Module Catalogue

Master of Science (M. Sc.) Sustainable Systems Engineering

Subject-specific Examination Regulations **2016**

Institut für Nachhaltige Technische Systeme
Technische Fakultät
Albert-Ludwigs-Universität Freiburg

April 16, 2021

Contents

The international Master's program Sustainable Systems Engineering

Science and engineering are basic tools to achieve sustainable development, not only in technology, but also in domains such as ecology, economics and society.
The international Master's program Sustainable Systems Engineering (SSE) provides in-depth engineering skills in sustainable materials, energy systems, and resilience engineering. Complementing interdisciplinary knowledge in natural resources and climate change, sustainable economy, technology and society is also taught during the two-year-program.

The Master's program in SSE is designed for highly qualified graduate students holding a Bachelor‘s degree in engineering or science. SSE students will have the opportunity to:

- be involved in cutting-edge research with internationally renowned professors,
- benefit from state-of-the-art equipment on a modern campus and pioneering laboratories at partner institutes,
- benefit from a European campus (www.eucor-uni.org), and
- live in one of Germany’s most appealing and green cities.

The SSE Master's is designed to prepare graduates in particular for a further career in research. Moreover, highly qualified SSE graduates will satisfy today’s needs of

- the conventional and renewable energy industry,
- supply companies, manufacturers and operators active in fields like mobility, energy, infrastructure planning, environmental engineering, risk & resilience, and (raw) materials.

Department of Sustainable Systems Engineering (INATECH)

The Department of Sustainable Systems Engineering (Institut für Nachhaltige Technische Systeme - INATECH) was founded by the University of Freiburg in October 2015. The aim was to connect teaching and research in the field of sustainable systems and to complement the university with an engineering research facility for research in sustainability. Together with the Department of Microsystems Engineering (IMTEK) and the Department of Computer Science (IIF), it builds the Faculty of Engineering.

In cooperation with the Fraunhofer Institutes in Freiburg, the following research emphases were conceptualized:

- Sustainable Materials - which can be produced and applied in an energy and resource friendly way.
- Energy Systems - which can provide a reliable and efficient supply and storage of renewable energies.
- Resilience - which can secure the robustness and adaptability of systems towards environmental disasters and climate change.

Examination regulations and module catalogue

This module catalogue has been compiled according to the 2016 examination regulations (Prüfungsordnung) for the study program Master of Science in Sustainable Systems Engineering. Examination regulations define the requirements for a specific degree. Usually the requirements consist of a mandatory and an elective section. These sections in itself are divided into compulsory or elective modules. A module is a self-contained unit within a scientific topic or area that is defined by specific learning goals. Modules may consist of one or more courses, course-based assessments and coursework – depending on the learning objectives. A course is the smallest unit described in this catalogue. There are different types of courses including lectures, exercises, laboratory courses and seminars.

This module catalogue describes the modules that constitute the curriculum of the master's program Sustainable Systems Engineering (SSE). Module descriptions clarify elements such as title, learning objectives, course content, name of the offering institution/professor, type of assessment, and – importantly – how many ECTS credit points according to the „European Credit Transfer and Accumulation System" (short: ECTS system) the student will earn when completing the module successfully. These credit points define the associated work load for the student. One credit point is equivalent to a work load of 30 hours. The recommended number of ECTS points to be completed per term is 30. The ECTS credits usually define the weighting of a module within the whole study program and its impact on the final grade (similar to grade point average (GPA)) – however, there are exemptions; these will be mentioned in the module description, too, if any. Students of the master's program SSE have to complete 120 ECTS credit points in total in order to earn their degree. This usually requires four terms or two years, respectively.

More information about the examination regulations of the master's program can be found at on INATECH's website.

Structure and curriculum of the Master of Science program

The master's program is divided into the following two main sections:

- Compulsory Modules with 65 ECTS (mandatory section)
- Elective Modules with 55 ECTS (elective section)

The **mandatory section** consists of eight compulsory modules with a total of 65 ECTS credits, which all must be completed.

- Fundamentals of Resilience (5 ECTS)
- Material Life Cycles (5 ECTS)
- Computational Materials' Engineering (5 ECTS)
- Solar Energy (5 ECTS)
- Energy Storage (5 ECTS)
- Control and Integration of Grids (5 ECTS)

- Master's Project (5 ECTS)
- Master's Thesis and Colloquium (30 ECTS)

The **elective section** of the SSE is divided into a technical and a non-technical specialization area with a total of 55 ECTS credits.

The Technical Specialization area is sub-divided into four different concentration areas:

- Energy Systems
- Information Processing Technologies
- Sustainable Materials
- Resilience Engineering

Within the concentration areas, a variety of modules are offered – these can be originating from INATECH, but also from other departments and faculties (such as IMTEK; IIF, or Physics). Due to their interdisciplinary content, a few modules are applicable to more than one concentration area and are therefore mentioned in both areas; in such cases, students must decide in which area the module shall be credited.

Students must select a minimum of two concentration areas, and in each of these two areas a minimum of 10 ECTS points must be completed. In addition, students must complete two modules with a total amount of 10 ECTS from the following three modules.

- Design and Monitoring of Large Infrastructures (5 ECTS)
- Power Electronic Circuits and Devices (5 ECTS)
- Security and Privacy in Resilient Systems (5 ECTS) - NOT OFFERED IN SUMMER TERM 2021! See substitute module on the subsequent pages.

The non-technical specialization is called "Interdisciplinary Profile". In the Interdisciplinary Profile students must complete a minimum of 10 ECTS points. Students can select modules mentioned in this handbook but also modules from all over the University for their Interdisciplinary Profile (for details on how to do this, please read further below).

The remaining 15 ECTS (to complete the 120 ECTS for the master's program) can be selected from either the technical or the non-technical specialization areas (see the study plan on the next page).

In the first semester six compulsory modules will get everyone on the same technical level. From the second semester on, students start concentrating on their favorite research field and select several interdisciplinary modules to enhance their holistic societal and scientific understanding. The following illustration shows the recommended curriculum as it is expected to lead to a balanced workload. It also ensures consistency in content since some modules build on the skills and knowledge gained in others.

Recommended STUDY PLAN for Master of Science *Sustainable Systems Engineering*

INATECH
DEPARTMENT OF SUSTAINABLE SYSTEMS ENGINEERING

status as of 07/2018; changes reserved

	Term 1	Term 2	Term 3	Term 4	
	Compulsory modules (30 ECTS) - Energy Storage - Control and Integration of Grids - Computational Materials' Engineering - Fundamentals of Resilience - Material Life Cycles (MLC) - Solar Energy	**Compulsory elective modules** (10 ECTS, two out of three) - Monitoring and Design of Large Infrastructures - Power Electronic Circuits and Devices - Security and Privacy in Resilient Systems	**Master's Project** (5 ECTS)	**Master's Thesis and Colloquium** (30 ECTS)	
		Technical Specialization (20 - 35 ECTS, min. 10 ECTS each in two of the four areas) - Energy Systems - Information Processing - Sustainable Materials - Resilience Engineering			
		Interdisciplinary Profile (10 - 25 ECTS)			
ECTS	**30**	**30**	**30**	**30**	**120**

Info: ECTS is a standard for comparing the study attainment and performance of students of higher education across the European Union and other collaborating European countries. For successfully completed studies in the *Sustainable Systems Engineering* master's program, 120 ECTS credits are awarded. One ECTS credit equals on average 30 hours of workload.

For more information see the *Examination Regulations* of the program, they set the legal framework for the studies.
The available modules within these sections and the associated classes as well as their admission requirements are listed and described in detail in the respective module handbook.

Overview of all compulsory and elective modules

Modules offered by INATECH, IMTEK or IIF (Faculty of Engineering) are available for registration in HISinOne. Usually there is no limitation of spots in lectures; however, there are a few exceptions with limited capacity. For example, the PV lab has limited seats available every semester, but such limitation is valid for other courses, too (check out the module description in HISINONE). These limited seats are allocated based on a lottery (NOT first-come-first-serve!) carried out by the HISinOne system. This lottery is objective and cannot be influenced by staff members. It is therefore highly recommended to also have a back-up plan since students cannot count on getting a seat in such a course. There is no legal right to get a seat in a specific course/module.
By clicking on the page number given next to the module name, you will be directed to the module description. If it says “IMTEK” or “IIF” or similar, you will find the module description online, in HISINONE.

1. Mandatory section

Compulsory modules

- Energy Storage (p.20)
- Control and Integration of Grids (p.18)
- Computational Materials' Engineering (p.16)
- Fundamentals of Resilience (p.22)
- Material Life Cycles (p.24)
- Solar Energy (p.26)

- Master Project (p.28)
- Master Thesis and Colloquium (p.30)

2. Elective section

Compulsory elective modules

- Design and Monitoring of Large Infrastructures (p.47)
- Power Electronic Circuits and Devices (p.94)
- Security and Privacy in Resilient Systems (p.113)
  NOT OFFERED IN SUMMER TERM 2021!
  The substitute module is: Resilience of Supply Networks (p.105, INATECH)

} must select 2 out of 3

Technical Specialization Areas

Energy Systems

- Characterization of solar cells: From feedstock quality to final cell efficiency (p.33)
- Compiler Construction (IIF)
- Electrochemical Energy Applications (IMTEK, changing technical focus)
- Electrochemical Methods for Engineers (IMTEK)
- Electromobility (p.52)
- Emerging and Future Photovoltaic Technology Options (p.54)
- Energy in Buildings: components and systems for energy supply (p.58)

- Energy in Buildings: energy demand and building physics (p.56)
- Functional Safety: Active Resilience (p.65)
- Hydropower (block course, usually only open for SSE if offered online due to limited space, Faculty of Environment and Natural Resources)
- Industrial manufacturing and application of solar cells and modules (p.68)
- Methods of Material Characterization for Waste Management (p. 83, INATECH/ Freiburger Materialforschungszentrum)
- Multi-junction solar cell technology and concentrator photovoltaic (Faculty of Mathematics and Physics)
- Nanotechnology (IMTEK)
- Operations Research for Energy Systems (p.87)
- Photovoltaic Energy Conversion (Faculty of Mathematics and Physics)
- Photovoltaic Laboratory (p.91)
- Power Electronics for E-Mobility (p.97)
- Power Electronics for Photovoltaics and Wind Energy (p.99)
- Python for Energy System and Sustainability Analysis (p.101)
- Quantification of Resilience (p.103)
- RF- and Microwave Circuits and Systems (p.107)
- RF- and Microwave Design Course (p.109)
- RF- and Microwave Devices and Circuits (p.111)
- Thermoelektrik und thermische Messtechnik (IMTEK)
- Wind energy systems (IMTEK)

Sustainable Materials

- Adhesive Bonding (p.31)
- Bioinspired functional materials (IMTEK)
- Bionic Sensors (IMTEK)
- Ceramic Materials for Microsystems (IMTEK)
- Composite materials (p.39)
- Continuum mechanics I with exercises (p.43)
- Continuum mechanics II with exercises (p.45)
- Crystal Growth Methods II (Faculty of Environment and Natural Resources)
- Dynamics of Materials: Material Characterization (p.50)
- Electrochemical Energy Applications (IMTEK, changing technical focus)
- Electrochemical Methods for Engineers (IMTEK)
- Engineering of Functional Materials (p.60)
- Epitaxy (Faculty of Environment and Natural Resources)
- High- Performance Computing: Fluid Mechanics with Python (IMTEK)
- High- Performance Computing: Molecular Dynamics with C++ (IMTEK)
- Industrial manufacturing and application of solar cells and modules (p.68)
- Life Cycle Management (3-week-block course; Faculty of Environment and Natural Resources)
- Lightweight Design and Materials (p.75)
- Material Flow Analysis (p.83)
- Materials for Electronic Systems (IMTEK)
- Materials Selection and Sustainable Development for Mechanical Engineering (p.81)
- Mechanical Properties and Degradation Mechanisms (IMTEK)
- Methods of Material Analysis (IMTEK)
- Methods of Material Characterization for Waste Management (p. 83, INATECH//Freiburger Materialforschungszentrum)
- Nanomaterials – Lecture (IMTEK)

- Physics of Failure (p.93)
- Surface Analysis (IMTEK)
- Surface Analysis Lab (IMTEK)
- Theory and Modeling of Materials (Department of Physics)

Resilience Engineering

- Bionic Sensors (IMTEK)
- Continuum mechanics I with exercises (p.43)
- Continuum mechanics II with exercises (p.45)
- Dynamics of Materials: Material Characterization (p.50)
- Functional Safety: Active Resilience (p.65)
- Hardware Security and Trust (IIF)
- Laser scanning for mapping large structures (p.73)
- Mechanical Properties and Degradation Mechanisms (IMTEK)
- Optical Metrology for Sustainable Production (p.90)
- Physics of Failure (p.93)
- Quantification of Resilience (p.103)
- Reliability Engineering (IMTEK)
- Structural Robustness: Resilient Designs (p.115)

Information Processing Technologies

- Artificial Intelligence Planning (IIF)
- Cyber-Physical Systems – Discrete Models (IIF
- Cyber-Physical Systems – Program Verification (IIF)
- Distributed Systems (IIF)
- Foundations of Artificial Intelligence (IIF)
- Functional Safety: Active Resilience (p.65)
- High-Performance Computing with Python (IMTEK)
- Image Processing and Computer Graphics (IIF)
- Introduction to Embedded Systems (IMTEK)
- Introduction to Mobile Robotics (IIF)
- Machine learning (IIF)
- Microcontroller Techniques - Laboratory (IMTEK)
- Micro-electronics (IMTEK)
- Modelling and System Identification (IMTEK)
- MST Design Lab (IMTEK)
- Numerical Optimal Control in Science and Engineering (IMTEK)
- Python for Energy System and Sustainability Analysis (p.101)
- Real-Time Operating Systems and Worst-Case Execution Times (IIF)
- Sensors and actuators circuit technology (IMTEK)
- Signal Processing (IMTEK)
- Verification of Digital Circuits (IMTEK)
- Wind energy systems (IMTEK)

Interdisciplinary Profile

The following list shows the various courses that have been credited for the Interdisciplinary Profile in the past. The list is sorted by name of the institution within the University offering the course. If the module name is in German, the course is held in German language. If the courses are not offered by the Faculty of Engineering, you will have to take care of further information about the course yourself. Normally, you will find information about the course and its contact person in HISinOne or on the respective websites of the institutions offering the courses. **The different faculties and departments may have different registration requirements and procedures.** Often, if you want to attend a course outside of your own degree program, you cannot register directly. In this case, you may have to contact the respective professor. Please make sure that you will inform yourself **in good time** and, if necessary, get in touch with the professors responsible. In particular, seminars have only a limited number of participants and therefore have special registration requirements.
For courses offered by University College Freiburg (UCF), SSE students will register online through HISinOne (modules are called energy Liberal Arts and Sciences Wahlmodul" – I , II, and III. Below each of these modules, you will find a range of offered courses). Take into account that there are just limited spots available in UCF courses. UCF reserves the right to allocate seats.
Please note that just because the course is listed below does not automatically mean that you may get a seat. Furthermore, some courses that are listed here are not offered regularly and therefore cannot be re-booked. Nevertheless, the list gives an insight into which institutions may offer interesting courses for your Interdisciplinary Profile.

You are welcome to select further courses from the extensive range offered by the University of Freiburg. **However, before students register for new courses (new = not listed below), the course has to be checked regarding its suitability for the M.Sc. SSE program. This is done by the dean of academic affairs. Students therefore must send an e-mail with all necessary information about their course of choice to the program coordinator (study@inatech.uni-freiburg.de) at the latest prior to the semester start (by April 1 / October 1)! Deadlines are strictly enforced! Please note, all incoming inquiries are collected throughout the semester, which will then be checked once per semester only (prior to the lecture start) for suitability.**
Registering first and/or participating in the course already and asking for "recognition" of the course later (basically after having "created facts") is considered inappropriate and will lead to non-recognition of the course. The necessary information includes at least: number, name and content outline of the course, ECTS credits, course-based assessment (PL), coursework (SL), internet link to further information if available, name of offering institution and/or contact person.

The following list shows the various courses that have been credited for the Interdisciplinary Profile in the past.

