the individual components in each sub-project, and will be combined to create a technical system for an optimized energy storage system.

PROJECT OVERVIEW

Within the interdisciplinary research project, EEBatt splits into several subprojects. To coordinate areas of interest and combine knowledge of all members, a subproject structure enables faster processes and makes proceedings easier.
The main subprojects are:

- Cell investigation
- Cell production
- Battery management systems
- Battery modules
- Energy management systems
- Power electronics
- System research
- Field testing
- Visions and future of storage systems
- Business cases

In the following, a short overview about the project, using excerpts from several subprojects, is given.

Concentrated research is done in 10 focus areas, each with special defined goals to reach.

FOCUS AREA - ENERGY MANAGEMENT

Out of the whole project, one part is the development of a new and active energy management system. In this part of the project a combination of different strategies of management and control is used and will be examined in new research tasks. At the end, the goal is to develop a new architecture for an energy management system for electrical energy distribution in smart grids.

The idea is to use cybernetic methods and an environmental coupling to reduce complexity and get more information to control the system or the grid. A major point in the development of the EMS is the definition of an economical and efficient operation strategy. The internal energy consumption should be increased by using the renewable energy sources in the grid and using the battery storage in such a way as to maximize the lifetime of the battery cells. On the aspect of mechanics, the whole system will be built in modules. Advantages of the modularity are the possibilities for building up storage, the chance to integrate new storage technologies in the future or to upgrade the hardware and electronics with innovations.
The first steps are the generation of a simulation model of sources and loads in a small grid. After that, building up a test bench and at the end a final demonstrator are the aims of the project part Energy Management System.

Completely new management algorithms based on cybernetic modeling methods are investigated.

FOCUS AREA – FIELD TEST

In subproject TP8, the initial prototypes of the developed Li-Ion battery storage systems will be assessed under real conditions in a field test. This includes the operation of the battery storage system for unloading the grid and increasing the local renewable energy consumption within a whole village, as well as the application of peak-load reduction for medium-size companies.

Two different field tests with the same storage type are planned

The aim of the field test is predominantly to validate the reliable operation of the storage system through monitoring and evaluation of all relevant parameters.

Battery performance and grid effects are being evaluated

Furthermore, the influence of the storage system on the grid is to be investigated by monitoring the necessary grid parameters and an estimation of the customer benefit will be performed.

Sub-Project 8 therefore is comprised of the following tasks:

- Identification of suitable field-test partners
- Development of possible operational modes
- Planning and implementation of the grid and customer connection
- System installation, operation and maintenance
- Recording and evaluating relevant measurement data

Battery storage for improving the integration of renewable energy

Battery storage can fulfill a variety of tasks when exploited to its full potential

As a consequence of the dependence on the weather, the feed-in power of photovoltaic (PV) systems experiences a high fluctuation. Therefore, it is not possible to ensure correlation between energy generation and demand at a single time-instant. Moreover, the solar feed-in of a region mostly occurs concurrently (i.e. PV systems across the entire region generate simultaneously), which has the potential to load power supply lines, cables and transformers above their maximum levels. Furthermore, due to the high grid load during periods of high insolation, permitted voltage limits can be exceeded. In order to reduce those critical effects and thereby increase the grid capacity of PV power plants, battery storage systems can be used to store the PV feed-in peaks and reduce the critical voltages by providing reactive power. Operating such a battery storage system can also be profitable for single PV system owners, when the renewable energy consumption in the local grid area is increased and correlating business models are developed.

In order to overcome the limitations imposed by high battery prices for stationary systems, further business models for such storage systems should be developed, e.g. a participation in the control power market during winter or the reduction of diesel generator usage during peak-load periods.

The development and implementation of battery control-algorithms for accomplishing these tasks are the main focus of the primary field test, which takes place in a small Bavarian low-voltage grid with a high PV-penetration.

Battery storage for peak-reduction and increasing PV self-consumption

With increasing electricity prices, the profitability of PV energy self-consumption is increasing, especially for industrial customers. When using a battery storage system to reduce the peak-load and therefore the demand rate to be paid, self-consumption from an existing PV power plant can be increased through the use of intelligent battery operational modes. Those operational modes are developed and implemented within the scope of the secondary field test, which takes place at a Bavarian medium-size manufacturing company that owns a PV power plant.

FOCUS AREA - LITHIUM ION CELL RESEARCH

The subproject TP2 consists of several research fields, from basic electrochemistry and specification to modelling of cell chemistry and performance tests, as well as production methods aging tests and different analysis methods in the field of neutron diffraction methods and in-situ spectroscopic characterization.
Several research topics from the listed fields above are introduced and highlighted in the following.

VARTA Storage GmbH is working on the preparation and description of advantages and disadvantages of diverse Lithium cell formats, as well as the definition of performance requirements for a battery cell that is suitable for an application in the field of stationary energy storage. From checking the legal and normative requirements, as well as performing aging tests on reference cells from different manufacturers, TP 2.400 recommends a round shaped or prismatic cell with the cell chemistry of graphite (C) anode and LiFePO4 (LFP) for this type of application with respect to performance and safety aspects. The results achieved represent a challenging benchmark for the cell, which should be developed during the EEBatt project.

LTO-based lithium cells and their gassing behavior were analyzed

In terms of safety and long-term cyclability, one of the research topics was the gassing behavior of Li4Ti5O12 (LTO) anodes in full- and half-cell tests, which was investigated by TP 2.200 [1]. Gases evolved by LTO-based cells using electrolytes with different water content were analyzed by on-line electrochemical mass spectrometry (OEMS) during charge and discharge. Using water containing electrolyte OEMS, results show H2 and CO2 are the main evolved gases, which are in accord with the relevant literature. However, cells assembled using nominally water-free components show only a negligible gas evolution upon the first charge/discharge cycle. Furthermore gas evolution occurs only in case of charged LTO electrodes and never prior to charging. These observations led to the conclusion that electrochemical reduction of water to hydrogen gas and hydroxyl anions at LTO surfaces is the main mechanism responsible for the observed hydrogen gassing, confirming the hypothesis previously reported by Belharouk et al. [2]. To conclude, reported gassing of battery cells with LTO anodes is most likely caused by the residual water content in poorly dried electrodes and separators or by cell assembly in ambient air.