Faculty of Engineering

- Advanced Database and Information Systems (IIF)
- Climate change: impact, key technologies, and policymaking (p. 36)
- Complex Networks (p.37)

- Computational Modeling with Matlab (p.41)
- Essentials of Programming Languages (IIF)
- Finance, climate change, and the global energy transition (p. 68, in corporation with the Faculty of Economics and Behavioural Sciences)
- Functional Programming (IIF)
- Gender Studies in MINT (IIF)
- Innovation and Evolution of Socio-Technical Systems (p.71)
- Neuroscience for Engineers (IMTEK)
- Operations Research for Energy Systems (p.87)
- Project management for engineers (IMTEK)
- Scientific writing and presentation (IMTEK)
- The science of complex systems - fundamentals and applications (p.117)

Faculty of Biology

- Ökologische Perspektiven einer nachhaltigen Entwicklung

Faculty of Economics and Behavioral Sciences

- Advanced Microeconomics I
- Basic Income and Social Justice
- Behavioral Economics
- Biomechanik menschlicher Bewegung
- Entrepreneurship und Social Entrepreneurship
- Futures and Options
- Intermediate Econometrics
- Management of Information Systems
- Organizational Behavior and Leadership
- Probability Theory for Economics and Finance
- Statistik
- Verhaltenswissenschaftliche Grundlagen des Public und Non-Profit Management

Faculty of Environment and Natural Resources

- Bioenergy
- Ecosystem management
- Environmental Statistics
- Hydropower
- Klima und Wasser
- Klimawandelanpassung in Ländern des globalen Südens
- Modelling Environmental Systems
- Resilience thinking: examining theory and application in geography and urban planning
- Thesis Project in Industrial Ecology (only in combination with a master’s thesis at the Chair of Industrial Ecology / Prof. S. Pauliuk)
- Umweltwahrnehmung und Umweltbildung

Faculty of Mathematics and Physics

- Laser-based Spectroscopy and Analytical Method

University College Freiburg

- Advanced Statistics

- Basic Chemistry and Biochemistry
- Behavioral Economics and the Individual Process of Decision Making
- Climate Change & Biodiversity
- Computational Modeling
- Ecology
- Energy
- Energy Policy
- Energy Technology
- Energy Transitions and Policy
- Environment, Risks, and Us
- Environmental Chemistry
- Environmental Controversies
- Environmental Humanities
- Environmental Impacts: Measurement & Political Use
- Environmental Psychology
- Geographic Information Systems (GIS) Seminar
- Geohazards
- Human Physiology
- Introduction to Earth and Environmental Sciences
- Journalism: Natural Science, Social Science, and the Humanities
- Knowledge for Change? Low-Carbon Transitions and Environmental Justice
- Natural Resource Policy and Environmental Governance Studies
- Pedosphere to Lithosphere – Resources Beneath Our Feet
- Quantitative Genomics: Genetics, Epigenetics and Bio-informatic analysis
- Resources and Sustainability
- Robot Design – Theory, Practice, Philosophy
- Sustainable Food Systems Transitions
- The Earth in the Universe
- The Ecological History and Nature of Human Nutrition
- Urban Environmental Planning in Response to Climate Change

The 8 UCF courses marked in green are open for M.Sc. SSE students in the summer term 2021, i.e. SSE students will definitely be able to get a seat in those courses. UCF uses a lottery strategy for the seat distribution. Once the course registration period is finished, students will see within a day if they got accepted.

Zentrum für Schlüsselqualifikationen / Center for Key Qualifications

- (Meine) Perspektiven nach dem Studium – Berufsfelder, Einstiegswege und Bewerbungstipps
- Basiskompetenzen Kommunikation und Gesprächsführung
- Der Businessplan: methodische Grundlagen für die unternehmerische Selbstständigkeit und zur Realisierung eigener Ideen
- Desktop Publishing – Grundlagen grafischer Gestaltung am Computer
- Entrepreneurship (lecture series)
- Grundlagen Rhetorik und Präsentation
- Intercultural Competence for international Students
- Journalistisches Schreiben
- Konflikttraining – Konflikte verstehen und lösen
- Lösungsorientierte Verhandlungs- und Gesprächsführung nach dem Harvard-Konzept
- Methoden zur Entscheidungsfindung
- Ökonomie und Verantwortung für Morgen – Nachhaltige Wirtschafts- und Lebensstile angesichts des Klimawandels

- Print- & Online-Publishing – Grafische Gestaltung an PC und mobilen Geräten
- Professions in Sustainability – Skills for Planning Sustainable Development as Exemplified by Tourism, Sport, and Nature Conservation
- SAP & Co. – eine Einführung in die Funktionsweise von Software zur Abbildung von Unternehmensprozessen
- Von der klassischen zur gegenwärtigen Rhetorik – überzeugend Reden und Vortragen

List of all mandatory modules (alphabetical order)

Modul / *Module*
Computational Materials Engineering (CME)

Nummer *Number*	11LE68MO-8050		
Modulverantwortlicher *Responsible person*	M. Moseler	**Einrichtung** *Organisational unit*	Physics/ Faculty of Engineering
Modultyp *Module Type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge in classical mechanics, analysis and vector calculus.		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte:** *ECTS credits*	5
SWS *Semester week hours*	2 lectures + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (64 hours full-time attendance course of study + 86 hours self-study)		

Lernziele / *Learning objectives*
Students will become familiar with the various methods of computational materials science: density functional theory, tight-binding, semi-empirical interatomic potentials, coarse grained models, continuum models. Students will be able to set up density functional and molecular dynamics simulations to understand and design sustainable materials.

Inhalte Vorlesung / *Content of the lecture*
An introduction into basic concepts of computational materials science will be given. The computational tools for different time and length scales will be introduced and it will be discussed how these tools can be combined in order to solve multiscale materials problems.The lecture will start with a brief introduction to density functional theory and tight binding. With both methods the short term dynamics of small units of materials can be studied. For the simulation of larger systems and longer time scales, classical interatomic potentials will be introduced allowing for the description of the different types of bonding in materials. The basic methodology of extended molecular dynamics simulations will be introduced. Finally, concepts for coarse grained methods to study the mesoscale and macroscale dynamics in solids and liquids will be discussed.

Inhalte Übung / *Content of the exercises*
The lecture is accompanied by a python-based hands-on programming course. For simple materials systems a working knowledge in molecular dynamics will be taught.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*
Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*
• Daan Frenkel, Berend J. Smit, Understanding Molecular Simulation, Elsevier, ISBN: 978-0-12-267351-1 • Michael Griebel, Stephan Knapek, Gerhard Zumbusch, Numerical Simulation in Molecular Dynamics, Springer, ISBN 978-3-540-68095-6 • Tamar Schlick, Molecular Modelling and Simulation, An interdisciplinary guide, Springer. ISBN 978-1-4419-6351-2 • C. Fiolhais, F. Nogueira, M. Marques, A Primer in Density Functional Theory. Springer. ISBN: 3540030832 • Lecture script M.Moseler "A brief introduction into Computational Materials Science"

Modul / *Module*
Control and Integration of Grids

Nummer *Number*	11LE68MO-8090		
Modulverantwortlicher *Responsible person*	Prof. Dr. Anke Weidlich	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 Term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen: *Recommended preconditions*	Fundamentals of Electrical Engineering or Engineering Physics		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte:** *ECTS credits*	5
SWS *Semester week hours*	3 Lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (42 hours full-time attendance course of study + 108 hours self-study)		

Lernziele / *Learning objectives*

The aim of this module is to get an understanding of the power and energy definition in energy systems and distribution grids. The module will cover the traditional electrical energy system structures as well as the renewable energy systems. Focus will be on the analysis of electrical grids, used for optimized integration of distributed energy resources.

Inhalte Vorlesung / *Content of the lecture*

- Energy system overview – generation, transmission, distribution, consumption
- Energy transport; power and energy definition
- Power generation analysis;
- Transition of the energy systems; renewable energy grid integration
- Power plants, storage, inverters
- Grid theory; DC, AC circuits; system theory
- System components: lines; transformers; generators;
- Grid calculation; reactive and active power flow
- Grid codes, grid regulation
- Operation and control of electricity grids; primary, secondary and tertiary control; voltage control
- Economic dispatch problem

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*
Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*
Power Generation Technologies; Paul Breeze ISBN 978-0-08-098330-1 Electric Power Generation Transmission and Disitribution; Leonard L. Grigsby; ISBN 978-1-4398-5628-4

Modul / *Module*
Energy Storage

Nummer *Number*	11LE68MO-8010		
Modulverantwortlicher *Responsible person*	M. Vetter, D. Schossig, T. Smolinka	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic understanding of Engineering Physics and Engineering Chemistry		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	3 lectures + 1 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (56 hours full-time attendance course of study + 94 hours self-study)		

Lernziele / *Learning objectives*

- Understanding the necessity of energy storage (short-term, mid-term, seasonal) for stationary applications (electric, thermal and chemical) as well as their technical and economic requirements
- Basic knowledge of different energy storage technologies such as pumped-hydro, SuperCaps, batteries, and thermal storage systems as well as hydrogen and Power-to-Gas (PtG) solutions
- Knowledge in design of battery systems with a focus on lihtium-ion technologies
- Knowledge in design of thermal storage systems
- Knowledge in design of hydrogen storage and PtG systems

Inhalte Vorlesung / *Content of the lecture*

1. Introduction and motivation energy storage (electric, thermal, PtG): Large-scale integration of renewable energies and the role of energy storage; technical requirements of power grids; overview of energy storage options and applications; key parameter of energy storage systems; technical requirements of storage systems; economic analyses for storage systems

2. Basics of energy storage systems: Mechanical (pumped hydro, CAES, fly wheels); Electric (SuperCaps); Electrochemical (Lead-acid, NiCd, NiMh, Lithium-ion; Sodium-ion; NaS / NaNiCl); thermal storage systems; chemical storage and PtG systems
3. Design of battery systems (focus Lithium-ion): Test and characterization of cells; Battery module and system design (components, construction, cooling); Safety issues; Battery management; Thermal management; System integration (system options, power and communication interface); Peripheral components (inverter, energy management)
4. Design of thermal storage systems
Description of technologies: sensible heat storage, latent heat storage, thermochemical storage. Technical applications: long term storage, short term storage, from cold storage to high temperature storage. Component and system layout, best case examples, limits and future expectations
5. Design of hydrogen storage and PtG systems: different system layouts and main components of hydrogen and PtG storage systems, water electrolysis as core component for PtG systems, advantages and drawbacks for repowering in fuel cells and thermal engines, best case examples of PtG installations, intersectoral extention to further Power-to-X technologies

Inhalte Übung / *Content of the exercises*

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*

Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*

T. Letcher: Storing Energy
G. Pistoia: Lithium-Ion Batteries Advances and Applications
A. Jossen: Moderne Akkumulatoren richtig einsetzen
J.-C. Hadorn: Thermal energy storage for solar and low energy systems
P. Moseley and J. Garche: Electrochemical Energy Storage for Renewable Sources and Grid Balancing

Modul / *Module*
Fundamentals of Resilience

Nummer *Number*	11LE68MO-8020		
Modulverantwortlicher *Responsible person*	S. Hiermaier	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Engineering Physics		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	4 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*

An engineering design that provides safety and security, comfort for the customer, efficient use of energy and resources, lowest possible emissions and economical advantages is called sustainable. Ongoing research towards sustainable solutions in engineering design show that the ability of systems to recover from catastrophic, disruptive events is another essential component in the list of attributes a sustainable solution needs to contain. Urban infrastructure, future mobility and energy technologies are key elements of a living society. Disruptive processes as for example natural disasters, terroristic assassinations, technical failure or human error cause a dramatic drop in the performance of the system. Resilience of the system can be measured using the time integral of lost performance. The better a system has been designed to over such a disaster the shorter is the time to recover and the higher is its resilience.

Inhalte Vorlesung / *Content of the lecture*

The lecture provides a clear understanding of the term “resilience” in an engineering context, specifically as compared to stability, robustness, flexibility or failure safety. Students realize that failure of transport systems, infrastructure, support chains and of other technical systems is not necessarily a consequence of technical malfunction or bad design. Students find that in contrast the ability to control failure of systems and catastrophes can be achieved by networks of perspective interaction, prevention and adaption. Continuous adaption of behavior of

individuals and of the control of facilities will be understood as necessary steps towards increasing resilience.

- key concepts and ideas in resilience engineering
- collection of typical systems addressed concerning their resilience
- introduction to tools for quantitative risk analyses

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*
Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*

- Thoma, Klaus/Scharte, Benjamin/Hiller, Daniel/Leismann, Tobias (2016): Resilience Engineering as Part of Security Research: Definitions, Concepts and Science Approaches. In: European Journal for Security Research, 1:1, 3-19.
- Häring, Ivo/Ebenhöch, Stefan/Stolz, Alexander (2016): Quantifying Resilience for Resilience Engineering of Socio Technical Systems. In: European Journal for Security Research, 1:1, 21-58.
- Häring, Ivo (2016): Risk Analysis and Management: Engineering Resilience. Singapore: Springer.
- Linkov Igor/Kröger, Wolfgang/Renn, Ortwin/Scharte, Benjamin et al. (2014): Risking Resilience: Changing the Resilience Paradigm, Commentary to Nature Climate Change, 4: 6, 407-409.

Modul / *Module*
Material Life Cycles (MLC)

Nummer *Number*	11LE68MO-8030		
Modulverantwortlicher *Responsible person*	S. Hiermaier, S. Kilchert	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Fundamental knowledge of Materials Science and Technology		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*
The aim of the lecture is to be introduced to a framework within which a student can form critical, independent assessments of Sustainable Developments. With a focus on the role of materials it recognizes the complexity inherent in discussions of sustainability and shows how to deal with it in a systematic way.

Inhalte Vorlesung / *Content of the lecture*
For that purpose the students are provided with procedures and tools, which allow them to analyze the financial, natural, human and social factors contributing to sustainable development. Within that context, the lecture addresses questions such as “How do we achieve sustainable development? How do we measure progress in achieving it? What does it mean in engineering practice? How do materials fit in?” The students will find that there is no completely “right“ answer to questions of sustainable development- instead, there is a thoughtful, well-researched response that recognizes the conflicting priorities of the environmental, the economic, the legal and the social aspects of a technological change.

Inhalte Übung / *Content of the exercises*

Students will learn to assess sustainability aspects of materials & processes via hands-on sessions using specialized databases.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*
Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*
Michael F. Ashby, "Materials and Sustainable Development", Elsevier, 2016. Michael F. Ashby, "Materials and Environment", Elsevier, 2013.

Modul / *Module*
Solar Energy

Nummer *Number*	11LE68MO-8060		
Modulverantwortlicher *Responsible person*	S. Glunz, K. Kramer, P. Schossig, A. Heimsath	**Einrichtung** *Organisational unit*	Faculty of Engineering / INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic understanding of physics		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	4 lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (42 hours full-time attendance course of study + 108 hours hours self-study)		

Lernziele / *Learning objectives*

Students will be able to understand the fundamentals and different technology variants of solar energy conversion such as photovoltaics and solar thermal. They will know the relevant physical background, technical characteristics, materials and designs used. The lecture will cover the component, product and system level. Furthermore students will understand trends of further development as well as limitations and possibilities in application of solar energy.

Inhalte Vorlesung / *Content of the lecture*

- Solar Energy - Theoretical and Technical Energy Potential (black body radiation, Carnot cycle, maximum efficiencies, …)
- Solar Energy Technologies - Tapping the sun's energy (overview of conversion technologies, system boundaries, seasonal fluctuation, ...)
- Photovoltaics - Physics of Solar Cells (introduction to semiconductors, Fermi levels, IV curves, conversion efficiency, quantum efficiency …)
- Photovoltaics - Technology Review (short introduction to the structure and technology of crystalline silicon solar cells)
- Solar Thermal - Physics of Solar Collectors (basics of thermo dynamics, fluid dynamics, absorption, emission, power output and other performance criteria)

- Solar Thermal - Technology Review (from low temperature applications up to power plants - examples)
- Heat pumps - Thermodynamics, electrical and thermal driven heat pumps and chillers, main components (compressor, evaporator, condensor etc.), system configurations (layout, sources, storages, control strategies etc)
- Heat pumps: field tests and best case examples - Heat pumps and smart grid interaction, Heat pumps and PV, Heat pumps + solar thermal, storage integration)

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*

Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature FORMAT bei allen Modulen konsistent*

- Duffie-Beckman: Solar Engineering of Thermal Processes,
- V. Quaschning: Understanding Renewable Energy,
- Peuser FA, Remmers K, et.al.:Solar thermal systems
- P. Würfel, Physik der Solarzelle, Spektrum - Akademischer Verlag 2000
- Goetzberger, B. Voß und J. Knobloch, Sonnenenergie: Photovoltaik, Teubner 1997
- M.A. Green, Solar Cells, University of New South Wales 1982
- K. Mertens, Photovoltaik, Hanser 2011
- J. Nelson, The physics of solar cells, Imperial College Press 2008

Modul / *Module*
Master‘s Project

Nummer *Number*	11LE68MO-7160		
Modulverantwortlicher *Responsible person*	Prof. Dr. Oliver Ambacher	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory module	**Moduldauer** *Module duration*	1 term
Lehrveranstaltungstyp *Type of course*	Individual project with colloquium	**Sprache** *Teaching language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte:** *ECTS credits*	5
SWS *Semester week hours*	3	**Angebotsfrequenz** *Regular cycle*	Each term
Arbeitsaufwand *Workload*	150 hours self-study.		

Lernziele / *Learning objectives*
Having successfully completed this module, students will be able to: • define a proper research idea related to sustainable systems • plan and design its implementation according to given circumstances, • gather and process data and information scientifically, • conduct the research including experimental work (if applicable), and • present the results/outcomes (poster, presentation) as part of a scientific workshop

Inhalte Kolloquium / *Content of the colloquium*
Research topics will be made available by internal or external supervisors (e.g. from the University or Fraunhofer institutes). Alternatively, students can come up with their own research topics and a suggestion for a possible supervisor. The topic must have technical proximity to the SSE program, be of scientific nature, and be suitable for the necessary work load of 150 hours which needs to be confirmed by the responsible person of this module. A regular colloquium will be offered in winter term (recommended term of study = 3). A professional two-day workshop will be organized at the end of the winter semester

during which all SSE students will present their results. All supervisors, SSE students, and professors will be invited to this event. It is highly recommended that all SSE students conduct their master project in winter term. However, they are allowed to also conduct it in summer term. Students, who conduct their master project during the summer term, will present their results during the examinations phase.

Zu erbringende Studienleistung / *Coursework*

Poster and oral presentation as part of the “Master-Project-Workshop”. Templates for the poster will be made available on ILIAS or by email. The poster must be submitted via e-mail by the student to the responsible person of this module by a given deadline (will be announced by the beginning of the semester). The presentation will be held either at the above mentioned workshop (winter term) or at a given examinations date to be defined (summer term).
In both, winter and summer term, students must not forget to register for the master project exam (Studienleistung)!