Moreover, on-line mass spectrometry in combination with ex-situ ATR FTIR and XRD showed that hydroxyl anions produced in the electrochemical reduction of H2O cause a ring opening reaction of alkyl carbonate molecules in the electrolyte, leading to CO2 evolution and formation of lithium alkyl carbonate oligomers. The latter are deposited as a passivation layer on the LTO anode and lead to strong capacity loss. Whether a protective solid electrolyte interphase (SEI), which is present on graphite anodes (recommended as anode material for the cell of EEBatt project by TP 2.400), can prevent water reduction and the concomitant hydrogen evolution and hydroxide anion formation is currently under investigation.

In 2014 EEBatt researchers will characterize porous media in advanced battery systems during a four day beam-time at the neutron research facility in Sacley, Paris

To fully understand results from different tests performed in each work package and to evaluate the performance of battery cells and decomposition products, in-situ or post-mortem analysis methods, respectively, are essential. Therefore, work package TP 2.900 deals with the characterization of battery materials in order to obtain structure- and electronic-performance relationships, ex-situ and especially in situ/operando.

Fundamental understanding of the materials and how they behave under charging/discharging conditions, as well as during/after different aging processes, will allow the rational design of better materials and systems. One part of the project was dedicated to the design and successful testing of a new operando spectroscopic cell (for X-ray Absorption Spectroscopy as well as other spectroscopy techniques like Raman and UV Vis).

The electrochemical cell will need to be slightly adapted to allow X-ray spectroscopy of Fe containing materials, i.e. LiFePO4 as envisaged in the EEBatt project specifically. In February 2014, within an approved beam time period for the group at the Diamond Light Source in the UK, preliminary X-ray absorption spectroscopy (XAS) data on LFP materials, both fresh and aged materials, will be collected. Additionally, for the period April-September 2014, XAS beam time for operando battery experiments using LFP/graphite and LFP/LTO electrodes has been applied for at the same synchrotron. The results of the application are so far unknown. The response of the LFP materials on different aging procedures and their material changes during cycling, including leaching of metal compounds in the electrolyte, will give valuable insights into the materials' properties as well as detailed electrochemistry mechanisms, allowing further development of electrode materials and battery processes.

FOCUS AREA - STRATEGY AND BUSINESS MODELS FOR ENERGY STORAGE

Beside technical questions, the energy storage problem is particularly a techno-economic topic, as energy storage systems will only be successful if business models can be identified which allow an attractive cost and revenue structure. Research at the two chairs at TUM School of Management, the Chair for Strategy and Organization (lead by Prof. Welpe) as well as the Chair of Marketing and Consumer Research (lead by Prof. Roosen) is therefore centered around the development of scenarios with high customer value proposition and thus a sustainable business model. The research is conducted in close collaboration with the strategic business development of VARTA Storage GmbH, in order to build sustainable business models which integrate the users´ and customers´ needs.

A broad variety of scenarios can be conceived involving different players such as end-users, energy cooperatives, utilities or network operators. Economic feasibility, systems integration, communication with the customers and commercialization of the new products and solutions are crucial, since investments will otherwise be unlikely and the technology will not diffuse. As different business models, such as short term peak shaving and long term load balancing, have totally different technical requirements, early work on identifying target scenarios was required. A series of expert interviews was carried out with all important stakeholders in energy markets, i.e. with employees of grid operators, renewable energy generation technology providers and project developers, end-user households, energy consultants, industrial energy consumers and energy storage systems providers. Based on the feasibility within the project and suitability for academic research, different applications of energy storage solutions were analyzed with respect to their market potential.

After a widespread market research, the most promising applications for EEBatt are: island usage, peak shaving and increase of self-consumption.

The following selection of the most promising applications for the EEBatt project are included in further analyses: island usage (on-grid and off-grid), peak shaving in industrial applications and residential storage.

A closer analysis showed that electricity generation through renewable energy together with energy storage devices is already attractive compared to generation solely employing diesel generators. Hence, a concept for remote areas or regional initiatives pursuing self-sufficiency through the use of renewable energy sources has to be developed. With an expected price decrease of lithium modules, scenarios competitive with conventional grid electricity can be conceived. Suitable user groups, as for example emerging sustainable communities, have thus to be identified.

Furthermore, it is relevant to explain and communicate the value of the new products and services to the target group. To accomplish the diffusion of energy storage solutions, these have to be economically reasonable and in demand by the relevant target group such as energy cooperatives or individual customers. Besides, regulations and subsidies influence greatly the attractiveness and the economic feasibility of solutions in the energy market.

This can particularly be seen using the example of the Erneuerbare-Energien-Gesetz (EEG), a feed-in tariff concept which, after its introduction in Germany, was adopted in many countries around the world. The case of photovoltaics shows that it is essential for analyses regarding business models in energy storage to pay close attention to the regulatory environment.

EEBatt focuses on political framework situations and regulation standards in the energy market in Germany to strengthen the systems impact factor on Industry.

The scenario analysis has identified target groups as follows: consumers, sustainable communities, energy cooperatives and regional initiatives. Energy autarky and participation models for community energy storage solutions such as energy cooperatives are currently the main research topics at the two research groups. Customer value analyses should provide insights into potential business models and conclusions should be drawn regarding relevant product requirements. In later stages, these investigations are further evaluated by willingness-to-pay analyses and the investigation of product-related services. Furthermore, the risks and opportunities of these new technologies and business models for the target groups will be analyzed. All together, the research results should help the diffusion and adoption of this much-needed technology and support the engineering of products with high market potential.

[1] R. Bernhard et al., J. Electrochem. Soc (2014) accepted

[2] I. Belharouak et al., J. Electrochem. Soc., 159, A1165 (2012).

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Müller, Marcus, “Konzeption eines dezentralen stationären Energiespeichersystems – Ergebnisse aus der Marktanalyse der TU München“, Renexpo Austria, Salzburg, November 28, 2013

Ehrl, Andreas, „Experimental determination of transport parameters for binary electrolyte solutions for use in numerical simulations“, ModVal 11, Winterthur, Schweiz, 18. März 2014

R. Bernhard, S. Meini and H.A. Gasteiger “On-Line Electrochemical Mass Spectrometry Investigations on the Gassing Behavior of Li4Ti5O12 Electrodes and Its Origins” Journal of the Electrochemical Society 161 (2014) A497 DOI:10.1149/2.013404jes

Marcus Müller, Rebecca Bernhard, Simon Müller, Bernhard Kalkbrenner, Alexander Zeh, Rolf Witzmann, Jutta Roosen, Isabell Welpe, Hubert Gasteiger, Andreas Jossen: „Stationary Energy Storage: EEBatt – Stationary Battery Research at the TUM”, 1st Singapore Battery Meeting 2014, Singapore, February 2014

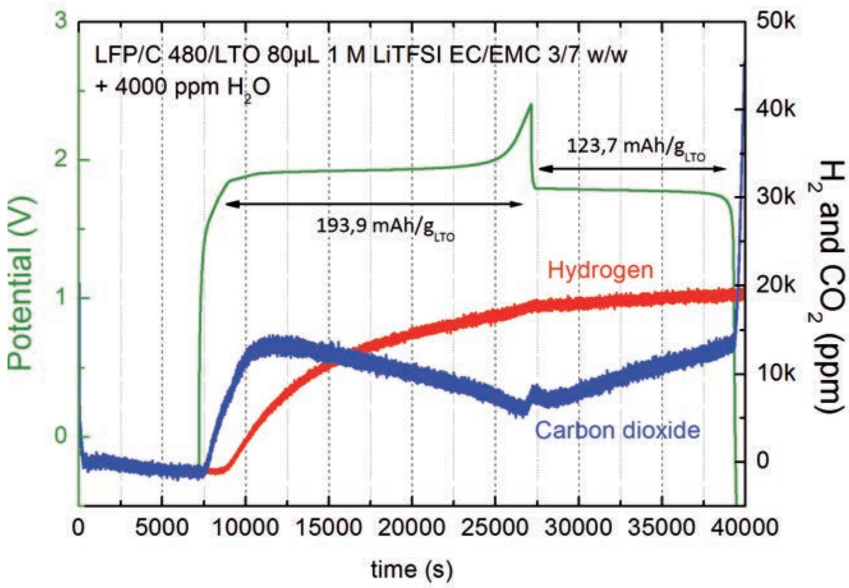
Zeh, Alexander, “Einsatz von Solarbatterien zur Netzunterstützung“, 2. Energiespeichertagung Umwelt-Campus Birkenfeld, 12. März 2014

RESULTS

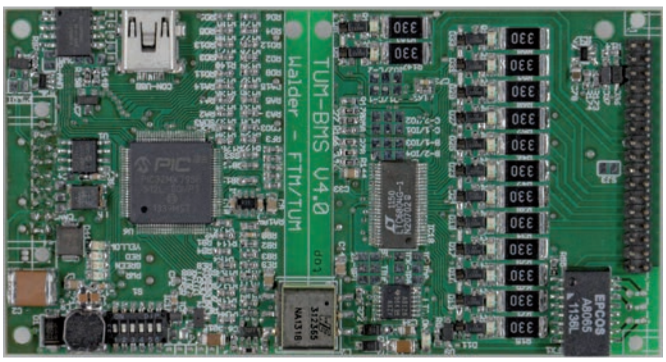
As EEBatt has a wide range of research fields, only a few results are shown in the following.

LTO Gassing

In the subproject cell research, investigations concerning lithium ion cells were made on the gassing behavior of Li4Ti5O12 containing electrodes and its origins with On-Line electrochemical mass spectrometry. As an example, Figure 1 shows the charging profile of an in-operando LTO/LFP full-cell containing 4000 ppm H2O. The voltage profile (green, left axis) follows the typical trend with its charge/discharge plateau at ≈ 2 V. Here, it is observed that the charging time takes longer than the expected 5 hours at a rate of C/5, equating to an overall “charge capacity” of 193,9 mAh/gLTO. The red and blue line (right axis) gives in-operando concentrations for hydrogen and carbon dioxide, respectively. As a result, reduction of water triggers a decomposition reaction of the solvent. Moreover, gassing can only occur in charged batteries, wherein the LTO anode‘s potential is lower than that for the reduction of water (potential of pristine LTO electrodes with ≈3 V vs. Li/Li+ is above the H2O reduction potential).



■ *Fig. 1 In-operando full-cell: galvanostatic charge of a LTO/LFO full-cell (6.21 mgLTOcm-2) at 0.22 mAcm-2 (green line) using 1 M LiTFSI in EC/EMC (3/7 g/g) with the addition of 4000 ppm H2O and real-time hydrogen (red line) and CO2 (blue line) gas concentration*



■ *Fig. 2 Experimental design of the TUM Battery Management System*

Battery Management Topologies

Researchers at TUM used their knowledge of the design of battery management systems and set up a first prototype of the TUM BMS to be used in EEBatt, shown in Figure 2. First investigations have shown that previous work on BMS at TUM can be adopted in the EEBatt project.

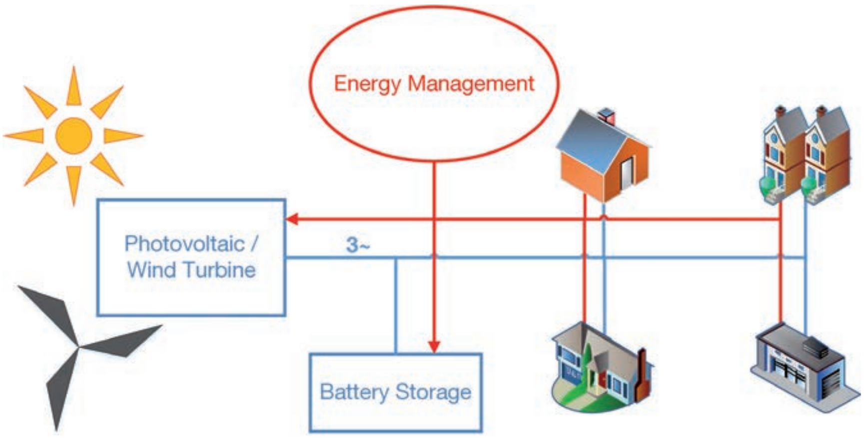
A completely new BMS system is set up by researchers in the EEBatt team for stationary devices.