Benotung / *Grading*

The grading of the master project will be related to the poster (weight 50%) and oral presentation (weight 50%) and will be defined by a group of advisors present in the workshop (winter term) or during the examination (summer term).

Literatur / *Literature*

Will be provided by the advisor of the master project and will be project specific.

Modul / *Module*
Master‘s Thesis

Nummer *Number*	11LE68MO-8700-672		
Modulverantwortlicher *Responsible person*	Examiners of the Department of Sustainable Systems Engineering	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory module	**Moduldauer** *Module duration*	1 term
Lehrveranstaltungstyp *Type of course*	Written thesis	**Sprache** *Teaching language*	German or English
Zwingende Voraussetzungen *Mandatory requirements*	Admission for the thesis can be granted once at least 70 ECTS-credits have been acquired within the course program.		

Empfohlenes Fachsemester *Recommended term of study*	4	**ECTS-Punkte** *ECTS credits*	30
SWS *Semester week hours*		**Angebotsfrequenz:** *Regular cycle*	Each term
Arbeitsaufwand *Workload*	900 hours (900 hours self-study)		

Lernziele / *Learning objectives*
The student shows with his/her Master thesis the ability to solve a given problem from sustainable systems engineering in a given time frame using scientific methodology. Skills and competencies obtained in the course program have been verifiably applied in accordance to the state of the art. The student has proven his/her ability to apply methods and knowledge as well as research and development competencies in the project, the scientific documentation and the oral presentation.

Inhalte / *Content*
The Master’s thesis is an independent research project. Is consists of a written documentation and a final presentation with discussion. The student works on a given topic for a given timeframe and has to deliver a scientific documentation.

Zu erbringende Prüfungsleistung / *Course-based assessment*
The Module consists of a written documentation of the thesis and an oral presentation of the results of the thesis. The final module grade is calculated from the grade of the written thesis.

Benotung / *Grading*
The final module grade is calculated from the grade of the written thesis.

List of elective modules offered by INATECH (alphabetical order)

Modul / *Module*
Adhesive Bonding

Nummer *Number*	11LE68MO-4208		
Modulverantwortlicher *Responsible person*	Dr. Michael May	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	None		
Zwingende Voraussetzungen: *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

The educational objective of this course is to develop an understanding of adhesive bonding. The students will learn about the chemistry and manufacturing of adhesive joints, potential applications and the environmental impact of the use of adhesive bonding technology in relevant applications.
Additionally, the students will understand the failure behavior of adhesively bonded joints and will be able to identify appropriate experimental characterization methods.
Furthermore, the the students will be able to describe adhesively bonded joints using appropriate modeling strategies.

Das primäre Lernziel dieser Veranstaltung ist, ein grundlegendes Verständnis für Klebverbindungen zu schaffen. Es werden Kenntnisse über die Chemie von Klebstoffen, die Herstellung von Klebverbindungen und, potentielle Anwendungen vorgestellt. Zudem wird der Einfluss auf die Umwelt diskutiert.
Zusätzlich werden die Kursteilnehmer das Versagen von Klebverbindungen verstehen und geeignete experimentelle Charakterisierungsmethoden auswählen können. Abschließend werden Modellierungsstrategien für die Beschreibung von Klebverbindungen vorgestellt.

Inhalte Vorlesung / *Content of the lecture*

In the field of mobility and transport, the use of novel materials and the especially clever combination of materials is the key for weight reduction, and consequently for increased energy efficiency. Adhesive bonding has shown to be a key technology to achieve these goals.

This course covers the basics of adhesive bonding technology. Building on this, the course will impart knowledge on experimental characterization of joints as well as modeling approaches.

Topics:
• Applications of adhesive bonding
• Chemistry of adhesives
• Manufacturing of adhesive joints
• Environmental impact of adhesives
• Failure mechanisms in adhesive oints
• Characterization of adhesives joints
• Simplified and detailed modeling approaches

Im Bereich der Mobilität und des Transportwesens ist der geschickte Einsatz verschiedener Materialkombinationen ein Schlüsselfaktor für die Reduktion des Fahrzeuggewichts und folglich der Energieeffizienz. Die Klebtechnik hat sich dabei als Schlüsseltechnologie zur Erreichung dieser Ziele herausgestellt.
Diese Vorlesung beschreibt die Grundlagen der Klebtechnik. Darauf aufbauend wird in der Vorlesung Wissen über die experimentelle Charakterisierung von Klebverbindungen sowie über geeignete Modellierungsansätze vermittelt.

Themen:
• *Anwendungen von Klebverbindungen*
• *Chemie von Klebstoffen*
• *Fertigung von Klebverbindungen*
• *Auswirkungen auf die Umwelt*
• *Versagensmechanismen in Klebverbindungen*
• *Mechanische Charakterisierung von Klebverbindungen*
• *Vereinfachte und detaillierte Simulationsansätze*

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Zu erbringende Studienleistung / *Coursework*
If any, they will be announced during the first lecture.

Literatur / *Literature*
Information will be given during the lectures.

Modul / *Module*
Characterization of solar cells: From feedstock quality to final cell efficiency

Nummer *Number*	11LE68MO-4104-ab042019 (!)		
Modulverantwortlicher *Responsible person*	Dr. Martin Schubert, Dr. Tim Niewelt	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and seminar	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Module “Solar Energy”		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

It is the aim of this module to get solid insight into characterization techniques for solar materials and solar cells with a strong focus on silicon technology. The module addresses both industrially used and lab-scale characterization methods in order to provide a solid background in loss analysis possibilities for solar cells.
This course is ideal to learn about typical real-life limitations of silicon material quality and silicon based solar cells and a very useful basis for anybody interested in the application, fabrication and improvement of solar cells.
The presentation of complex topics / scientific studies to a qualified audience will be discussed and practiced in the seminar of this module.

Inhalte Vorlesung / *Content of the lecture*

State-of-the-art measurement techniques for

- silicon material analysis: feedstock, blocks, wafers, cells
- cell characterization: local and global loss analyses
- identification of efficiency losses
- quantification of efficiency limitations
- lab-scale in-depth analyses
- industrial application
- approaches for non-silicon cells

Inhalte Seminar / *Content of the seminar*
The seminar is intended to allow for a deepened understanding of the application of characterization methods in photovoltaic research. Each student chooses an aspect / a method from the lecture contents and prepares a presentation on a recent scientific application for the fellow students. The seminar includes an introduction to means and methods for the preparation and realisation of such presentations. Furthermore, the seminar includes hands-on training in the simulation of solar cell structures and its application to optimization and problem solving in solar cell production.

Zu erbringende Studienleistung / *Coursework*
Oral presentation; attendance during the seminar (85%)

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised exam or oral exam.

Literatur / *Literature*
• Schroder, Dieter K. Semiconductor material and device characterization. John Wiley & Sons, 2006. • Würfel, Peter, and Uli Würfel. Physics of solar cells: from basic principles to advanced concepts. John Wiley & Sons, 2009.

Modul / *Module*
Climate change: impact, key technologies, and policymaking

Nummer *Number*	11LE68MO-5566		
Modulverantwortlicher *Responsible person*	Prof. Dr. Stefan Hiermaier Dr. Matthias Breitwieser Dr. Severin Vierrath	**Einrichtung** *Organisational unit*	INATECH & IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture series	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hrs		

Lernziele / *Learning objectives*

The accelerating consequences of climate change are one of the worlds' most important disruptions in the 21th century. However, tackling this challenge is very complex and requires multiple scientific and political disciplines. The lecture provides a broad and interdisciplinary overview on the topic "climate change" ranging from physical backgrounds, technological solutions to important political and financial aspects.

Students will learn the ecological and physical background of climate change and its implications on biosphere. In addition, they acquire knowledge about the possible technical solutions for CO2-free energy production, emission-free mobility, energy efficiency and sector coupling. Finally they will be able to critically analyze present and future economical and political aspects such as circular economy, international climate policy, energy policy and the impact of financial flows on decarbonisation. As conclusion, sociological and psychological implications are included into the discussion.

Inhalte Vorlesung / *Content of the lecture*

1. Basics I: The physical basis of climate change
2. Basics II: International climate politics: From Kyoto to Paris
3. Technology I: Energy Conversion – Solar Energy

4. Technology II: Energy Conversion – Nuclear Energy
5. Technology III: Energy Efficient Buildings
6. Technology IV: Energy Storage: Hydrogen as key to a sustainable economy
7. Technology V: Emission-free mobility
8. Policymaking I: Circular Economy & Industrial Ecology
9. Policymaking II: Energy Policy I
10. Policymaking III: Energy Policy II
11. Policymaking IV: Energy Scenarios
12. Policymaking V: The role of the financial sector for decarbonization

The lecturers are an interdisciplinary and experienced team from university of Freiburg, Fraunhofer institute for solar energy systems (ISE), the institute for applied ecology Freiburg and experienced scientists from external partners.

Zu erbringende Prüfungsleistung / *Course-based assessment*
None (because interdisciplinary profile)

Zu erbringende Studienleistung / *Coursework*
Written supervised exam

Literatur / *Literature FORMAT bei allen Modulen konsistent*

Modul / *Module*
Complex Networks

Nummer *Number*	11LE68MO-5559		
Modulverantwortlicher *Responsible person*	Dr. Mirko Schäfer	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture with integrated exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge of matrix and probability theory. Basic knowledge of Python recommended.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 h lectures and integrated exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 (in class + preparation of classes)		

Lernziele / *Learning objectives*

After the completion of the course the student is expected to be able to

- describe how complex systems can be represented as networks
- calculate various measures for a given network
- compare the structure of different real world networks
- describe and explain network models covered in the course
- implement and analyse network models in the programming language Python, import data, plot results, visualise networks
- communicate and discuss the methods and results presented in current research papers from the field of complex networks

Inhalte Vorlesung / *Content of the lecture*

- the language of graph theory
- random graphs, small world and scale-free networks

- centrality measures
- economic and financial networks
- network components and the configuration model
- transport, contagion and diffusion processes on networks
- network synchronization
- network aspects of the electricity system
- large-scale renewable energy networks
- multiscale infrastructure networks

Zu erbringende Prüfungsleistung / *Course-based assessment*
None (because interdisciplinary profile)

Zu erbringende Studienleistung / *Coursework*
Written supervised exam

Literatur / *Literature*
• A.L. Barabási, *Network Science*, available at networksciencebook.com • Further literature will be announced in class

Modul / *Module*
Composite Materials

Nummer *Number*	11LE68MO-4209		
Modulverantwortlicher *Responsible person*	Dr. Michael May	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Participation in the module "Physics of failure" Participation in the module "Dynamics of materials"		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

The educational objective of this course is to develop an understanding of the properties of composite materials. Aside high-performance materials, special emphasis is given to bio-based composite materials and their potential applications. The students will learn to predict the characteristic properties of composite materials. Additionally, the students will understand and describe damage and failure behavior of composites.

Das primäre Lernziel dieser Veranstaltung ist ein grundlegendes Verständnis für Faserverbundwerkstoffe zu schaffen. Besonderes Augenmerk liegt dabei - neben Hochleistungswerkstoffen - auf biobasierten Verbundwerkstoffen und deren Anwendungsmöglichkeiten. Die Kursteilnehmer werden lernen, die charakteristischen Eigenschaften von Verbundwerkstoffen zu prognostizieren. Zusätzlich wird Wissen über das Schädigungs- und Versagensverhalten von Verbundwerkstoffen vermittelt.

Inhalte Vorlesung / *Content of the lecture*

Composite materials offer high potential for the development of sustainable engineering structures. On the one hand, due to their unique material properties, composite materials are of particular interest for high-performance lightweight structures (e.g. modern aircraft) or structures requiring a certain amount of durability, such as wind turbines or marine turbines. On the other hand, the use of renewable natural resources (natural fibers, bio-polymers) in composite materials could be a path towards more sustainable consumption of limited resources such as oil.

In the first part of this course, the students will gain knowledge about typical anisotropic properties of high-performance composite materials. The students will learn approaches to estimate the mechanical properties of composite materials based on the constituents as well as approaches to determine the properties of a composite layup based on the properties of a single ply. Composite specific damage and failure mechanisms are discussed; experimental characterization and modeling approaches are described.
The second part of this course specifically covers composite materials made from renewable natural resources. Here, the students will learn about the potential and limitations of bio-based composites. The participants will learn about different types of natural constituents and their properties as well as the special behavior of their composites.

Faserverstärkte Kunststoffe (FVK) eignen sich hervorragend für die Entwicklung nachhaltiger Ingenieurstrukturen. Einerseits sind FVKs auf Grund ihrer einzigartigen Materialeigenschaften von besonderem Interesse für Hochleistungsleichtbaustrukturen (wie z.B. moderne Flugzeuge) oder Strukturen, welche eine lange Lebensdauer aufweisen, wie z.B. Windturbinen oder Gezeitenkraftwerke. Andererseits können durch den Einsatz erneuerbarer natürlicher Rohstoffe (Naturfasern, Biopolymere) Verbundwerkstoffe geschaffen werden, welche begrenzte natürliche Ressourcen wie z.B. Erdöl, schonen.
Im ersten Teil dieser Vorlesung werden die typischen anisotropen Eigenschaften von Hochleistungsverbundwerkstoffen vermittelt. Lehrinhalte sind insbesondere Ansätze zu Abschätzung der mechanischen Eigenschaften von Verbundwerkstoffen basierend auf den Eigenschaften der Konstituenten sowie Berechnungsansätze zur Bestimmung der Eigenschaften eines Laminats basierend auf den Eigenschaften der Einzellagen. Verbundwerkstoffspezifische Schädigungs- und Versagensmechanismen werden diskutiert; Experimentelle Charakterisierungsmöglichkeiten sowie Modellierungsansätze werden vorgestellt.
Der zweite Teil der Vorlesung beschäftigt sich explizit mit Verbundwerkstoffen auf Basis nachwachsender Rohstoffe. Das Potential dieser Werkstoffe wird ebenso dargestellt wie mögliche Hinderer. Die Teilnehmer werden verschiedene Arten natürlicher Ausgangsrohstoffe besprechen sowie Fertigungsmethoden und thermo-mechanische Eigenschaften dieser speziellen Materialklasse kennenlernen.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Zu erbringende Studienleistung / *Coursework*

If any, they will be announced during the first lecture.

Literatur / *Literature*

Isaac M. Daniel, Ori Ishai: Engineering Mechanics of Composite Materials, second edition, Oxford University press, ISBN-13: 978-0195150971

Wirasak Smitthipong, Rungsima Chollakup, Michel Nardin (Eds.): Bio-based composites for high-performance materials - from strategy to industrial application, CRC press, ISBN: 978-1-4822-1448-2

Modul / *Module*
Computational Modeling with Matlab

Nummer *Number*	11LE68MO-5557		
Modulverantwortlicher *Responsible person*	Dr. Reto Schölly	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Practical exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	No technichal requirements. Students who are attending or have attended Python for Energy System and Sustainability Analysis course can NOT take the Matlab course and vice versa.		
Empfohlene Voraussetzungen *Recommended preconditions*	An open mind and a determination to learn computational modeling and programming are absolute requirements. Clinging to pre-learned ideologies is not recommended.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 practical exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180h		

Lernziele / *Learning objectives*
After successfully completing the course, students will have the ability to create, simulate and analyse computational models with Matlab.

Inhalte Vorlesung / *Content of the lecture*
This course introduces students to the basics of computational modeling with MATLAB. This software is a programming langu-age designed specifically for the creation, simulation and ana-lysis of mathematical models, including algebraic functions and differential equations. MATLAB can be described as the standard environment for engineering computing, and is capable of supporting all mathematical systems that can be computed numerically. There is a vast number of modules from various engineering fields available, including computer vision, finite element methods and others. Since other SSE courses focus on advanced models and simu-lations, course will only address the fundamentals of mathe-matical modeling with MATLAB. Its primary task is to teach students how to think as a programmer, how to turn a model into a functioning computer programme, and to solve basic problems from various fields. It is not designed to

address SSE-specific tasks, however, diligent students will be able to apply the knowledge gained to their academic interests.

Topics are:

- MATLAB fundamentals,
- Simulink fundamentals,
- digital image processing,
- economic models,
- differential equations with Simulink,
- artificial life models,
- population models,
- predator-prey systems.

During the course, students will get the opportunity to pick their own topic for the Final Project. Additionally, students will be given a list of project suggestions, out of which they can choose a topic, if they cannot find one on their own. It is highly recommended that the students choose a topic that interests them, be it on an academic or a personal level. Students are required to present the finished Final Project during the last few sessions (the dates for these will be announced at the beginning of the course). A presentation should take around 20 minutes, and working in groups of up to three is allowed.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Keine / None.
Nur Studienleistung / Only Course Work

Zu erbringende Studienleistung / *Coursework*

A total of 50 % score or more has to be achieved in order to pass the Studienleistung.
The Studienleistung consists of:

1. solving the tasks in the exercise sheets and uploading the results in time,
2. completing a Final Project and presenting it.
3. Attendance is obligatory.

Students must complete all exercise sheets and upload them to ILIAS as ZIP-compatible archives.
The course is an interactive guided exercise and, thus, students need to be present during at least 80 % of this time, in compliance to academic rules.
A Final Project must be completed and presented during a ~20 minutes presentation. Working in groups up to three is permitted.

Literatur / *Literature*

Students must have a laptop available throughout the course.