To fulfill all requirements of a stationary storage system, the BMS design will be renewed using new topologies and microcontrollers from the latest research.

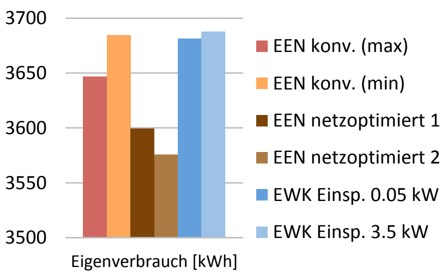
Energy Management Topologies

To exploit the benefits of combining renewable energies with electric storage systems, different operational strategies for battery storage systems together with solar power systems for self-consumption, as shown in Figure 3, were investigated. These strategies form an important entry to the complex structure of energy management in a non-transparent grid.
In this investigation it could be shown, that a feed-in damping approach is recommended for a grid-optimized application of a PV system and in addition only very rough prediction data is needed.

At present six different strategies have been evolved by EEBatt. In 2014 researchers await several more, due to a better understanding of grid functionalities.



■ Fig. 3 Grid load (blue line) and maximum feed-in limit Pgrid,max (red line) for an investigated operational mode of a PV system



■ Fig. 4 Different operational strategies adopted on self-consumption for PV systems

Due to the project structure, investigations concerning operational strategies were made under different chairs with different knowledge bases. This fact led to the investigation shown in Figure 4. Research on diverse strategies in PV storage system applications was carried out and the results combined. It could be shown that single focused observations cannot fulfill the requirements for decentralized systems. This is caused by the number of boundary conditions in complex PV storage systems, which relate to environmental conditions. In the next steps those models will be combined in a grid structured decentralized energy system on distribution network level.

ZAE division in Garching will strongly support the field test with their expert knowledge in field testing

EXTERNAL PROJECT PARTNERS

ZAE Bayern

The Bavarian Center for Applied Energy Research (ZAE Bayern) is a registered, non-profit association. The association was founded in December 1991 and has its registered office in Würzburg. It was established to promote energy research as well as education, further training, consultation, information and documentation in all fields significant to energy research.

The association supports a scientific research institute with three divisions in Würzburg, Erlangen and Garching, employing about 180 scientists, technicians, administrative personnel and students. In EEBatt, the ZAE division in Garching will survey and support the field test in the late phase of the project, as well as researching heat distribution in the system.

VARTA Storage GmbH

The traditional company VARTA Micro Group is a leading international manufacturer of OEM (Original Equipment Manufacturer) - and retail batteries with more than 100 years of experience in the development and production of batteries of many electrochemical systems and sizes. As a global system supplier, the company is able to offer effectively customized battery solutions.

VARTA Micro Group constantly invests in basic research of new technologies to further expand its technology leadership. Thus, numerous basic patents connected to the lithium-ion battery technology are held by the VARTA Micro Group.

For the promising residential energy storage market any development and resulting sales activities of the VARTA Micro Group are consolidated in a 100% owned subsidiary, the VARTA Storage GmbH, located in Nördlingen / Bavaria. The VARTA Storage GmbH has substantial know-how in the field of energy storage using long-life lithium-ion batteries and conducts in this context innovative research and development activities. Consequently the company represents the industrial partner within the collaborative research project 'EEBatt'.

Besides the know-how about all components of an energy storage system, such as lithium-ion-cells, battery modules and power electronic devices, VARTA Storage contributes its experiences with relevant technical standards and tests in order to guarantee the success of the overall project.

Outreach

TUM Applied Technology Forum

INSTITUTIONAL STRATEGY OF TUM

The TUM Applied Technology Forum is one module within the institutional strategy of TUM. To stay competitive in the research field of engineering, competences have to be bundled. Therefore the TUM Applied Technology Forum offers a new form of research cooperation with five Universities of Applied Sciences (UoAS) within the Munich Metropolitan Area: Deggendorf Institute of Technology, Ingolstadt University of Applied Sciences, Munich University of Applied Sciences, Rosenheim University of Applied Sciences, Weihenstephan-Triesdorf University of Applied Sciences. MSE has developed this program to support outstanding young research talents from UoAS in the field of energy research. Research Tandems consisting of professors from both universities team up and work on a collaborative project, offering promising graduates from UoAS the possibility to earn a doctorate at TUM. The first call for applications was submitted in January 2013 and the first eight projects were selected by a group of reviewers in May 2013. The interim results of their projects will be presented at a symposium in April 2014.

CURRENT PROJECTS

Biomassepellets aus Pferdemist
Prof. Dr. Dominikus Bücker (Rosenheim UoAS)
Prof. Dr. Wolfgang Alto Mayer (WZ Straubing/TUM)
PhD student: Dipl.-Ing. (FH) Cornelius Uhl
Start: 1.9.2013

Ressourceneffizienz von Stadtquartieren
Prof. Dr.-Ing. Nathalie Eßig (Munich UoAS)
Prof. Dr.-Ing. Gerd Hauser (BGU/TUM)
PhD student: Matthias Heinrich
Start: 1.11.2013

Erforschung und Entwicklung von transparenten Elektroden aus Carbon Nanotubes Schichten und deren Laserstrukturierung für die organische Photovoltaik
Prof. Dr. Heinz Paul Huber (Munich UoAS)
Prof. Paolo Lugli (EI/TUM)
PhD student: Jürgen Sotrop M.Sc
Start: 1.8.2013

Analyse des Energieeinsatzes bei der Herstellung von hoch-präzisen Optiken
Prof. Dr.-Ing. Rolf Rascher (Deggendorf Institute of Technology)
Prof. Dr.-Ing. Michael Zäh (MW/TUM)
PhD student: Christian Trum
Start: 1.11.2013

Praxisorientierte Erarbeitung systemspezifischer Grundlagen für die Implementierung eines Smart-Grid fähigen On-Farm Energie Management Systems für Milchviehställe mit regenerativer Energieproduktion („On-Farm EMS“)
Prof. Dr. Jörn Stumpenhausen (Weihenstephan-Triesdorf UoAS)
Prof. Dr. Heinz Bernhardt (WZW/TUM)
PhD student: Manfred Höld
Start: 1.10.2013

Netzgestaltung und Ertragsoptimierung solarthermisch unterstützter Nahwärmenetze im Geschosswohnbau
Prof. Dr.-Ing. Wilfried Zörner (Ingolstadt UoAS)
Dr. Vicky Cheng (MSE/TUM)
PhD student: Dipl.-Ing. (FH) Daniel Beckenbauer
Start: 1.1.2014

Akzeptanz unterschiedlicher Windenergiekonzepte in Bayern unter Berücksichtigung von Bürgerbeteiligungsmodellen
Prof. Dr. Klaus Menrad (Weihenstephan-Triesdorf UoAS)
Prof. Dr. Jutta Roosen (WZW/TUM)
PhD student: Katharina Langer
Start: 1.2.2014

Betriebsfestigkeitsnachweis von Schweißverbindungen bei Windkraftanlagen
Prof. Dr.-Ing. Imke Engelhardt (Munich UoAS)
Prof. Dr.-Ing. Martin Mensinger (BGU/TUM)
PhD student: Richard Schiller
Start: 1.3.2014

Munich School of Engineering

Technische Universität München

President Herrmann, Prof. Dr. Hamacher,
Prof. Dr.-Ing. Adams, Prof. Dr. Gasteiger,
Prof. Dr.-Ing. Lang, Prof. Dr.-Ing. Lienkamp,
Prof. Dr. Müller-Buschbaum,
Prof. Dr.-Ing. Spliethoff, Prof. Dr.-Ing. Wall

"Research towards innovative energy systems and materials"

04.07.2013 – 8.30 am to 9.00 pm

8.30 - 9.00 am
Registration

9.00 - 9.15 am
Opening
Thomas Hamacher, Director Munich School of Engineering

9.15 - 9.45 am
Keynote: Shale Gas Revolution
Olaf Martins, ExxonMobil

9.45 - 11 .00 am
Session Chair: Hartmut Spliethoff, CPG MSE

Flexible Power and Synthesis Plant Concepts with Integrated Chemical Power Storage
Alexander Buttler, Institute for Energy Systems

Explosive Combustion of Stratified Hydrogen-Air Mixtures – Experimental Observations and Conclusions for Safety Applications
Lorenz Böck, Chair for Thermodynamics

Table-top Electron-beam Induced Plasma Chemistry
Andreas Himpsl, Chair for Experimental Physics

11.00 - 11.45 am
Poster Presentation, Coffee Break

11.45 - 1.00 pm
Session Chair: Werner Lang, ZNB MSE

Processes for the Gasification of Biomass and Current Developments
Markus Ulbrich, Chair for Energy Systems

Smart Grid Simulation
Christoph Doblander, Chair for Application and Middleware Systems

Heat Consumption Analysis on a City Scale
Peter Böhme, Institute for Energy Economics and Application Technologies

1.00 - 2.30 pm
Poster Presentation, Lunch Break

2.30 - 3.45 pm
Session Chair: Peter Müller-Buschbaum, NRG MSE

Large-Scale Spray Deposition of Functional Materials for Photovoltaics
Alaa Abdellah, Institute for Nanoelectronics

Alternative Supports for Applications in Electrocatalysis: Ethanol Oxidation on Pt/TiOxCy
Celine Rüdiger, Institute of Advanced Study

Highly Conductive PEDOT:PSS as Electrode for Flexible Structured ITO-free Organic Electronics
Claudia M. Palumbiny, Chair of Functional Materials

3.45 - 4.30 pm
Poster Presentation, Coffee Break

4.30 - 5.45 pm
Session Chair: Markus Lienkamp, WZE MSE

Greenhouse Gas Emissions from Induced Impacts in the Built Environment
John E. Anderson, Institute for Energy Efficient Building and Design

A Need- and Willingness-based Approach for Online Electric Vehicle Charging Control
Victor del Razo, Chair for Application and Middleware Systems

Power Systems Research – Why we Should Cooperate
Herbert Mangesius, Institute for Information-Oriented Control;
Matthias Huber, Institute for Energy Economics and Application Technologies

5.45 - 6.00 pm
Summary of the Day

6.00 - 6.45 pm
Keynote: Climate Science - What Do We Know About Past, Current and Future Climate Change?
Janina Körper, Freie Universität Berlin

6.45 - 9.00 pm
Poster and Presentation Award, Colloquium Dinner

Location:
TUM – Institute for Advanced Study, Garching

Registration:
http://www.mse.tum.de free for TUM-Members

MSE Colloquium

ANNUAL PRESENTATION OF CURRENT ENERGY-RELATED RESEARCH AT TUM

The MSE Colloquium is the annual meeting of many MSE researchers working in the field of energy research. The Colloquium offers a unique opportunity to learn about the diversity of energy research at the TUM. Most of the presentations are delivered by young scientists doing their doctorate.

On July 4th 2013 the 3rd MSE Colloquium “Research Towards Innovative Energy Systems and Materials” took place. 180 participants from TUM as well as external participants from other universities and industry attended the presentations of our young researchers and had vivid discussions with our researchers at the 36 posters. Key note speeches were given by Olaf Martins from ExxonMobil on Shale Gas and by Janina Körper from FU Berlin on Climate Science. The three best presentations and posters were elected by a jury. The best presentation and the best poster received a price, donated by the energy supplier Lechwerke AG.