Modul / *Module*
Continuum mechanics I with exercises

Nummer *Number*	11LE68MO-4302		
Modulverantwortlicher *Responsible person*	Dr. Dirk Helm	**Einrichtung:** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Advanced mathematics; engineering mechanics		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 Lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (64 hours Full-time attendance course of study + 116 hours Self-study)		

Lernziele / *Learning objectives*

The objective of the module is to master the mathematical foundations of continuum mechanics in form of tensor algebra and tensor analysis as well as the knowledge of the basic structure of continuum mechanics.
The content of the topics of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Inhalte Vorlesung / *Content of the lecture*

- Mathematical foundations of continuum mechanics (specialized to orthonormal base systems) consisting of tensor algebra and tensor analysis
- Introduction to the basic strucutre of continuum mechanics (kinematics, balance equations, constitutive relations).

The focus lies on the treatment of small deformations and simplified examples with reference to engineering mechanics.

Inhalte Übung / *Content of the exercises*

The content of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*
• M. Itskov, Tensor Algebra and Tensor Analysis for Engineers, Springer, 2013

Modul / *Module*
Continuum mechanics II with exercises

Nummer *Number*	11LE68MO-4304		
Modulverantwortlicher *Responsible person*	Dr. Dirk Helm	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Continuum mechanics I with exercises		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 h lecture + 2 h exercise	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 h (60 h attendance + 120 h self-study)		

Lernziele / *Learning objectives*

The objective of the course is the knowledge of nonlinear continuum mechanics and its applications in solid state and fluid mechanics. The content of the topics of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Inhalte Vorlesung / *Content of the lecture*

- Kinematics for finite deformations: representation of motion, strain tensors etc. at large deformations, geometric linearization
- Balance relations of mechanics and thermomechanics
- Principles of mechanics: principle of D'Alembert, principle of virtual displacements
- Constitutive relations for fluids and solids (e.g. lienar-elastic fluid, finite elasticity, viscoelasticity, plasticity, viscoplasticity, heat conduction, ...)
- Extension of the mathematical foundations of tensor algebra and tensor analysis to general base systems and curved coordinates

Inhalte Übung / *Content of the exercises*

The content of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*
• P. Haupt, Continuum Mechanics and Theory of Materials, Springer Verlag, 2002

Modul / *Module*
Design and Monitoring of large Infrastructures

Nummer *Number*	11LE68MO-9020b		
Modulverantwortlicher *Responsible person*	Prof. Dr. A. Reiterer, Dr. A. Stolz	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Compulsory Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lectures + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*
The growing world population, the ongoing urbanization, tin combination with an ever increasing need for sustainable transport and energy systems poses a large challenge to the existing and future supply and transport systems. Besides the increasing complexity of the systems and growing interdependicies between systems also the amount of considerable threats in terms of natural hazards or manmade deliberated attacks rises. In general the network perfomance and reliabilty relies for a large portion on the robustness of the networks built infrastructure elements like windmills transformator stationand also bridges. Therefore, smart designs and monitoring of large infrastructures are required. Within this context the lecture provides insight in the basic requirements for a safe, secure and resilient design of construction and monitoring of those large infrastructures. In detail students will learn about - A set of fundamentals and tools to enable structural engineers to assess risks assess tfor the given infratsructure - Concepts to integrate safety portions into the design, Methods and tools for the actual structural dimensions of the structures. - An overview about measurement techniques for monitoring such structures - A deep view on the corresponding sensor and measurement concepts (focusing on optical systems)

- Using real time data streams for monitoring the resilience of infrastructure

Die wachsende Weltbevölkerung, die fortschreitende Urbanisierung, die Kombination mit einem immer größer werdenden Bedarf an nachhaltigen Verkehrs- und Energiesystemen stellt eine große Herausforderung für die bestehenden und zukünftigen Versorgungs- und Transportsysteme dar.
Zusätzlich zur zunehmenden Komplexität der Systeme und der wachsenden Interdependenz zwischen den Systemen, wächst zudem auch noch die Anzahl der maßgeblichen Bedrohungen in Form von Naturgefahren oder vom Menschen geplanten Angriffen.
Im Allgemeinen verlässt sich die Netzwerk-Performance und -Zuverlässigkeit zu einem großen Teil auf die Robustheit der gebauten Infrastrukturen wie Windrädern und auch Brücken.
Hierfür sind intelligente Designs und die Überwachung großer Infrastrukturen erforderlich. In diesem Zusammenhang gibt die Vorlesung einen Einblick in die grundlegenden Anforderungen an eine sichere und belastbare Gestaltung und Überwachung dieser großen Infrastrukturen.
Im Detail lernen die Studenten Folgendes kennen
- Eine Reihe von Grundlagen und Werkzeugen, die es Statikern ermöglichen, Risiken für die jeweilige Infrastruktur zu bewerten.
- Konzepte zur Integration von Sicherheitsteilen in das Design
- Methoden und Werkzeuge für die tatsächlichen Strukturdimensionen der Strukturen.
- Ein Überblick über Messtechniken zur Überwachung solcher Strukturen
- Ein tiefer Einblick in die entsprechenden Sensor- und Messkonzepte (Schwerpunkt optische Systeme)
- Nutzung von Echtzeit-Datenströmen zur Überwachung der Ausfallsicherheit der Infrastruktur

Inhalte Vorlesung / *Content of the lecture*

- Key concepts and ideas to design and monitor a large infrastructure
- Design concepts for sensor application and structural health monitoring
- Data analysis methods for interoperating and visualizing measurements
- Software aided assessment of infrastructures

- *Schlüsselkonzepte für das Design und die Überwachung großer Infrastrukturen*
- *Design Konzept für Sensorsysteme und Structural Health Monitoring*
- *Methoden der Datenanalyse für die Interpretation und Visualisierung*
- *Software-basierte Beurteilung der Infrastruktur*

Inhalte Übung / *Content of the exercises*

- Key concepts and ideas to design and monitor a large infrastructure
- Design concepts for sensor application and structural health monitoring
- Data analysis methods for interoperating and visualizing measurements
- Software aided assessment of infrastructures

- *Schlüsselkonzepte für das Design und die Überwachung großer Infrastrukturen*
- *Design Konzept für Sensorsysteme und Structural Health Monitoring*
- *Methoden der Datenanalyse für die Interpretation und Visualisierung*
- *Software-basierte Beurteilung der Infrastruktur*

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written examination and presentation

Literatur / *Literature*
• Literature will be provided at the beginning of the lecture

Modul / *Module*
Dynamics of Materials: Material Characterization

Nummer *Number*	11LE68MO-5118		
Modulverantwortlicher *Responsible person*	S. Hiermaier	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*

Lernziel des Moduls ist die Kenntnis experimenteller und numerischer Grundlagen zum mechanischen Verhalten von Werkstoffen bei dynamischer Belastung. Mit den erarbeiteten Methoden können die Studierenden Spannungs-Verzerrungs-Beziehungen in Abhängigkeit von der Belastungsgeschwindigkeit bestimmen und in numerischen Verfahren als Materialmodell implementieren. Übergeordnetes Lernziel der Lehrveranstaltung ist die Beherrschung der Grundfähigkeiten zur experimentellen Charakterisierung und numerischen Model lierung dynamischen Materialverhaltens.

Aim of the course is the knowledge of experimental and numerical basics on the mechanical behaviour of materials under dynamic loading conditions. It enables the students in deriving strain-rate dependent stress-strain relations and in implementing the resulting constitutive models into numerical codes. General aim is the basic ability for experimental characterization and numerical modelling of dynamic material behaviour.

Inhalte Vorlesung / *Content of the lecture*

Werkstoffcharakterisierung:

- Statische und dynamische Werkstoffprüfung
- Die Verzerrungsrate als Maß für die Materialdynamik
- Nutzung von Wellenausbreitung zur Materialprüfung
- Verzerrungsratenabhängige Elastizität, Plastizität und Versagen
- Mathematische Modellierung des Materialverhaltens

- Auftreten von Stoßwellen in Festkörpern
- Zustandsgleichung als Komponente des Spannungstensors
- Nichtlineare Zustandsgleichungen

Numerik dynamischer Deformationsprozesse:

- Räumliche und zeitliche Diskretisierung dynamischer Prozesse in Festkörpern
- Finite Differenzen Verfahren in Raum und Zeit
- Finite Element Verfahren
- Implizite und explizite Zeitintegration
- Netzfreie Diskretisierungsverfahren

Materials Characterisation:

- *Static and dynamic testing of materials*
- *Strain rate as a measure for dynamic material behaviour*
- *Use of elastic waves for materials testing*
- *Strain-rate dependent elasticity, plasticity, and failure*
- *Mathematical modelling of material failure*
- *Shock waves in solids*
- *Equations of state and the total stress tensor*
- *Nonlinear Equations of state*

Numerical modelling of dynamic deformation

- *Spatial and Time Discretization of dynamic deformation of solids*
- *Finite differences for space and time*
- *Basics of the Finite Element method*
- *Implicit and explicit time integration*
- *Basics of meshfree discretization methods*

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral exam

Literatur / *Literature*
• S. Hiermaier, "Structures under Crash and Impact", Springer, 2008

Modul / *Module*
Electromobility

Nummer *Number*	11LE68MO-4111		
Modulverantwortlicher *Responsible person*	Dr. Matthias Vetter	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	English
Voraussetzungen zwingend *Preconditions mandatory*	Lecture and exam in energy storage		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

- Know-how in various aspects and concepts of electro-mobility for automotive applications (light electric vehicles LEV, electric vehicles EV, plug-in hybrid electric vehicles PHEV), public transport, light and heavy load transport, marine sector as well as aerospace sector.
- Know-how in electrical storage technologies for mobile applications.
- Know-how in system design for mobile applications including peripheral components.
- Know-how in infrastructure concepts and challenges (e.g. fast charging stations).

Inhalte Vorlesung / *Content of the lecture*

- Electromobility in various sectors: Automotive, public transport, marine sector, aerospace, etc.
  - System concepts
  - Typical system designs
  - Infrastructure challenges and solutions
- Overview on relevant electric storage technologies for electromobility
- Storage system design for various mobile applications: module design, electrical, thermal and mechanical interconnections, thermal management, storage management, integration of peripheral components
  - Safety aspects and criteria
  - Environmental issues

Zu erbringende Prüfungsleistung / *Course-based assessment*

Oral exam

Literatur / *Literature*
• STATUS ELECTROMOBILITY 2016: OR HOW TESLA WILL NOT WIN, Prof. Dr.-Ing. Markus Lienkamp. • G. Pistoia: Lithium-Ion Batteries Advances and Applications.

Modul / *Module*
Emerging and Future Photovoltaic Technology Options

Nummer *Number*	11LE68MO-4105-ab042018		
Modulverantwortlicher *Responsible person*	Dr. Jan C. Goldschmidt	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Solar Energy		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 lecture + 2 exercise	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (39 hours full-time attendance course of study + 141 hours self-study)		

Lernziele / *Learning objectives*

The overarching goal of this module is to enable the students to participate in research & development of advanced photovoltaic technologies, as well as to critically assess the potential benefit of new PV technologies for a sustainable energy system in an industrial or political context.
The participants of this module will be able to explain how efficiency limitations of the current silicon solar cell technology and the current cost structure of PV electricity motivate the ongoing efforts to develop alternative PV technologies.
The students will be able to name the relevant PV technology options that are currently being investigated, describe their working principle as well as the limitations and challenges these options face.
The students will be able to list critical key indicators for perfomance, potential, market readiness and relevance of a PV technology and to use those to critically assess new emerging PV technologies.

Inhalte Vorlesung / *Content of the lecture*

- Historic development of PV technology and past misconception of alternative PV technologies
- Challenges for the dominant silicon technology: Approaching efficiency limits and system cost structure
- Dye Sensitized-, Organic-, and Perovskite Solar Cells
- Quantum Dots and Nanowire Solar Cells

- Tandem Approaches
- Spectral Management
- The role of Nanophotonics
- Hot Carrier Solar Cells and Thermophotovoltaics
- Thermodynamic limits to future developments
- Disruptive vs. Evolutionary Change
- The importance of efficiency and stability
- Resource limitations and life cycle analysis

Inhalte Übung / *Content of the exercises*

- Cost calculations
- Efficiency calculations
- Assessment of photovoltaic technologies
- Small simulation models for different technologies

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written examination

Zu erbringende Studienleistung / *Coursework*

Attendance of at least 80% of the lectures and exercises.

Literatur / *Literature*

- M. Green, Third Generation Photovoltaics
- J. Nelson, The Physics of Solar Cells
- Würfel, Peter, and Uli Würfel. Physics of solar cells: from basic principles to advanced concepts. John Wiley & Sons, 2009.

Modul / *Module*
Energy in Buildings: energy demand and building physics

Nummer: *Number*	11LE68MO-4112-ab042019		
Modulverantwortlicher: *Responsible person*	Prof. Dr. H.-M. Henning, Dr. S. Hess, B. Rodenbücher, R. Eberle	**Einrichtung:** *Organisational unit*	INATECH
Modultyp: *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	lecture and practical exercise	**Sprache:** *Language*	English
Empfohlene Voraussetzungen: *Recommended preconditions*	Energy Storage, Solar Energy		
Zwingende Voraussetzungen: *Mandatory requirements*	none		

Empfohlenes Fachsemester:: *Recommended term of study*	2	**ECTS-Punkte:** *ECTS credits*	6
SWS: *Semester week hours*	4	**Angebotsfrequenz:** *Regular cycle*	Summer term
Arbeitsaufwand: *Workload*	180 hours (total incl. preparation and lecture attendance)		

Lernziele / *Learning objectives*
The students know the influencing factors on the energy demand of buildings. They know about the requirements and prerequisites for low energy and passive houses. They are familiar with methods for setting up energy balances for buildings and the relevant technical indoor equipment. Students are able to judge under which circumstances zero-energy or plus-energy buildings (with respect to the annual primary energy balance) are attainable. They know the requirements and criteria for indoor comfort in buildings and they are able to estimate the influence of different renovation and retrofit measures on the energy demand and indoor comfort. They know use cases and limits of different heat transfer systems for heating and cooling of indoor environments and are familiar with low exergy concepts for building energy systems.

Inhalte Vorlesung / *Content of the lecture*

- Selected chapters of building physics regarding energy demand of buildings for heating and cooling
- Indoor comfort in buildings
- Ventilation demand and ventilation concepts
- The passive house concept
- Passive use of solar energy in buildings; physics of transparent building components
- Passive systems / concepts for cooling of buildings
- Exergetic evaluation of building systems
- Heat transfer systems to rooms for heating and cooling
- Efficient energy conversion chains, „low-ex“ systems

Inhalte Praktische Übung / *Content of the practical exercise*

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details. The practical exercise includes calculations, practical experiments (e.g. on thermal insulation and optical properties), system simulations (with polysun) and/or case studies.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised exam

Zu erbringende Studienleistung / *Coursework*

Attendance during the practical exercise is required (minimum 85 % attendance). Work on (weekly) exercise sheet and written documentation.

Literatur / *Literature*

Energy Performance of Buildings - Energy Efficiency and Built Environment in Temperate Climates. Editors: Boemi, Sofia-Natalia, Irulegi, Olatz, Santamouris, Mattheos (Eds.). Springer. ISBN 978-3-319-20831-2

Modul / *Module*

Energy in Buildings: components and systems for energy supply

Nummer *Number*	11LE68MO-4113-ab102019		
Modulverantwortlicher *Responsible person*	Prof. Dr. H.-M. Henning, Dr. Stefan Hess, Beatrice Rodenbücher, R. Eberle	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and practical exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Energy Storage, Solar Energy, Energy in Buildings: energy demand and building physics		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

The students know important technical components for energy supply (heating, cooling, air dehumidification) of buildings. Classical processes such as gas burners and compression chillers are covered as well as processes involving renewable energy (especially solar energy and ambient heat). The students are familiar with the physical principles of these processes and are able to derive key figures of merit from these principles. They are aware of the state of the art in these technologies and they can describe focal points of recent research and development work in this field. They are able to assess and compare different energy supply systems for buildings based on economic, ecologic and energy related figures of merit. They are also familiar with some basic methodologies for economic assessment of technical systems (life cycle cost assessment).

Inhalte Vorlesung / *Content of the lecture*

Covered technologies:
- Burners, condensing boiler technology
- Combined heating and power (CHP) units for buildings
- Heat transformation: principles, compression, absorption, adsorption

- Solar energy utilization: principles, solar thermal collectors, photovoltaics applied in buildings
- Energy storage: thermal storage, electrical storage and their system integration

Beside the technologies overall systems are analysed and specific figures of merit to assess different technical solutions are defined and applied. Basic methods for cost assessment as well as methods to assess building sustainability are presented and discussed.

Inhalte Praktische Übung / *Content of the practical exercise*

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details. The practical exercise includes calculations and system simulations (with polysun).

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised exam

Zu erbringende Studienleistung / *Coursework*

- Attendance during the practical exercise is required (minimum 85 % attendance)
- Work on (weekly) exercise sheets
- Written documentation

Literatur / *Literature*

Ursula Eicker: Solar Technologies for Buildings. Springer. ISBN-13: 978-0471486374

Solar Cooling Handbook 3rd Revised & enlarged Edition. by Hans-Martin Henning (Editor), Mario Motta (Editor), Daniel Mugnier (Editor). Ambra. ISBN-13: 978-3990434383

Modul / *Module*
Engineering of Functional Materials / Technische Funktionswerkstoffe

Nummer *Number*	11LE68MO-4222		
Modulverantwortlicher *Responsible person*	Prof. Dr.-Ing. Frank Balle, Michael Becker, Florian Staab	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture + Laboratory	**Sprache** *Language*	German
Empfohlene Voraussetzungen *Recommended preconditions*	Grundlagenwissen im Bereich der Materialwissenschaft und Werkstoffkunde (Bachelor-Studium)		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** ECTS credits	6
SWS *Semester week hours*	4	**Angebotsfrequenz** Regular cycle	Summer term; max 20 participants
Arbeitsaufwand *Workload*	180h		

Lernziele / *Learning objectives*
In diesem Modul sollen die Studierenden werkstoffkundliche Grundlagen auffrischen bzw. vertiefen, um Ingenieurwerkstoffe für technische Anwendungen bewerten zu können. Sie sind somit in der Lage relevante Anforderungsprofile für technische Funktionswerkstoffe zu formulieren und hinsichtlich deren Wichtigkeit zu priorisieren. Sie lernen wichtige Prozesse und Verarbeitungsverfahren für Ingenieurwerkstoffe können incl. den Vor- und Nachteilen ausgewählter technischer Funktionswerkstoffe und sind in der Lage Möglichkeiten zur gezielten Beeinflussung (multi-) funktionaler Werkstoffeigenschaften zu erläutern. Darüber erlernen die Studierenden anhand ausgewählter Beispiele Nachhaltigkeitsaspekte von aktuellen Werkstofflösungen und deren Prozesstechnik für Ingenieuranwendungen. Die theoretischen Inhalte werden durch praktische Versuche im Labor flankiert und vertieft.

Inhalte Vorlesung / *Content of the lecture*
Die Veranstaltung baut auf den materialwissenschaftlichen Grundlagen zum Aufbau der Struktur und den resultierenden Eigenschaften von Ingenieurwerkstoffen auf. Anschließend

werden ingenieurwissenschaftliche Anforderungen an Technische Funktionswerkstoffe erarbeitet – insbesondere im Hinblick auf Nachhaltigkeitsaspekte. Es werden ausgewählte Werkstoffsysteme in Bezug auf deren Hauptanforderungen besprochen wie Werkstoffe mit Leitfunktion, Isolierfunktion, magnetischen und dielektrischen Funktionen. Darüber hinaus werden technisch relevante Prozesse für Ingenieurwerkstoffe mit spezifischem Anforderungsprofil vorgestellt. Dieser Themenkomplex umfasst Lehrinhalte und Anwendungsszenarien von Funktionswerkstoffen bzw. Funktionsschichen hinsichtlich Korrosionsschutz, Oxidationsschutz und Verschleißschutz als auch Werkstoffe zur Fertigungs- und Bearbeitungstechnik sowie Verbindungstechniken für Technische Funktionswerkstoffe. Im letzten Teil der Vorlesung werden multifunktionale Werkstoffkonzepte, zumeist auf Basis von Verbundwerkstoffen oder hybriden Werkstoffen bzw. Strukturen behandelt, die neben strukturellen Vorteilen insbesondere verschiedene Funktionen in einem System vereinen.

Inhalte Praktische Übung / *Content of the Laboratory*

Die Praktische Übung greift ausgewählte Themen und vorgestellte Methoden zur Charakterisierung, Bewertung und auch Verarbeitung von Ingenieurwerkstoffen auf und wird begleitend zur Vorlesung “Technische Funktionswerkstoffe” angeboten. Die Studierenden haben die Möglichkeit forschungs- und anwendungsrelevante Werkzeuge und Methoden praktisch kennen zu lernen, um den theoretisch erlernten Hintergrund zu erleben und somit zu untermauern.
Die Praktische Übung setzt sich aus verschiedenen materialwissenschaftlichen Einzelversuchen zusammen, zu deren Vorbereitung jeweils eine Einführungsveranstaltung angeboten wird. Zu Beginn jedes Versuches findet ein mündliches Kolloquium statt, um die notwendigen Grundlagen zur Versuchsdurchführung sicherzustellen. Dieses Kolloquium muss von allen Teilnehmer bestanden werden, um am Versuch erfolgreich teilnehmen zu dürfen. Es besteht die Möglichkeit maximal 2 Versuche zu wiederholen. Die Praktische Übung gilt als bestanden, wenn alle (max. 8) Versuche erfolgreich absolviert wurden.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Mündliches Prüfungsgespräch über die Inhalte aus der Vorlesung und der Praktischen Übung (Modulabschlussprüfung). Es sind keine Hilfsmittel zugelassen.

Zu erbringende Studienleistung / *Coursework*

100% Anwesenheit in der Praktischen Übung und erfolgreiches Absolvieren des Praktischen Übung: Zu Beginn jedes Versuches findet ein mündliches Kolloquium statt, um die notwendigen Grundlagen zur Versuchsdurchführung sicherzustellen. Dieses Kolloquium muss von allen Teilnehmern bestanden werden, um am Versuch erfolgreich teilnehmen zu dürfen. Es besteht die Möglichkeit maximal 2 Versuche zu wiederholen. Die Praktische Übung gilt als bestanden, wenn alle (max. 8) Versuche erfolgreich absolviert wurden.

Literatur / *Literature*

- W. Bergmann: Werkstofftechnik 1 und 2, Carl Hanser Verlag, 2008 / 2009
- M. Bäker: Funktionswerkstoffe, Springer Vieweg Verlag, 2014

- G. Gottstein: Materialwissenschaft und Werkstofftechnik, Springer Vieweg Verlag, 2014
- H. Hofmann, J. Spindler: Werkstoffe in d. Elektrotechnik, Carl Hanser Verlag, 2013
- E. Macherauch, W. Zoch: Prakitkum in Werkstoffkunde, Springer Vieweg Verlag, 2014

Modul / *Module*
Finance, climate change, and the global energy transition

New seminar within the Interdisciplinary Profile as of the winter semester 2020/21

Nummer *Number*	11LE68MO-5567		
Modulverantwortlicher *Responsible person*	Dr. Mirko Schäfer; Prof. Dr. Eva Lütkebohmert-Holtz	**Einrichtung** *Organisational unit*	Faculty of Economics and Behavioral Sciences/INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Seminar	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Irregular (max. 10 seats available for M.Sc. SSE students)
Arbeitsaufwand *Workload*	180 hours (of which 30h for attendance in class)		

Lernziele / *Learning objectives*

After successful completion of the course, the student is able to…

- Describe scenarios for climate change and for the transformation to a low-carbon economy
- Discuss current global trends for the investment in low-carbon energy systems
- Relate climate risks and policy risks to systemic risk in financial systems
- Communicate key points from current reports and scientific articles covering the global energy transition, climate risks, and their relation to the financial system

Inhalte Vorlesung / *Content of the lecture*

- Scenarios for climate change and for the transition to a low-carbon economy
- The role of climate change and the energy transition for financial stability
- The interplay between policy, investment dynamics, and technological development
- Classification of sustainable investments and assessment of climate-related risks
- The impact of the energy transition on capital markets
- The fossil fuel divestment movement

Zu erbringende Prüfungsleistung / *Course-based assessment*
None (because interdisciplinary profile)

Zu erbringende Studienleistung / *Coursework*
Written report and oral presentation

Anmeldung Seminar / *Seminar registration*
The seminar is a cooperation between the Faculty of Economics and Behavioral Sciences and INATECH. Registration information for M.Sc. SSE students: Please note, the number of participants for this seminar is limited. In order to register for the seminar, please e-mail your "application" to Dr. Mirko Schäfer (mirko.schaefer@inatech.uni-freiburg.de) including the following information: • Name of your study program / year of study • Matriculation number • Current transcript of record Find further information and the **registration deadline** (normally few weeks before the semester start) on https://www.finance.uni-freiburg.de/ Home › Teaching.

Literatur / *Literature FORMAT bei allen Modulen konsistent*
„A call for action – Climate change as a source of financial risk", Network for Greening the Financial System (NGFS), 2019 „Annual Review 2018-2019", Carbon Tracker, 2019 „World Energy Investment 2020", International Energy Agency (IEA), 2020 "Climate change challenges for central banks and financial regulators", E. Camiglio et al., Nature Climate Change 8, 462-468, 2018 Further literature will be announced in the course.

Modul / *Module*
Functional Safety: Active Resilience

Nummer *Number*	11LE68MO-5120		
Modulverantwortlicher *Responsible person*	Dr. Ivo Häring	**Einrichtung:** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture with integrated exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Any basics in any of the following areas would be helpful but are not mandatory: • system description and modelling, • graphical/ semiformal modelling, • product and development life cycles, • classical system analysis, • reliability analysis for any engineering discipline, e.g. electronics, computer science, mechanical, civil and aerospace engineering.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 h (28 h attendance + 62 h self-study)		

Lernziele / *Learning objectives*
Main learning objectives include: 1. Know main (emerging) application domains of functional safety, e.g. industry 4.0, automation, autonomous cars, transportation, aerospace, and energy 2. Knowledge how to achieve acceptable overall performance, risk control and resilience of socio-technical (safety relevant and critical) systems through reliable (safety) functions 3. Knowledge and tailoring of definitions, types and effects of safety functions 4. Relation of functional safety to related concepts 5. Knowledge and tailoring of safety life cycle, development processes and process steps to develop safety functions 6. Knowledge, tailoring, process-driven application, quantification and evaluation, executive conclusions development and litigable documentation of mainly quantitative system analysis methods 7. Know how to efficiently combine and tailor modern system analysis methods 8. Know failure types and how to avoid and control them with techniques and measures for hardware and software 9. Knowledge and application of assessment quantities for functional safety e.g. safety integrity level (on demand or continuous), hardware failure tolerance, diagnostic coverage, safety failure fraction

10. Knowledge of reliability prediction methods and related standards
11. Applicable knowledge of related standardization landscape

Inhalte Vorlesung / *Content of the lecture*

Main contents:
1. Definition of functional safety, safety functions, safety integrity level (SIL), safety related systems
2. Relation of functional safety to reliability, availability, resilience, safety and security
3. Safety and resilience life cycle models (development process for safety and resilience): general and phase-specific requirements
4. System definition and graphical/semi-formal modelling for system analysis, e.g. with UML and SysML
5. Overview on methods for SIL determination: graphical, numerical, analytical, statistical
6. Basic (inductive) analytical tabular system analysis methods: e.g. preliminary hazard list (PHL), hazard analyses (PHA, SSH, O&SHA, HAZOP), hazard log, failure mode and effects analysis (FMEA, FMEDCA), Double failure matrix
7. Basic (deductive) graphical system analysis methods: Reliability block diagram (RBDs), Fault tree analysis (FTA, TDFTA), Markov models, Petri nets, event tree analysis, Fishbone diagram
8. Application process of system analysis methods: qualitative and quantitative implementation, evaluation, e.g. risk priority numbers, parts count and parts stress using reliability prediction for FMEA, Boolean algebra and importance measures for FTA, quantitative measures for graph-based methods, computation approaches for Markov and Petri-Models
9. Key functional safety quantities, e.g. SIL, hardware failure tolerance, complexity, diagnostic coverage, safe failure fraction
10. Functional safety and resilience architecture allocation, e.g. MooN, MooND
11. Overview on techniques and measures for hardware and software to avoid and control systematic errors and to avoid and control statistic errors of hardware
12. Combination and tailoring of processes and methods
13. Application domains and examples: e.g. automation, production, automotive, transport, energy supply
14. Standardization landscape, e.g. functional safety standards IEC 61508, ISO 26262 and safety of intended function ISO 21448
15. Emerging standards, future risk control and resilience generation challenges, e.g. AI and superintelligence control

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written examination

Zu erbringende Studienleistung / *Coursework*

None

Literatur / *Literature*

Example literature/ Sample literature:

1. Satisfying safety goals by probabilistic risk analysis, Hiromitsu Kumamoto, Springer 2007
2. Modern statistical and mathematical methods in reliability, Alyson Wilson et. al. (eds.), World Scientific, 2005
3. Mathematical and statistical methods in reliability, Bo H Lindqvist and Kyell A Doksum, World Scientific, 2003
4. FRAM: the functional resonance analysis method, Erik Holnagel, Ashgate, 2012
5. Control systems safety evaluation and reliability, William M. Gobe, 2010
6. System reliability theory: models, statistical methods and applications, Marvin Rausand, Arnljot Hoyland, Wiley-Interscience, 2004
7. Risk assessment: theory, methods, and application, Marvin Rausand, Wiley, 2011
8. Reliability of safety-critical systems: theory and applications, Marvin Rausand, Wiley, 2014
9. Risk and resilience: methods and application in environment, cyber and social domains, Eds.: Igor Linkov, Jose Manuel Palma-Oliviera, Springer, 2017
10. Functional safety for road vehicles: new challenges and solutions for e-mobility and automated driving, Hans-Leo Ross, Springer, 2016
11. Functional safety in practice, Harvey T Dearden, CreateSpace Independent Publishing Platform, 2018
12. Modeling for reliability analysis: Markov modeling for reliability, maintainability, safety, and supportability analyses of complex systems, Jan van Pukite, Paul Pukite, Wiley-IEEE Press, 1998
13. Applied reliability engineering and risk analysis: probabilistic models and statistical inference, Editor(s): Ilia B. Frenkel, Alex Karagrigoriou, Anatoly Lisnianski, Andre Kleyner, John Wiley & Sons, 2013
14. Reliability engineering: theory and practice, Alessandro Birolini, Springer, 2013
15. Electronic safety systems: hardware concepts, models, calculations, Josef Börcsök, Hüthig, 2004.
16. Elektronische Sicherheitssysteme, Josef Börcsök, Hüthig, 2004
17. Funktionale Sicherheit: Grundzüge sicherheitstechnischer Systeme, Hüthig, 2014
18. Zuverlässigkeitstechnik, Arno Meyna and Bernhard Pauli, Hanser, 2010
19. The safety critical systems handbook, David J. Smith, Butterworth-Heinemann, 2010
20. Reliability and availability engineering: modeling, analysis, and applications, Kishor S. Trivedi, Andrea Bobbio, Cambridge University Press, 2017

Further information:

Sample related standards for information

https://www.iec.ch/functionalsafety/

https://www.iso.org/standard/68383.html

https://www.iso.org/standard/70939.html

Modul / *Module*
Industrial manufacturing and application of solar cells and modules

Nummer *Number*	11LE68MO-4114		
Modulverantwortlicher *Responsible person*	Dr. Dirk Holger Neuhaus	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English *(or German)*
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	• Basic understanding of physics and chemistry • Module “Solar Energy“		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 h lecture with integrated exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90h (in class + preparation of classes)		

Lernziele / *Learning objectives*
Die Studenten bekommen einen umfassenden Einblick in die Herstellung von Solarzellen und Solarmodulen. Dabei werden neben Anlagen, Materialen und Prozessen auch Herstellungskosten, Energieverbrauch und verursachte Treibhausgasemissionen betrachtet. Anwenderrelevante Eigenschaften des Solarmodules wie Modulleistung, jährlichen Energieertrag, Modulzuverlässigkeit und Stromgestehungskosten können berechnet werden. Der Student bekommt einen Überblick über weltweite Märkte und Produktionskapazitäten sowie neu aufkommende Märkte der integrierten Photovoltaik. *The students will gain a comprehensive insight into the manufacturing process of solar cells and solar modules. In addition to equipment, materials and processes, the lecture will cover total manufacturing cost, energy consumption and generated greenhouse gas emissions. Students will be able to calculate user-relevant properties of solar modules such as module power, annual energy yield, module reliability and levelized costs of the*

generated electricity. The students will gain an overview of global markets and production capacities as well as emerging markets of integrated photovoltaics.

Inhalte Vorlesung / *Content of the lecture*

- Weltweite Märkte und Produktionskapazitäten
- Herstellung von kristalline Silizium Solarzellen und Solarmodulen mit dem Fokus auf die heute dominierenden Prozesstechnologien, Anlagen und Materialien
- Verlustmechanismen in Solarmodulen (optische Gewinne, optische Verluste, Modultemperatur, elektrische Verluste)
- Material- und Energieverbrauch bei der Herstellung von Solarmodulen, Herstellungskosten sowie verursachte Treibhausgasemissionen
- Modulzuverlässigkeit und Ausfallmechanismen, Qualifizierung, Testverfahren
- Berechnung des solaren Energieertrages unter Berücksichtigung der solaren Einstrahlung, der Umgebungstemperatur, Modul- und Systemeigenschaften
- Berechnung der Stromgestehungskosten von Solarmodulen (LCOE)
- Integrierte Photovoltaik, bei der Solarzellen in Bauteile integriert werden und zusätzliche Funktionen übernehmen (Gebäude-integrierte Photovoltaik, Vehikel-integrierte Photovoltaik, …)

- *Global markets and production capacities*
- *Manufacturing of crystalline silicon solar cells and solar modules with focus on state-of-the-art production processes, equipment and materials*
- *Loss mechanisms in solar modules (optical gains, optical losses, module operation temperature, electrical losses)*
- *Material and energy consumption required for the production of solar modules, total manufacturing cost as well as generated greenhouse gas emissions*
- *Technologietrends / Technology trends*
- *Module reliability and failure mechanisms, qualification and test procedures*
- *Modelling of the solar energy yield considering the local solar insulation, the local ambient temperature as well as module and system parameters*
- *Calculation of the power generation cost of solar modules (LCOE)*
- *Integrated photovoltaics, with solar cells integrated into constructional elements that carry additional functionalities (building-integrated photovoltaics, vehicle-integrated photovoltaics, …)*

Zu erbringende Prüfungsleistung / *Course-based assessment*

Klausur / *written supervised exam*

Zu erbringende Studienleistung / *Coursework*

Zur Vertiefung der Vorlesungsinhalte werden Übungsaufgaben ausgegeben. Diese werden mit der Systemsimulationssoftware polysun zu Hause bearbeitet und in der Vorlesung besprochen. Die Studenten erhalten für die Vorlesung eine kostenfreie Lizenz für polysun.