PRESENTATION AWARD WINNERS:

1. Claudia M. Pallumbiny, Chair of Functional Materials “Highly Conductive PETOT: PSS as Electrode for Flexible Structured ITO-free Organic Electrodes”
2. Herbert Mangesius, Institute for Information-Oriented Control; Matthias Huber, Institute for Energy Economics and Application Technologies “Power Systems Research – Why we Should Cooperate”
3. Alaa Abdellah, Institute for Nanoelectronics “Large-Scale Spray Deposition of Functional Materials for Photovoltaics”

POSTER AWARD WINNERS:

1. Manuel Bentlohner, M.Sc., Chair of Inorganic Chemistry/Noel Materials “Ordered non-oxide semiconductor networks for hybrid inorganic-polymer solar cells assembled from Zintl clusters”
2. Stephan Pröller, B.Sc., Chair of Functional Materials “Hybrid solar cells based on TiO2-nanoparticles and water soluble polymer”
3. Matthias Huber, Dipl.-Ing., Institute for Energy Economics and Application Technologies “Decomposition methods for large-scale optimization of power systems”

By now, the annual MSE Colloquium is established as a competitive exhibition of the comprehensive research work within TUM and the MSE in the field of energy research. It developed as an excellent platform to promote networking and future collaborations.

TOPICS OF PREVIOUS COLLOQUIA:

1st MSE Colloquium “Sustainable Energy Supply of the Future” (18.7.2011)
2nd MSE Colloquium “Energy Challenges – Germany 2050” (28.6.2012)

■ *Poster Agenda 2013*

Internationalization

MSE AND THE WORLD

The international perspective is necessary in all research fields first to understand the problems which are rather diverse from country to country; second, internationalization offers the possibility of benchmarking. And third, cooperation with people offering alternative expertise and ideas. Therefore it is important to identify possible international cooperation partners and to design cooperation schemes.

While this is important in all research fields it is particularly important in the energy field. Energy markets are internationally dominated, especially oil and coal markets. CO_2-emission can only be curbed if international agreements can be reached and followed. Energy technologies are not only designed for individual markets but for the global market. In the recent past Asia started to dominate the demand for energy. The US developed new exploration technologies to produce oil but especially gas.

Three possible partners to do common energy research were identified to enter this important future market. Nanyang Technological University (NTU) and TUM signed a Memorandum of Understanding to establish the International Center for Energy Research (ICER) on the 11th of April. A formal cooperation contract will follow soon. Possible projects are already discussed.
TU Munich and Singapore have a long tradition in cooperation. GIST in Singapore offers Bachelor´s and Master´s courses. A possible course in energy management might soon be added. The TUM-Create project offers a unique research platform to develop new and innovative concepts in electromobility. Based on this experience new cooperations in subjects like photovoltaics, wind or marine technologies will be developed. Singapore also offers the opportunity to be a bridge to the rest of Asia, especially South-East-Asia. This world region is on the way to cooperate within the so called ASEAN group. A free trade treaty might soon come in force. This will also offer German industry the possibility to enter this important future market.

A partner in the US is necessary to capture the dynamics of this large market which is especially strong in fossil technologies, but which does also offer unique opportunities in other cutting edge technologies like information technology. New ventures between the car industry and the internet company google show this.

TU Graz offers interesting research in many energy technologies but also the possibility to work commonly on the energy transition within Bavaria. This will certainly be more successful if a strong cooperation between Austria and Bavaria can be initiated.
Joint projects and exchange programs are potential schemes.

Student Project in Simbabwe ■

Energy and Geopolitics

ENERGY IN CONTEXT:
SOCIAL AND LEGAL IMPACT OF LARGE-SCALE ENERGY PROJECTS

HEAD

Prof. Dr. Giorgi Khubua
Energy and Geopolitics (MSE)

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The social and legal impacts as well as the security policy context of large scale energy projects have yet to be investigated. Comparative energy research offers the opportunity to discuss energy issues in a global context and to develop international research profiles.

"Energy and Geopolitics" is striving to promote and strengthen dialogue in energy research across national borders as well as construct a transfer system for technological cooperation. It seeks to provide a common basis for comparative energy research, particularly in Caucasus and Central Asia. It also offers the opportunity for researchers to discuss their work in a broad and global context and to develop an international profile.

The main research areas are the geopolitical, social and legal implications as well as the ecological context of large-scale energy projects. Furthermore, research issues include political implications that are of central importance concerning ethnic antagonisms and the nascent state of civil society in transition countries. Within this research context, it is assumed that the interests of both corporate and governmental actors have merged in newly founded democracies and thus differ significantly from the Western European market economy. Accordingly, research focus is put not only on governmental institutions but also on their substructures, such as lobbyists, corporations and social groups.

Key issues of research are:

- Relationship between national security interests of states (classical geopolitics) and transnational economic criteria of multinational corporations (geo-economics)
- Promotion of democratization processes through energy projects and impact of democratic deficits on energy projects
- Successful establishment of institutions for energy governance in transition countries
- Neutralization of uncertainty to guarantee a comparatively uniform distribution of (perceived) benefits from energy projects
- Assessment of opportunities and risks as well as identification of possible compensation for (potential) winners/losers in energy projects and subsequent balancing of disparities between energy resources of individual countries for the benefit of all parties involved

The envisioned energy forum, participated in by countries in Caucasus and Central Asia, offers scientists and politicians as well as corporations a broad platform for discussion to promote further economic and scientific cooperation, efficiency and innovation in the energy sector.

SEEIT

A EUROPEAN STRATEGIC PARTNERSHIP
FOR SUSTAINABLE ENERGY EDUCATION, INNOVATION AND TECHNOLOGY

The European project SEEIT - Partnership for Sustainable Energy, Education, Innovation and Technology - is a strategic platform to explore global challenges and needs and the enormous social, economic and technological potential of a "low carbon" economy. It aims to find and implement potential solutions in light of the EU 2020 program Strategic Energy Technology Plan (SET-Plan).

TUM is a full member of the SEEIT-consortium, whose goal is to foster cooperation between outstanding European institutions within the field of renewable energy technologies. SEEIT is developing one of the leading platforms in Europe in the areas of research, education and innovation in the long term.

Thus the SEEIT partnership pursues four main objectives:
- becoming a global leader in connecting experts with initiatives in the area of sustainable energy,
- accelerating the development of sustainable energy technologies,
- becoming a central agent in improving sustainable energy innovations and
- working towards integrating education, innovation and research across Europe.

SEEIT activities can be divided into diverse innovation and education tools that foster research and innovation in sustainable energy.