To further improve the knowledge of the lecture the student will receive written excrescences. The student has to solve the exercise with the system simulation software polysun at home; discussion of the exercise will take place within the lecture. The students will receive a free licence for polysun for the duration of the lecture.

Literatur / *Literature*

- D.H. Neuhaus, K.A. Münzer, Industrial Silicon Wafer Solar Cells, Advances in OptoElectronics 2007, https://www.hindawi.com/journals/aoe/2007/024521/abs/
- K.A. Münzer, Photovoltaik Technologie – Mein Berufsleben für die Photovoltaik, Berlin 2015, ISBN 978-3-86460-273-3
- A. Goetzberger, B. Voß, J. Knobloch, Sonnenenergie: Photovoltaik, Teubner, Stuttgart 1994, ISBN 3-519-03-214-7
- M.A. Green, Solar Cells, University of New South Wales, Kensington 1982, ISBN 0-85823-580-3
- M.A. Green, Silicon Solar Cells – Advanced Principles & Practice, University of New South Wales, Kensington 1995, ISBN 0-7334-0994-6
- W. Hoffmann, The Economic Competitiveness of Renewable Energy, John Wiley & Sons, New Jersey 2014, ISBN 978-1-118-23790-8
- J.A. Duffie, W.A. Beckman, Solar Engineering of Thermal Processes, 4th Edition, New Jersey 2013, John Wiley & Sons, ISBN 978-0-470-87366-3
- polysun simulation software, user manual, Vela Solaris AG, Winterthur/Switzerland 2017, https://www.velasolaris.com

Modul / *Module*
Innovation and Evolution of Socio-Technical Systems

Nummer *Number*	11LE68MO-5565		
Modulverantwortlicher *Responsible person*	Dr. Klaus Markus Hofmann	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	Seminar	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 Seminar	**Angebotsfrequenz** *Regular cycle*	Summer term, max 21 participants
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

- Systemic understanding of evolution of technological, social systems and infraculture
- Insight in innovation process, innovation-networks, eco-systems, transition process
- Awareness of technical, societal, environmental and legal influences on innovation process
- Understanding basics economics of infrastructure provisioning and emergence/role of institutions
- Ability to analyse societal patterns, economic, spatial structures and their effects on eco-systems
- Ability to identify synergies in infrastructure development, even across sectors
- Principles of open innovation, transdisciplinary cooperation and co-development with prosumers
- Overview about technological platforms for energy, communication and transport
- Sustainability indicators for infrastructure design and operation (local, regional and national level)

Inhalte Vorlesung / *Content of the lecture*

- Innovation and Innovation, Infracultural Analysis and Development Framework
- Sustainable infrastructures enable meeting societal needs to move, have access, communicate, trade and maintain relationships without sacrificing future societal or ecological requirements
- Assessment of requirements, cultural patterns and for communication and mobility infrastructure
- Aspects on innovation, digitalization, technology sociology, path dependency and human ecology

- Applied system thinking (e.g. Complex adaptive Systems, LTIS) regarding societal, environmental, cultural and economic contexts for transformation of technical systems,
- Identifying existing and emerging patterns of communication, transport & mobility
- Concepts of commons; modern commons, dilemmas (e.g. market failure, free rider)
- Systemic approach towards platforms, programmes and application layers in infrastructure sector
- Design of sustainable business models in cooperation of actors in the private and public sector
- Impacts of digital transformation (IoT) on infrastructure systems, men, society and environment
- Cases: electrical mobility, data analytics, smart grids, IoT, and ethical boundaries

Methods/didactics:
- Oral presentation, media
- discussion, interactive Q&A
- worksheets, literature briefs
- individual & group work
- case studies presentations

Zu erbringende Prüfungsleistung / *Course-based assessment*
Individual papers + poster presentation of project results.

Zu erbringende Studienleistung / *Coursework*
Active participation; attendance and readings (tbd) are required.

Literatur / *Literature*
• tbd

Modul / *Module*
Laser Scanning for Mapping Large Structures

Nummer *Number*	11LE68MO-4205		
Modulverantwortlicher *Responsible person*	A. Reiterer	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Grundverständnis für optische Messtechnik; Grundlagen in Optik und Physik *Basic understanding of optical measurement techniques; Basics of Optics and Physics*		
Zwingende Voraussetzungen *Mandatory requirements*	Keine / *None*		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours		

Lernziele / *Learning objectives*

Vermittlung des Verständnisses für den Aufbau und Einsatz von Laser Scanning für die Erfassung, Dokumentation und Überwachung von Großstrukturen. Einordnung von Spezifikationen kommerziell erhältlicher Systeme und Lösungen. Vor- und Nachteile von Laser Scannern für ausgewählte Anwendungen.

The lecture provides an understanding of the design and use of laser scanning for documentation and monitoring of large structures. Classification of specifications for commercially available systems and solutions. Advantages and disadvantages of laser scanners for selected applications.

Inhalte Vorlesung / *Content of the lecture*

- Grundlagen der messtechnischen Begriffe (Genauigkeit, Präzision, Auflösung, etc.)
- Komponenten eines Laser Scanners
- Herausforderungen beim mobilen Laser Scanning
- Registrierung von Punktwolken
- Geo-Referenzierung von Punktwolken
- Projektbeispiele
- Übung: Lösung konkreter Projektbeispiele (Konzipierung von Messsystemen, Vor- und Nachteile verschiedener Ansätze)
- *Basics of measurement terminology (accuracy, precision, resolution etc.)*

- *Components of a laser scanner*
- *Challenges of mobile laser scanning*
- *Registration of point clouds*
- *Georeferencing of point clouds*
- *Project examples*
- *Exercise: Solution of concrete project examples (design of measurement systems, advantages and disadvantages of different approaches)*

Zu erbringende Prüfungsleistung / *Course-based assessment*
Oral examination

Zu erbringende Studienleistung / *Coursework*
Keine *None*

Literatur / *Literature*
Literature will be provided at the beginning of the lecture

Modul / *Module*
Lightweight Design and Materials

Nummer *Number*	11LE68MO-4221		
Modulverantwortlicher *Responsible person*	Prof. Dr.-Ing. Frank Balle	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 Semester
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English or German
Empfohlene Voraussetzungen *Recommended preconditions*	B.Sc. Mechanical Engineering, Materials Science, Production Engineering, Materials Design		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90h (28 h Präsenz + 62 h Selbststudium/Vor- und Nachbereitung)		

Lernziele / *Learning objectives*

Die Studierenden sind in der Lage:

- Auswahlkriterien für Leichtbaukonzepte zu formulieren und zu bewerten,
- Leichtbau als einen wichtigen Ansatz zur Nachhaltigkeit technischer Systeme zu erklären und weiterzuentwickeln,
- die zentralen metallischen Leichtbauwerkstoffe zu benennen und aktuelle Anwendungen incl. deren Legierungs- und Gefügevarianten zu beschreiben sowie korrespondierende Herstellverfahren und ausgewählte Weiterverarbeitungsmöglichkeiten zu erläutern,
- Einsatzmöglichkeiten und -grenzen für den metallischen Leichtbau im Vergleich zum Leichtbau mit Verbundwerkstoffen zu bewerten,
- selbstständig werkstoffspezifische Lösungsstrategien für den werkstofflichen Leichtbau zu definieren und vorzuschlagen,
- bestimmte Werkstoffkonzepte vergleichend zu bewerten und

- diese für typische Anwendungsfälle im konstruktiven Maschinenbau mit besonderem Blick auf eine nachhaltige Entwicklung technischer Systeme auszuwählen.

The students are able to:

- *to frame and evaluate selection criteria for lightweight design concepts*
- *to explain and to develop lightweight concepts as one important approach to the sustainability of technical systems based on lightweight materials*
- *to specify essential light metal alloys and current applications including their alloying and structural concepts*
- *to select corresponding manufacturing methods and further processing options*
- *to evaluate possible applications and limits for lightweight metallic concepts in comparison to an approach by composite materials*
- *to define and propose material-specific strategies for lightweight solutions*
- *to evaluate and compare certain material concepts for lightweight components*
- *to compare modern lightweight solutions with a special focus on sustainable development of engineering systems*

Inhalte Vorlesung / *Content of the lecture*

- Motivation von Leichtbaukonzepten und Ansätze für Nachhaltige Technische Systeme
- Leichtbaustrategien und Auswahlkriterien
- Metallische Leichtbauwerkstoffe: Aluminium, Titan und Magnesium und deren Legierungen
- Leichtbau mit Stählen
- Leichtbau mit polymeren Verbundwerkstoffe
- Weitere Ansätze zum werkstofflichen Leichtbau (z.B. Faser-Metall-Laminate, amorphe Metalllegierungen, metallische und keramische Verbundwerkstoffe)

- *Basics and motivation of lightweight design by materials engineering*
- *Lightweight strategies and criteria for materials selection*
- *Light alloys: Aluminium, Titanium, Magnesium and their alloys*
- *Lightweight steels*
- *Lightweight with Polymer-Matrix-Composites (PMC)*
- *Further lightweight approaches:*
  - *Fiber-Metal-Laminates (FML)*
  - *Bulk metallic glasses (BMG)*
  - *Metal- and ceramic-matrix-composites (MMC, CMC)*

Zu erbringende Prüfungsleistung / *Course-based assessment*

Mündliches Prüfungsgespräch

Oral examination

Zu erbringende Studienleistung / *Coursework*

None

Literatur / *Literature*
• B. Klein: Leichtbau-Konstruktion – Berechnungsgrundlagen und Gestaltung; 10. Auflage, Springer Vieweg, Wiesbaden, 2013 • H.E. Friedrich (Hrsg.): Leichtbau in der Fahrzeugtechnik, Springer Vieweg, Wiesbaden, 2013 • F. Henning (Hrsg.), E. Moeller (Hrsg.): Handbuch Leichtbau – Methoden, Werkstoffe, Fertigung; Carl Hanser Verlag, München, 2011 • H.P. Degischer (Hrsg.), S. Lüftl (Hrsg.): Leichtbau – Prinzipien, Werkstoffauswahl und Fertigungsvarianten; Wiley-VCH, 2009 • F. Ostermann: Anwendungstechnologie Aluminium, 3. Auflage, Springer Vieweg, Wiesbaden, 2014 • Peters, Manfred / Leyens, Christoph (Hrsg.): Titan und Titanlegierungen 3. Auflage, Wiley-VCH Verlag, Weinheim, 2002 • H. E. Friedrich, B. L. Mordike, Magnesium Technology - Metallurgy, Design Data and Applications; Springer Berlin Heidelberg, 2006 • E. Moeller, Handbuch Konstruktionswerkstoffe: Auswahl, Eigenschaften, Anwendung; Carl Hanser Verlag, 2007

Modul / *Module*
Material Flow Analysis

Nummer *Number*	11LE68MO-4224		
Modulverantwortlicher *Responsible person*	Prof. Dr. S. Hiermaier, Dr. S. Kilchert	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture with integrated exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Module: Material Life Cycles		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** ECTS credits	3
SWS *Semester week hours*	2 lecture with integrated exercises	**Angebotsfrequenz** Regular cycle	Summer term
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

The aim of the module “Material Flow Analysis” is to introduce the students to the fundamentals of Material Flow Analysis (MFA), which is a core method to explore the environmental and socio-economic consequences of material flows and stocks in socio-ecological systems. Throughout the course, the students are familiarised with current research.

The students will obtain knowledge about:
- holistic approaches to complex systems and assessing their information content
- the theoretical foundations of MFA
- flows and stocks of various materials and their role in socio-ecological systems
- scientifically sound methods for handling data uncertainties in material flow models
- scenario analysis and the role of time in MFA systems

At the end of the course, the students will be able to:
- identify key materials in socio-ecological systems

- perform a moderately complex MFA under supervision, including mathematical system representation and data analysis
- estimate the criticality of materials and assess resource efficiency in a broader context

Inhalte Vorlesung / *Content of the lecture*

This course provides an introduction to material flow analysis (MFA), a central method of industrial ecology and a major environmental sustainability assessment tool. MFA is used to model stocks and flows of substances and goods across time and space on various scales. By that, MFA studies help inform decision makers about the environmental consequences of resource flows as well as the socio-economic and geopolitical risks and opportunities. Starting off from core concepts of MFA, the students will gradually progress toward more advanced forms of material flow modelling.

The course comprises the following theoretical/methodological core aspects:
- terminology and system definition
- mathematical system representation
- information content, parameter sensitivity, error propagation, and data reconciliation
- dynamic MFA and scenario modelling
- special forms of MFA

The theoretical foundations are supplemented by real world examples primarily based on current research. These include insights into socio-economic systems such as housing, transport, telecommunications, agri- and silviculture, electronics, and the respective materials, that is: steel, aluminium, copper, concrete, plastics, phosphorous, rare earth metals, and others. A specific focus is placed on the end-of-life section of systems, hence emphasising the concept of a circular economy. Accompanying the transfer of theoretical knowledge and giving practical examples, the lecture also contains interactive elements.

Inhalte Übung / *Content of the exercises*

The exercise sessions serve for deepening the understanding of crucial concepts and methods taught in the lecture. The students practice the independent application of scientific methods individually as well as in groups. This ranges from basic system definitions to advanced models and also includes data analysis and the visualisation of results. By that, students familiarise themselves with multiple facets of the socio-economic metabolism and learn to anticipate consequences of resource use on multiple temporal and spatial scales. Support for solving assignments is provided in the exercises. In addition, the use of relevant software is practiced and exemplified using simplified real-world data.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Term paper & written group work (report)

Zu erbringende Studienleistung / *Coursework*

None

Literatur / *Literature*
Tbd.

Modul / *Module*
Materials Selection and Sustainable Development for Mechanical Engineering

Nummer *Number*	11LE68MO-4220		
Modulverantwortlicher *Responsible person*	Prof. Dr.-Ing. Frank Balle	**Einrichtung** *Organisational unit*	INATECH-EFM
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture + exercise	**Sprache** *Language*	English or German
Empfohlene Voraussetzungen *Recommended preconditions*	B.Sc in Mechanical Engineering, Materials Science, Production Engineering, Materials Design or similar areas		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** ECTS credits	6
SWS *Semester week hours*	2 lecture + 2 exercise	**Angebotsfrequenz** Regular cycle	Winter term
Arbeitsaufwand *Workload*	180h (56 h Präsenz + 124 h Selbststudium/Vor- und Nachbereitung)		

Lernziele / *Learning objectives*

Die Studierenden sind in der Lage:

- die zentralen Werkstoffgruppen und Verarbeitungsverfahren für Ingenieuranwendungen zu benennen.
- Unterschiede zwischen diesen Werkstoffgruppen und Verarbeitungsverfahren zu erklären.
- verschiedene Kriterien der Werkstoffauswahl zu kombinieren und deren Wichtigkeit einzuschätzen.
- eine Aufgabe zur Werkstoffauswahl zu analysieren und die kennengelernten Methoden gezielt an Beispielen einzusetzen.
- konfliktäre Kriterien der Werkstoffauswahl zu beurteilen und abzuwägen.
- die getroffene Werkstoffauswahl mit einem passenden Fertigungsverfahren zu kombinieren und zu hinterfragen bzw. alternative Werkstoffe zu benennen.

The students are able:

- *to define the central material families and processing methods for engineering applications and to explain their differences*
- *to combine different criteria for materials selection and assess their importance*
- *to analyze an example for the selection of materials and to apply the methods learned by case studies*
- *to evaluate and judge conflicting criteria for materials selection*
- *to combine and to question a given materials selection in the context of a suitable development and finally to propose alternative materials*
- *to solve a self-defined case study and to review a foreign approach*

Inhalte Vorlesung / *Content of the lecture*

Die Auswahl des geeigneten Werkstoffes ist von zentraler Bedeutung für den Erfolg eines Produktes. Die Anzahl der verfügbaren Werkstoffe ist enorm und steigt stetig durch Neu- und Weiterentwicklungen verbunden mit veränderten und verbesserten Eigenschaftsprofilen. Die Werkstoffauswahl ist somit ein dynamischer Prozess, der für den Erfolg eines Produktes bzw. Unternehmens von entscheidender und nachhaltiger Bedeutung sein kann.

Es werden folgende Schwerpunkte behandelt:

- Allgemeine Aspekte der Werkstoffauswahl für nachhaltige technische Systeme
- Die wichtigsten Werkstoffgruppen und deren Eigenschaften
- Ausgewählte Methoden der Werkstoffauswahl
- Werkstoffeigenschaftsschaubilder und Materialindizes
- Konfliktäre Kriterien bei der Werkstoffentscheidung
- Geometrieeinflüsse der Werkstoffauswahl (Formfaktoren)
- Einflüsse der Einsatztemperatur
- Industriedesign und Fertigungseinflüsse
- Werkstoffauswahl im Kontext einer nachhaltigen Produktentwicklung (Eco-Audit)
- Berücksichtigung aktueller Werkstoffentwicklungen im Auswahlprozess
- Ausgewählte Übungsbeispiele (Praktische Vertiefung in den Übungen)

The selection of the right material is of central importance for the success of a product. The number of available materials is enormous and is constantly increasing due to innovations, research and development combined with changed and improved property profiles. So the selection of engineering materials is a dynamic process that can be of decisive importance for the success of a product or entire company.

Following topics will be discussed:

- *Introduction and Motivation for Materials Selection and Sustainable Engineering*
- *The Families of Engineering Materials and their Properties*
- *Selected Concepts for Materials Selection in Mechanical Design*
- *Materials Property Charts and Material Indices*
- *Multiple Constraints and Conflicting Objectives for Materials Selection*
- *Materials and their Shape*
- *Hybrid Materials and Structures*
- *Industrial Design and the World of Processes*
- *Materials and the Environment*
- *Sustainability for Engineering Applications – the Ultimate Challenge?!*
- *Corresponding Case Studies (during the exercises)*

Inhalte Übung / *Content of the exercises*

Vorlesungsbegleitende Übungsbeispiele und intensive Nutzung der Lernsoftware CES-EduPack (Granta Design, Cambridge Uk) nach Einführung in die Möglichkeiten der Software.
Die Studierenden haben die Möglichkeit eigene Beispiele und Fragestellungen einzubringen und im Rahmen der Übungen zur Diskussion zu stellen bzw. in moderierter Gruppenarbeit zu lösen.

The exercises are synchronized with the lectures. So all important aspects will be reiterated and studied by the intensive use of the learning software CES EduPack (Granta Design, Cambridge UK). The EduPack-Software is introduced in the first exercises and central tool of all exercises.
The students have also the opportunity to contribute their own examples or self-defined case studies and discuss them during the hands-on exercises or to solve them in a self-organized group, which is coached by the lecturer and his team.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Mündliches Prüfungsgespräch

Oral examination

Zu erbringende Studienleistung / *Coursework*

None

Literatur / *Literature*

- M. F. Ashby: Materials Selection in Materials Design. 5th edition, Elsevier Verlag, 2017
- M.F. Ashby, A. Wanner (Hrsg.) C. Fleck (Hrsg.): Materials Selection in Mechanical Design: Das Original mit Übersetzungshilfen. Easy-Reading-Ausgabe, 3. Aufl., Spektrum Akademischer Verlag, 2006
- M. Reuter: Methodik der Werkstoffauswahl – Der systematische Weg zum richtigen Material. Hanser Verlag, 2. Auflage, 2014
- J. M. Allwood, J. M. Cullen: Sustainable Materials – without the hot air. UIT Cambridge, 2015
- M. F. Ashby: Materials and Sustainable Development. Elsevier-BH Verlag, 2016
- M. F. Ashby: Materials and the Environment. Elsevier-BH Verlag, 2013
- K.G. Budinsky and M.K. Budinsky : Engineering Materials, Properties and Selection. 6th edition, Prentice Hall, London, UK, 1999
- M. Kutz: Handbook of Materials Selection. John Wiley & Sons, New York, USA, 2002
- M. Bonnet: Kunststoffe in der Ingenieuranwendung. Vieweg-Teubner Verlag, 2009
- H. J. Maier, T. Niendorf, R. Bürgel: Handbuch Hochtemperatur-Werkstofftechnik. Springer-Vieweg-Verlag, 2015

- J. Shackelford: Introduction to Materials Science for Engineers. Pearson Verlag, 2009

Modul / *Module*
Methods of Material Characterization for Waste Management

Nummer *Number*	11LE68MO-5562		
Modulverantwortlicher *Responsible person*	Prof. Dr. Michael Fiederle	**Einrichtung** *Organisational unit*	FMF
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture + exercise	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basics in the area of materials sience and engineering (Bachelor studies)/ Grundlagenwissen im Bereich der Materialwissenschaft und Werkstoffkunde (Bachelor-Studium)		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	3 (2V + 1Ü)	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 h (48h Präsenz + 132h Selbststudium)		

Lernziele / *Learning objectives*

Advanced analytical methods are essential for the investigation of materials. The theory and applications of the methods are an important part of this curriculum. The module includes spectroscopic, diffraction methods and tomography covering a broad range of characterization tools from basic knowledge to advanced data analysis. The module refers to the knowledge gained in the others modules of Material Science. The computer tomography by X-rays will be covering the major part of the lecture.
The students will be competent in choosing techniques for characterization of material systems and perform material analysis towards waste management.
In this module students select and apply principles of common analytic methods by using material characterization methods.

Inhalte Vorlesung / *Content of the lecture*

The course provides tools for the characterization of materials by using spectroscopy, x-ray diffraction and x-ray tomography. The basic theory of tomographic techniques and algorithm will be presented. Besides the different techniques the major part of the lecture is dedicated to the X-ray Computer tomography.

Teaching form:

- 3D multimedia introduction into the various methods, supported by solving problems and discussion of results.
- Lecture + exercise: students will learn to use X-ray CT and evaluate the obtained data for different types of objects and materials.

CONTENT OF THE EXERCISE

The tools of material characterization require detailed analysis and theory. In the exercise the different theories and tools will be applied and extended towards applications. The students will prepare a presentation based on application-oriented examples.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written exam (Klausur) and oral presentation

Zu erbringende Studienleistung / *Coursework*

- Attendance in the exercise is mandatory (85%)
- Written and practical work
- Oral presentation

Details will be defined during first lecture.

Literatur / *Literature FORMAT bei allen Modulen konsistent*

- Schroder, D.K. (2006), Semiconductor Material and Device Characterization, 3rd Edition, Wiley, USA
- Fultz, B. & Howe, J.M. (2001): Transmission Electron microscopy and diffractometry of materials. Springer, Berlin.
- Muammer Kaya, Electronic Waste and Printed Circuit Board Recycling Technologies (The Minerals, Metals & Materials Series) 2019, Springer, Berlin
- Erhard Hornbogen Recycling: Materialwissenschaftliche Aspekte (Deutsch) Taschenbuch, 1993, Springer Berlin
- Mi Wang, Industrial Tomography: Systems and Applications (Woodhead Publishing Series in Electronic and Optical Materials), 2015, Woodhead Publishing

Modul / *Module*
Operations Research for Energy Systems

Nummer *Number*	11LE68MO-5558		
Modulverantwortlicher *Responsible person*	Prof. Dr. Anke Weidlich	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture, exercise & seminar	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	3 lecture, exercise & seminar	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150h		

Lernziele / *Learning objectives*

The students have an overview of different optimization problems in the energy sector and can choose an appropriate method for problem solving. They understand the mathematical background of linear programming, mixed-integer linear programming and other techniques that are widely applied in the energy economy. They are able to formulate mathematical models (objective functions, constraints) and are able to apply optimization methods with the help of computational tools. The students understand the background of different forecasting methods and can carry out forecasts based on time series and multiple linear regression.

Die Studierenden haben einen Überblick über verschiedene Optimierungsprobleme im Energiesektor und können eine geeignete Methode zur Problemlösung auswählen. Sie verstehen den mathematischen Hintergrund von linearer und gemischt-ganzzahliger linearer Programmierung sowie weiteren in der Energiewirtschaft verbreiteten Methoden. Sie sie sind in der Lage, mathematische Modelle (Zielfunktionen, Nebenbedingungen) zu formulieren und sie rechnergestützt zu lösen. Die Studierenden verstehen den Hintergrund verschiedener Prognosemethoden und können Prognosen basierend auf Zeitreihen und multipler linearer Regression durchführen.

Inhalte Vorlesung / *Content of the lecture*

- *Optimization problems in energy economics (e. g. unit commitment, resource scheduling)*
- *Linear and mixed-integer linear programming*
- *Dynamic programming*
- *Multi-criteria decision analysis*
- *Multiple linear regression*
- *Time series-based forecasting*

Associated exercise:
Computational tools for optimization

- Optimierungsprobleme in der Energiewirtschaft (z. B. Kraftwerkseinsatzplanung)
- Lineare und gemischt-ganzzahlige lineare Programmierung
- Dynamische Programmierung
- Multi-kriterielle Entscheidungsunterstützung
- Multiple lineare Regression
- Zeitreihenbasierte Prognosen

Associated exercise:
- Computational tools for optimization

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written documentation + written supervised examination

Zu erbringende Studienleistung / *Coursework*
Keine

Benotung / *Grading*
The module grade will be based on the written documentation (30%) and the final written supervised exam (70%).

Literatur / *Literature*
• Suhl, L., Mellouli, T.: Optimierungssysteme : Modelle, Verfahren, Software, Anwendungen. 2. Auflage, Berlin : Springer, 2009. • Poler, R., J. Mula, M. Díaz-Madronero: Operations Research Problems: Statements and Solutions, Springer, Berlin / Heidelberg, 2014. • Williams, H. P.: Model Building in Mathematical Programming, 5th Edition, John Wiley & Sons, 2013.

Modul / *Module*

Optical metrology for quality assurance in sustainable production

Nummer *Number*	11LE68MO-4305		
Modulverantwortlicher *Responsible person*	Dr. Daniel Carl	**Einrichtung:** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Fundamental knowledge about photonics		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Irregularly (currently: summer term 2021)
Arbeitsaufwand *Workload*	90 h		

Lernziele / *Learning objectives*

Metrology plays for the majority of manufacturers one of the most important roles in quality control, being essential to avoid production of “non-good” parts and hence to stop wasting of energy, materials, and productivity. Here optics helps to make efficient use of resources and to produce high-quality parts and goods that finally really work for a long period of use. This are immediate benefits for a more sustainable world. Since here economic and environmental aspects are in line, penetration of this technology is happening. The key is to identify the chances and to develop the tailored, reliable optical metrology to do this job. Within this context, the lecture gives insights into the fundamental principles and methods of optical metrology for production control.

In detail, the students will learn
- Basic principles of geometrical optical measurements,
- Fundamentals of wave optics,
- Operation of optical sensors,
- Principles of digital data/image processing,
- Different optical measurement methods and their applications.
- Schematics to identify opportunities to improve the efficiency of production processes by optical metrology

Inhalte Vorlesung / *Content of the lecture*

- Basic principles of geometrical optical measurements
- Fundamentals of wave optics
- Optical Sensors
- Overview of optical measurement principles and their applications
- Incoherent methods (Triangulation, Fringe projection, …)
- Coherent methods (Interferometry, Speckle, Holography, …)
- Confocal methods
- Examples for successful implementation of optical metrology in industry, with economical and sustainability win-win situations

The lecture includes an excursion to production control laboratories at Fraunhofer IPM.

Zu erbringende Studienleistung / *Coursework*
None

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised exam.

Literatur / *Literature*
- LEACH, Richard (Hg.). Optical measurement of surface topography. Berlin: Springer, 2011. - Saleh, Bahaa EA, and Malvin Carl Teich. Fundamentals of photonics. John Wiley & Sons, 2019.

Modul / *Module*
Photovoltaic Laboratory (PV lab)

Nummer *Number*	11LE68MO-4108		
Modulverantwortlicher *Responsible person*	Prof. Dr. Stefan Glunz; R. Eberle	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Exercise	**Sprache** *Language*	English
Voraussetzungen zwingend *Preconditions mandatory*	Mandatory module “solar energy”		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6 ECTS
SWS *Semester week hours*	3	**Angebotsfrequenz** *Regular cycle*	Each term; max. 10 participants
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

The Photovoltaic Laboratory provides an opportunity for hands-on experience with the PV-related topics introduced in the Solar Energy course. Students will get to know solar cells from a practical view and gain experience in interconnection and operation of solar cells, including evaluation of their performance. Students will understand the electrical properties of solar cells e.g. the IV-curve and related parameters; they will experience the influence of environmental conditions such as temperature, intensity of the incoming light and the angle of incidence. The examination of solar cells as a component part in electrical circuits will enable students to solve typical problems, e.g. how to connect a couple of single cells reasonably to build up a module or how to avoid problems caused by shading. Knowledge about the behavior and performance on load when used as power source is very important for the application of solar cells. Off-Grid systems will also be investigated as a practical application scenario for photovoltaic. This will bring students in contact with electrical components such as load-regulators, storage etc. These are elementary topics for solid knowledge of solar cells and crucial for ongoing research of a more application-oriented use of solar cells.

Inhalte Vorlesung / *Content of the lecture*

A broad variety of laboratory experiments will address the operating characteristics of solar cells and photovoltaic modules. Different experiments will be performed each week. These experiments include:

- Fundamental electric basics: series and parallel connection of solar cells

- Geometrical aspects and environmental conditions: Illumination, angle of incidence and temperature dependence of the solar cell power
- Solar cell characterization: IV-curve in the dark and under illumination, maximum power point and fill factor
- Building up PV modules: I-V-characteristics of different solar modules and partial shading
- Working principle of mpp-tracking: DC/DC inverter
- Solar cells as power supply: on-load power and internal resistance
- Components and operation of a solar off-grid system
- Comparison and operation of different charge controllers: shunt-, series- and PWM regulator
- Discharge protection and DC/AC inverter

Zu erbringende Prüfungsleistung / *Course-based assessment*

- Presentation of experimental results

Zu erbringende Studienleistung / *Coursework*

- Students need to attend all laboratory sessions and need to write protocols of performed laboratory experiments

Literatur / *Literature*

- Smets, Solar Energy, UIT Cambridge 2016
- P. Würfel, Physik der Solarzelle, Spektrum - Akademischer Verlag 2000
- A. Goetzberger, B. Voß und J. Knobloch, Sonnenenergie: Photovoltaik, Teubner 1997
- M.A. Green, Solar Cells, University of New South Wales 1982
- K. Mertens, Photovoltaik, Hanser 2011
- J. Nelson, The physics of solar cells, Imperial College Press 2008

Modul / *Module*
Physics of Failure

Nummer *Number*	11LE68MO-5121		
Modulverantwortlicher *Responsible person*	S. Hiermaier	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (32 hours Full-time attendance course of study + 58 hours Self-study)		

Lernziele / *Learning objectives*
With this module Students are able to distinguish between damage and failure as two distinct process types in materials as other thermo-mechanic behaviors. Basic differences between phenomenological and physics based modeling approaches become evident. Specifically, the multi-scale character of the process is recognized. The resulting dimension of related resources for computations as well as the necessity for scale-bridging methodologies is learnt. Furthermore, a variety of experimental and numerical methods for characterizing and modeling the processes is investigated. *Die Studierenden können zwischen Schädigungs- und Versagensprozessen unterscheiden und beides in das übrige thermo-mechanische Verhalten von Werkstoffen einordnen. Sie erkennen die Unterschiede zwischen phänomenologischen und physikalischen Modellierungen von Schädigungs- und Versagensprozessen. Insbesondere wird der skalenübergreifende Charakter dieser Vorgänge deutlich. Die daraus resultierenden Dimensionen im Berechnungsaufwand sowie mögliche Lösungen mit skalenüberbrückenden Methoden erschließen sich.* *Daneben wird klar, dass es unterschiedlicher experimenteller und numerischer Verfahren zur Charakterisierung und Modellierung dieser Prozesse bedarf.*

Inhalte Vorlesung / *Content of the lecture*
tba

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Modul / *Module*
Power Electronic Circuits and Devices

Nummer *Number*	11LE68MO-9010		
Modulverantwortlicher *Responsible person*	O. Ambacher, R. Quay, B. Burger	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge of electric and electronic circuits		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 2 exercise	**Angebotsfrequenz** *Regular cycle*	Each summer term
Arbeitsaufwand *Workload*	150h (52h full-time attendance course of study + 98h self-study)		

Lernziele / *Learning objectives*

Students will be enabled to understand materials, functioning and design of up to date power devices and circuits suitable for energy efficient power electronic systems. The lecture comprises three aspects: fundamental material and device concepts, power conversion-circuitry and power conversion systems. This includes high voltage AC-DC converter, solar energy photovoltaic converters and convertres for engines or windcraft systems. The basic concepts of power conversion, of passive and active semiconductor devices, high-voltage operation, converter- and control concepts, device protection and aspects of system and power network theory are provided.
The students will be competent to analyze, understand the fabrication, design of passive and active power devices such as MOSFETs, Insulated Gate Bipolar IGBTs, Junction FETs (JFET), diodes, and thyristors. Students will be able to design and analyze feedback control systems based on state space control technologies and apply them to power devices.

Die Studenten werden in die Lage versetzt, Materialien, Entwurf und Funktionen von modernen Leistungsbauelementen und Schaltkreisen zu verstehen, die für energieeffiziente leistungselektronische Systeme geeignet sind. Die Vorlesung umfasst drei Aspekte: grundlegende Materialkonzepte, Bauelementkonzepte und Spannungswandler sowie Stromrichter-Systeme. Dazu gehören Hochspannungs-AC-DC-Wandler, photovoltaische Photovoltaik-Konverter und Konverter für Motoren oder Windkraftanlagen. Die grundlegenden Konzepte der Leistungswandlung, der passiven und

aktiven Halbleiterbauelemente, des Hochspannungsbetriebs, der Umrichter- und Steuerungskonzepte, des Geräteschutzes sowie der System- und Netzwerktheorie werden vorgestellt. Die Studenten werden ausgebildet, um die Herstellung von passiven und aktiven Leistungsbauelementen wie MOSFETs, Bipolar-IGBTs, Junction-FETs (JFET), Dioden und Thyristoren zu analysieren und zu verstehen. Die Studierenden werden in der Lage sein, Rückkopplungs-Steuerungssysteme basierend modernen Architekturen zu entwerfen und zu analysieren und sie auf leistungselektronische Systeme anzuwenden.

Inhalte Vorlesung / *Content of the lecture*

The lecture deals with the materials, topologies and concepts of power devices and circuits. It comprises three parts: fundamental material and device concepts, power conversion-concepts and actual power conversion systems. At the interface of modern electronics, circuit design, and control theory, advanced analysis, fabrication, and characterization techniques are introduced in order to bridge the gap from modern power conversion to the understanding of systems and network systems with all aspects of power conversion. The methodologies of power-analysis, design of circuits, complex power flow, processing of devices, their modelling, their characterization, and control are introduced along with the demonstration of their relevance to real power-components and -systems. Circuits and system concepts for power conversion, such as half and full bridges, current controls, aspects high voltage operation, and design for robustness are presented, and several examples are discussed in detail. Typical applications include DC-DC conversion for server systems, photovoltaic power conversion, application to microscopic power converters, and high-voltage windcraft systems.