MSE especially contributes to activities that are linking universities more closely in the field of STEM-education. Thus it provides a platform where different universities can implement thesis topics for international work under the co-supervision of TUM and the partnering university. In a first step and pilot project, this platform will be open only for Master´s students. If this model is successful, it can be opened to generate a unique platform for joint theses that are accepted throughout all contributing universities. In the longer term it is also possible to open the platform for interdisciplinary fields and different scientific levels as well as partners from the business environment.

Thus, the platform provides the opportunity to work on some of the gaps and needs addressed in the SET-plan roadmap: practice- and problem-oriented education can be offered by addressing industry-driven topics. Mobility of learners as well as intercultural competences can be promoted through working and research periods at the supervising universities.

This platform may then serve as a flagship for similar projects promoting the TUM motto: At home in Bavaria, successful in the world.

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Future Challenges

In 5 Years

MSE PERSPECTIVES

Energy research is done in various institutions outside and inside of universities. In the past a strong focus was put on nuclear research, which was mainly done in the nowadays so-called institutes of the Helmholtz Association. The institutes were ideally suited to do research in large research facilities, which was the prerequisite to do proper nuclear research. The envisioned energy transition requires also a restructuring of energy research. At the moment, universities seem best suited to do the research which is necessary for the envisioned energy transition. Universities offer most of the expertise on the technical as well as the economic side and also on legal issues. They also offer the possibility to bring young unprejudiced researchers - which seem to be always necessary if a major transition will be organized - into the process. Still universities require organizational changes to become reliable and prominent partners for industry and politics in this process. The aim of MSE is to raise the level of individual research efforts in various institutes of the university to a level which is on the "system level", here with a first focus on energy and especially the electricity system. This will require not only communication skills, in the end new organizational schemes need to be established which make cooperative work within the university possible. The Energy Valley Bavaria and the EEBatt projects are excellent examples to study how such structures should and could look like in the future. Developing these organizational questions will require an open debate within the university about research on a "system" level. These questions certainly go far beyond the energy question alone and deal with many issues starting from water going to traffic, health and the food sector.

The other side of this medal focuses on the communication between university and the outside world. MSE should become a natural entry point for industry, administration and politics to the university related to energy issues. This should certainly not hinder any bilateral communication existing between individual institutes and outside partners. But this means also that MSE takes part in the political debate around energy questions. The past years have seen inflation in engagement by various institutions into the debate about laws like the feed-in-tariff or new building codes. Many of these statements lack a sound scientific basis or are strongly interest-driven, which is not bad per se but which needs more balanced views from the scientific sphere. The noble attitude of many scientists not to get "dirty hands" by dealing with politics needs to be overcome. But this needs of course also very special care so that not again interest-driven reasoning and scientific rationality are mixed.

Energy Transition in Bavaria

Bavaria currently is one of the economy forerunners in Germany with a very good infrastructure like the airport in Munich. Concerning the energy side, Bavaria invested into an infrastructure which brought oil directly to the state by pipelines from Italy already during the sixties and seventies. This lead to the development of the refinery center in Ingolstadt. The absence of gas and coal promoted nuclear energy as the technology of choice in the electricity sector. Nuclear power offered rather affordable tariffs not at least to industrial customers. No other German state is so dependent on nuclear energy as Bavaria is. This makes the transformation away from nuclear power a real challenge. The introduction of more fossil fuels in the power mix is again not easy, because supply of coal is a challenge due to logistics reasons and at least conventional gas power plants find no investors these days because of economic reasons. Still a capacity lack is expected to arise sometime in the near future when nuclear capacity is switched off at latest in the year 2022.

MSE could, together with the Bavarian government, develop strategies to make this transition happen. These strategies need to include various items: a realistic development plan for wind energy within Bavaria, extension and development of transportation and distribution networks, a Bavarian wide combined heat and power initiative including the possibilities of geothermal power and heat.

Energy transition is a major challenge for Bavaria and also the Bavarian universities. The development of new institutional settings and new forms of cooperation is a challenge but also an opportunity which might bring Bavaria not only a new more sustainable energy infrastructure but also new forms of scientific cooperation which will help to solve also other demanding problems on the long term.

Wind Energy

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Dr.-Ing. Mark Capellaro
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Pietro Bortolotti (Doctoral candidate)

The mission of the Wind Energy Institute is to educate students and contribute to the development of wind energy technology. These goals are pursued by advancing the understanding of the physics that underlie the energy conversion process from wind, and by developing engineering solutions that exploit this knowledge.

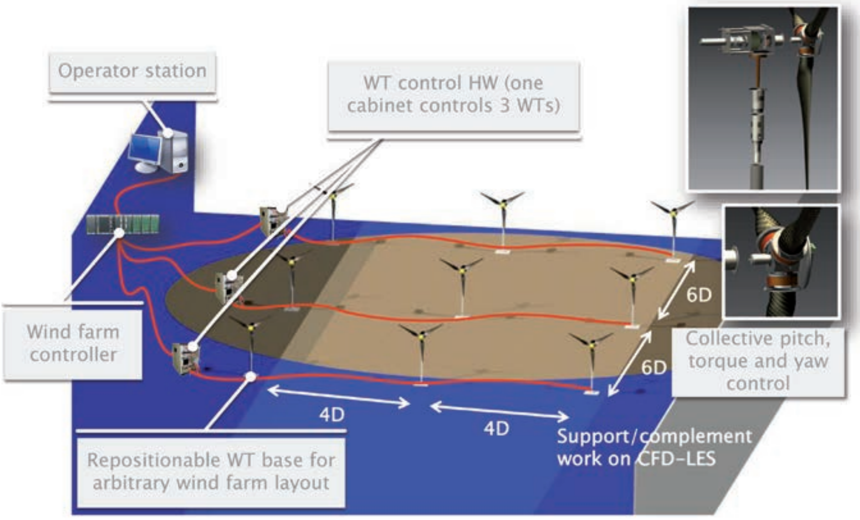
The Wind Energy Institute works both on basic scientific and application-oriented problems. Research in this field is highly multi-disciplinary, reflecting the multi-physics nature of the conversion process that takes place at the level of the individual wind turbine and within a wind farm. Relevant disciplines include the aerodynamics of turbulent flows, aero-hydro-servo-elasticity, controls, materials and manufacturing, generator and grid technology, health monitoring, and others.

The Institute has four main thrust areas: simulation, testing, control and design. Among the pillars of wind energy research, simulation technology and experimental testing play crucial roles and go hand in hand. The former provides the tools for simulating wind energy systems, while the latter provides the data for the validation and calibration of the simulation tools, thereby establishing their level of fidelity to reality. Controls play central roles in establishing performance as well as ultimate and fatigue loading. Finally, design, with its holistic view of the problem, is the ultimate judge of any technological innovation, leading to the understanding of cost/benefit tradeoffs.

■ *Figure 1. Reduced solidity blade, for storm load mitigation.*

The Wind Energy Institute is at work for lowering the cost of wind energy and reducing its impact, with particular reference to the wind sites that are available in Bavaria. This is achieved by designing advanced rotors, and by building a better understanding and simulation capability of the wind flow over complex terrains.
Advancements in light-weight rotor design are being investigated through improvements in the aerodynamics, in the structural design and the use of smart sensing and control strategies. By the combination of these technologies, reduced ultimate and fatigue loads can be achieved and exploited for reducing weight and improving performance, thereby in turn reducing cost.

To help in the understanding of the effects of complex terrains on power output and loading of wind turbines, work is underway on advanced simulation tools and on wind tunnel testing. Through simulation, increased shear and turbulence in complex sites are being investigated, and their adverse effects are mitigated through active and passive load alleviation strategies. Wind tunnel models are used for the experimental investigation of some of these technologies in the controlled environment of the lab, this way alleviating some of the limits and hurdles of full scale testing. A new scaled wind farm experimental facility is being developed, that will support work at the Institute on wake interaction among wind turbines, and the testing of wind farm control algorithms for improved power production and load mitigation.



■ *Figure 2. Scaled wind farm model under development at TUM, for supporting research on wind farm aerodynamics and control.*

RECENT PUBLICATIONS

C.L. Bottasso, F. Campagnolo, A. Croce, S. Dilli, F. Gualdoni, M.B. Nielsen, `Structural Optimization of Wind Turbine Rotor Blades by Multi-Level Sectional/Multibody/3DFEM Analysis', Multibody System Dynamics, doi:10.1007/s11044-013-9394-3, 2013.

C.L. Bottasso, F. Campagnolo, C. Tibaldi, `Optimization-Based Study of Bend-Twist Coupled Rotor Blades for Passive and Integrated Passive/Active Load Alleviation', Wind Energy, doi:10.1002/we.1543, 2012.

C.L. Bottasso, F. Campagnolo, V. Petrović, `Wind Tunnel Testing of Scaled Wind Turbine Models: beyond Aerodynamics', Journal of Wind Engineering & Industrial Aerodynamics, 127:11-28, doi:10.1016/j.jweia.2014.01.009, 2014

Center for Geothermics

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The greater area of Munich has drawn a lot of attention due to its hydrothermal energy potential. This potential is easily accessable and can contribute significantly to reduce CO2 emissions in Heat and Power Production. During the last two years an increase of 165 % of installed capacity compared to 2011 has been achieved and a lot of other plants are planned in the near future.

Therefore it is about time to bundle activities for geothermal energy inside the Munich School of Engineering. Chairs such as the Institute of Energy Systems and the Chair of Hydrogeology have a comprehensive expertise to takle this interdisciplinary topic. Besides that, understanding the hydrochemistry and reliable operation of tubomachinery is also a challenging task, where TUM has already a lot of experience and specialized research groups. Moreover public participation and communication already in the planning process can increase acceptancy for such projects. This is where TUM MSEs focus for public participation can contribute quite significantly.

In the next years MSE wants to increase and strengthen its activities in Geothermal Energy for a sustainable and CO2-lean energy mix.

■ *Recently commissioned Geothermal Power Plant in Sauerlach*

Power-to-Gas

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The German transition towards an energy system based on renewables still struggles with a plethora of problems and drawbacks. As the 'Energiewende' proceeds, the magnitude of the economic and technological and political challenges becomes more and more evident. Furthermore, approaches and opinions regarding the perfect outline for the future energy system differ strongly leading to heated debates and political uncertainty, although the necessity for energy storage systems in a fluctuating renewable-based energy system is widely agreed.

The power-to-gas concept and Synthetic Natural Gas (SNG) as chemical energy carrier respectively, might be part of a solution and could form a key aspect in future energy systems. The idea behind the power-to-gas concept is to connect existing infrastructure (natural gas grid) with the overburdened electrical grid especially for energy transport, distribution and storage. The natural gas grid has today a capacity of more than 200 TWh. This huge storage potential can be used by converting excess electrical power to SNG with approximately the same composition and behavior as fossil natural gas and injecting it into the gas grid. For reconversion of the SNG to electrical power, existing combined-cycle and gas turbine power plants can be used.

The main challenges for this technology are the remaining technical issues in key process steps. Especially the scale-up and dynamics of the electrolysis units and the heat removal and design of the synthesis reactor to convert hydrogen and carbon dioxide to SNG still required elaborate research. The final barrier to be tackled is finding a viable and innovative business plan combined with the necessary political will to support and bring the technology to market.

In this regard, we would like to invite you to the TUM-Workshop
SNG as a key for future energy systems – power-to-gas and biomass-to-gas

Date:	Friday the 9th of Mai 2014
Location:	Institute for Advanced Studies (IAS) building Research Campus Garching, Lichtenbergstraße 2a, Garching

This workshop will address current research needs and activities, showing the existing research at TUM and beyond and bringing together people from industry, small and medium-sized companies, politics, business development and research for this one day event. The thematic focus will be on the thermochemical route to SNG via gasification of biomass with subsequent gas cleaning and conversion and the power-to-gas route via electrolysis of excess electricity and subsequent synthesis with carbon dioxide.

The program will include talks and presentations from TUM Professors and research staff as well as external presentations from industry and research. Also there will be a call for posters and a small exhibition.

We want to invite you to join us on this exciting event on Mai 9. For further information and registration please visit the website of MSE/CPG (http://www.powergen.mse.tum.de/) or contact Mr. Fendt (sebastian.fendt@tum.de).

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