Die Vorlesung beschäftigt sich mit den Materialien, Topologien und Konzepten von Leistungsbauelementen und Schaltungen. Sie besteht befasst sich mit drei Themen: grundlegenden Material- und Bauelementkonzepten, Energiekonversionskonzepten und Energiewandlungssystemen. An der Schnittstelle von moderner Elektronik, Schaltungsentwurf und Steuerungstheorie werden moderne Analyse-, Herstellungs- und Charakterisierungstechniken eingeführt, um das Wissen von ausgehend von modernen leistungselektronischen Bauelementen bis zum Verständnis von Systemen zur Energieumwandlung bereitzustellen. Die Methoden der Leistungsanalyse, der Entwurf von Schaltungen, der Prozessierung von Schaltungen, ihrer Modellierung, ihrer Charakterisierung und Regelung werden vorgestellt und ihre Relevanz für reale Leistungskomponenten und -systeme demonstriert. Schaltkreise und Systemkonzepte für die Energieumwandlung, wie Halb- und Vollbrücken, Stromsteuerungen, Hochspannungsbetrieb und Designs mit hoher Robustheit werden vorgestellt. Typische Anwendungen sind die DC-DC-Wandlung für Serversysteme, die photovoltaische Leistungsumwandlung, die Anwendung in mikroskopischen Stromrichtern und Windkraftanlagen.

Inhalte Übung / *Content of the exercises*

In the exercises, the contents of the lecture will be illustrated and deepened by means of examples. The students learn in their home studies on the basis of exercise sheets, e.g. to calculate the electrical properties of power electronic devices and circuits, as well as to estimate the lifetime, ruggedness, and energy efficiency of power electronic systems. During the exercises the solutions of the tasks and problems are presented by tutors and explained in detail.

In den Übungen werden die Inhalte der Vorlesung anhand von Beispielen veranschaulicht und vertieft. Die Studierenden erlernen im Eigenstudium anhand von Aufgabenblättern z.B.

die elektrischen Eigenschaften von leistungselektronischen Bauelementen und Schaltungen zu berechnen sowie die Lebensdauer, Robustheit und Energieeffizienz von leistungselektronischen Systemen abzuschätzen. Die Lösungen der Aufgabenblätter werden in der Übung durch Tutoren vorgestellt und detailliert erklärt.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised exam

Zu erbringende Studienleistung / *Coursework*
None

Literatur / *Literature*
• Joachim Specovices „Grundkurs Leistungselektronik“ Vieweg + Teubner (2009) ISBN 9783834805577 • Manfred Michel „Leistungselektronik“ Springer (2011) ISBN 9783642159831 • C. Kamalakannan et al. „Power Electronics and Renewable Energy Systems“ Springer (2014) ISBN 8132221184

Modul / *Module*
Power Electronics for E-Mobility

Nummer: *Number*	11LE68MO-4106		
Modulverantwortlicher *Responsible person*	S. Reichert	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture with embedded exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	Power Electronic Circuits and Devices (elective module)		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand: *Workload*	90 hours (28 hours full-time attendance course of study + 62 hours self-study)		

Lernziele / *Learning objectives*

It is the aim of this module to get a fundamental understanding of power electronic circuits used in E-Mobility applications like traction inverters, bidirectional chargers and onboard energy management.
The students will learn different circuit topologies and basic control structures for power electronic circuits. The interaction between the power grid and electric vehicles will be discussed.

Inhalte Vorlesung / *Content of the lecture*

Power Electronics for E-Mobility applications:

- Conductive and inductive chargers for electric vehicles
- Traction inverters and electric motors
- DC/DC converters for onboard energy management
- Control of grid connected inverters
- E-Mobility as an instrument for a better grid integration of renewable energies

Exercises/Tutorials are included in the lecture (WS 2020: 3 exercises x 2 hrs, conducted by Benjamin Stickan).

Zu erbringende Prüfungsleistung / *Course-based assessment*

written or oral examination

Literatur / *Literature*
Teodorescu R., Liserre M., Rodriguez P.; Grid Converters for Photovoltaic and Wind Power Systems, Wiley-IEEE, 2011

Modul / *Module*
Power Electronics for Photovoltaics and Wind Energy

Nummer *Number*	11LE68MO-4107		
Modulverantwortlicher *Responsible person*	B. Burger	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	Power Electronics Circuits and Devices (elective module)		
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge in Electrical Components (Semiconductors, Inductors, Capacitors)		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (28 hours full-time attendance course of study + 62 hours self-study)		

Lernziele / *Learning objectives*
Power electronics circuits convert the DC power of PV modules to grid compatible AC power. Wind turbines produce AC power with variable frequency, which has to be converted to AC with grid frequency. The commonly used hardware topologies of power electronic converters for renewable energies are shown and explained in detail. Additional aspects like MPP-tracking, supply of reactive power, low voltage ride through (LVRT) etc. are discussed.

Inhalte Vorlesung / *Content of the lecture*
• Solar Module Integrated Electronics • Single Phase String Inverters • Three Phase String Inverters • Battery Chargers and Off-Grid Inverters • PV System Technology • Frequency converters for Wind Energy

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Literatur / *Literature*
Robert W. Erickson, Dragan Marksimovic: Fundamentals of Power Electronics Mohan, Undeland, Robbins: Power Electronics http://nptel.ac.in/courses/Webcourse-contents/IIT%20Kharagpur/Power%20Electronics/New_index1.html https://en.wikipedia.org/wiki/DC-to-DC_converter https://en.wikipedia.org/wiki/Power_inverter https://en.wikipedia.org/wiki/Variable-frequency_drive

Modul / *Module*
Python for Energy System and Sustainability Analysis

Nummer *Number*	11LE68MO-6002		
Modulverantwortlicher *Responsible person*	Prof. Dr. Anke Weidlich, Jan Frederick Unnewehr, Ramiz Qussous	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Computer lab and lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Control and Integration of Grids		
Zwingende Voraussetzungen *Mandatory requirements*	Attendance during the first lecture is obligatory for those who want to keep their seat.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 computer lab + integrated lectures	**Angebotsfrequenz** *Regular cycle*	Summer term: max. 20 seats
Arbeitsaufwand *Workload*	180 h (45 h in class, 60 class preparation, 75 project)		

Lernziele / *Learning objectives*

The students

- Can apply basic techniques for solving mathematical problems with Python
- Understand engineering problems described in flowcharts, and can translate flowchart descriptions into a computer program
- Can apply Python to solving mathematical problems in different scientific fields, especially in the energy and sustainability domain
- Can analyse energy system models implemented in Python
- Can create an appropriate model for approaching a research question in the energy or sustainability field and implement it in Python

Inhalte Vorlesung / *Content of the lecture*

- General introduction to Python, integrated development environment
- Fundamentals (data types, expressions, conditional execution, iterations, functions, files, matrix operations)
- Algorithms (flowcharts, pseudocode, complexity and runtime estimation)

- Modelling techniques and application examples from energy systems and sustainability analysis (power flow analysis, merit order models, simulations, system dynamics and others)
- Multi-criteria decision analysis for energy systems
- Geodata processing (visualization, potential analysis)
- Relevant data sources for the energy sector
- Data evaluation (data import and export, plotting results)

Zu erbringende Prüfungsleistung / *Course-based assessment*

Project and presentation – students choose an own research challenge, decide on a model for addressing the challenge, implement it in Python, execute it with appropriate input data, plot and interpret results, and describe the project in a report. They present their project in the class.

Zu erbringende Studienleistung / *Coursework*

Implementation assignments

Literatur / *Literature*

- Literature will be announced in the lecture
- Starting book: A. Sweigart, Automate the Boring Stuff with Python: Practical Programming for Total Beginners, No Starch Press (2015)

Modul / *Module*
Quantification of Resilience

Nummer *Number*	11LE68MO-4110		
Modulverantwortlicher *Responsible person*	Dr. Ivo Häring	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture with embedded exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	• Basic Knowledge in any of the following domains would be of avail without being mandatory: system modeling and simulation, failure modelling, statistics, probability theory, stochastic processes, engineering models for the determination of system behavior in case of adverse, damage or disruptive loads or events, supply network modeling, critical infrastructure models, graph and network models, discrete models, coupled physical models, modeling and simulation of cyber-physical and socio-technical systems.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 h (32 h attendance, 58 h self-study)		

Lernziele / *Learning objectives*
Main learning targets incluce: 1. Know objectives, options and opportunities of resilience quantification for (socio) technical systems 2. Gain overview on currently used methods for informed selection and combination 3. Know methods and their main (traditional) application areas 4. Be capable to apply and tailor methods for resilience quantification

Inhalte Vorlesung / *Content of the lecture*
Main contents comprise: 1. Context, basic definitions, objectives and options of resilience quantification: resilience management process, resilience quantification and development process 2. Overview of methods for resilience quantification of socio technical cyber physical systems: resilience dimensions, resilience method taxonomy 3. Qualitative and semi-quantitative resilience assessments: ontologies, schemes and evaluation 4. Graphical and semi-formal approaches: heuristics vs. models 5. Resilience dimensional order expansions and resulting quantification bounds 6. Application of classical system analysis approaches, e.g. deterministic flux-based

approaches, Markov models, stochastic processes
7. Graph-based and topological approaches: system definition, identification of disruption vector, response and recovery determination and response strategy optimization
8. Resilience quantification based on event propagation through resilience analysis layers using resilience transition matrix elements and related statistical-empirical, probabilistic, engineering and physical-simulative methods: inductive and deductive propagation
9. Input-output models, operability models: discrete and continuous
10. Coupled agent-supported engineering grid-model approaches for overall system modelling, simulation and resilience determination, in particular also for modeling of operators, citizens as well as organizational, policy and framing influences
11. Combinations of resilience quantification approaches and optimization problems in resilience engineering
12. For all resilience quantification approaches: model assumptions, application domains and examples, typical input and output data
13. Standards, emerging standards and ongoing standardization efforts

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised examination

Literatur / *Literature*

- Vulnerable systems, Wolfgang Kröger and Enrico Zio, Springer, 2011
- Catalogue of risks: natural, technical, social and health risks, Dirk Proske, Springer, 2008
- Resilience engineering: models and analysis, Nii O. Attoh-Okine, Cambridge University Press, 2016
- Urban resilience for emergency response and recovery: fundamental concepts and applications, Gian Paolo Cimellaro, Springer, 2016
- Risk assessment and decision analysis with Bayesian networks, Norman Fenton and Martin Neil, CRC Press, 2013
- Risk analysis and management: engineering resilience, Ivo Häring, Springer 2015
- Principles of cyber-physical systems, Rajeev Alur, MIT Press, 2015
- Cyber-physical systems: from theory to practice, Danda B. Rawat, Joel J.P.C. Rodrigues, and Ivan Stojmenovic (eds.), CRC Press, 2016
- Cyber-physical systems: integrated computing and engineering design, Fei Hu, CRC Press, 2013
- Agent-based modelling of socio-technical systems, Koen H. van Dam, Igor Nikolic and Zoifia Lukszo (eds.), 2012, Springer
- Introduction to agent-based modeling, Uri Wilenski, Springer, 2015

Additional information:

http://www.leistungszentrum-nachhaltigkeit.de/themen/resilience-engineering/
http://www.academy.fraunhofer.de/de/weiterbildung/energie-nachhaltigkeit/resilience-engineering.html
http://www.lrfoundation.org.uk/publications/resilience-engineering.aspx
http://www.lr.org/en/news-and-insight/news/lrf-res-eng.aspx
http://frs.ethz.ch/
https://www.irgc.org/irgc-resource-guide-on-resilience/
http://link.springer.com/article/10.1007/s41125-015-0001-x
http://www.din.de/de/; http://www.iso.org/iso/home.html; http://www.iec.ch/; https://ansi.org/
Suche nach / searched for “resilience”

Modul / *Module*
Resilience of Supply Networks

Substitute module for "Security and Privacy in Resilient Systems" in summer term 2021

Nummer *Number*	11LE68MO-9030c (corresponding lecture and exercise: 11LE68V-5564 and 11LE68Ü-5564)		
Modulverantwortlicher *Responsible person*	Prof. Dr. Alexander Stolz; Dr. Mirjam Fehling-Kaschek	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Compulsory Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 h lectures + 2 h exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	150 hours (52 hours Full-time attendance course of study + 98 hours Self-study)		

Lernziele / *Learning objectives*

- Capability to discretize and model supply networks
- Understand and apply graph theory methods for resilience analysis to supply networks
- Understand and apply agent-based modelling methods for resilience analysis to supply networks
- Calculate Resilience curves based on network simulation

Inhalte Vorlesung / *Content of the lecture*

In 2015 the United Nations defined 17 Sustainable Development Goals in order to provide guidance on how to make the world more sustainable within the future. Within these goals the demand to:

- Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

as well as the goal to

- make cities and human settlements inclusive, safe, resilient and sustainables explicitly addressed.

Furthermore, world leaders recognized unanimously that transportation and mobility and consequently the supply of people and areas are central to sustainable development. Hence robust and resilient supply networks are a significant factor for the better integration of the economy while respecting the environment. improving social equity, health, and especially ensuring the resilience of cities, urban-rural linkages and productivity of rural areas.
The lecture will explain how supply networks can be assessed and improved in terms of their resilience. Hence students will learn:

- How to discretize and model supply networks
- How to understand and apply graph theory methods for resilience analysis to supply networks
- How to understand fundamentals of fundamentals and of agent-based modelling methods for resilience analysis to supply networks
- How to calculate resilience curves based on network simulation

Inhalte Übung / *Content of the exercises*

Students will gain practical experience in modelling, analyzing and simulating various examples of critical infrastructures.
Parts of the exercises will be analytical assessments, covering general aspects of supply networks and graph theory. Additionally, models will be implemented in programming exercises during practical sessions. For the programming exercises open-source programming languages will be introduced and applied (python, R, QGIS) - no programming background is needed.

The exercise will be conducted by Dr. Mirjam Fehling-Kaschek.

Zu erbringende Prüfungsleistung / *Graded assessment*

- Project presentation in front of the group, at the end of the exercises, duration: max. 30 min.; 50 %
- Final oral examination (one-on-one) at the end of the semester, duration: 30–40 min. per student; 50 %

The duration is just an approximate and will be provided during the lectures.

Zu erbringende Studienleistung / *Pass/fail assessment*

None

Literatur / *Literature*

Information will be given during the lecture.

Modul / *Module*
RF- and Microwave Circuits and Systems

Nummer *Number*	11LE50MO-5232		
Modulverantwortlicher *Responsible person*	Prof. Dr. Rüdiger Quay	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 h	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 h (30 hours attendance + 60 hours self-study)		

Lernziele / *Learning objectives*

The students will be enabled to understand concepts, functioning, and design of modern complex RF-andmicrowave circuits and systems. This includes the understanding of basic RF-concepts, of more complexpassive and active circuits, of modern antennas, of combined functionalities, data acquisition, and aspectsof systems and communication theory. The students will be competent to analyse passive and active RF-structures and circuits, full RF-functions, analyze complex signal and data flows, and full system conceptsand data acquisition. System concepts for communication, such as for a full transmit-receive system, forremote sensing including imaging and radar, are presented and several examples discussed in detail.

Inhalte Vorlesung / *Content of the lecture*

The lecture RF- and Microwave circuits and systems deals with the fundamentals and concepts of RF-cirand systems. It comprises three parts: fundamental RF-concepts with focus on communications andsensing, more complex RF-circuits, and actual RFsystems. At the interface of modern electronics, wavepropagation, circuit design, and advanced communication and sensing, advanced analysis and characterisation techniques are introduced in order to bridge the gap from modern integrated circuits to the understanding of RF-communication and sensing systems with all aspects of frequency conversion, amplification,noise, distortion, and detection. The methodologies of RF-analysis, design of circuits, complex signal flows,their modelling and their characterisation are introduced along with the demonstration of their relevance toreal RF-components and (micro)-systems. Typical

applications include a mobile handset such as the SmartPhone, automotive radar, and wireless data communication links for high-data-rate transmission.

Zu erbringende Prüfungsleistung / *Graded assessment*
Oral examination, duration: 30 min.

Zu erbringende Studienleistung / *Pass/fail assessment*
None

Literatur / *Literature*
RF- and Microwave passives • Zinke/Brunswig, Hochfrequenztechnik, Band 1, Springer, 1999 Further literature for systems are presented during the lecture.

Modul / *Module*
RF- and Microwave Design Course

Nummer *Number*	11LE68MO-5344		
Modulverantwortlicher *Responsible person*	Prof. Dr. Rüdiger Quay	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen: *Mandatory requirements*	The prior or parallel participation in either module *RF- and Microwave Devices and Circuits* or *RF- and Microwave Circuits and Systems* is required.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 h	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 h (26 hours full-time attendance + 64 hours self-study)		

Lernziele / *Learning objectives*

The students will be enabled to understand, design and layout modern RF- and microwave componentsand systems by means of the electronic design environment Agilent Advanced Design System includingthe two- and three dimensional electromagnetic simulators Momentum and EMPro 3D. The detailed use ofa complex RF-software environment is a dedicated target of this course. This includes the numerical analysis of complex passive and active devices, the design and layout of hybrid and integrated circuits, andtheir packaging and signal flow. The students will be competent to design and layout passive and active RF-structures including packages and interconnects and circuits of relevance to everydays communication andsensing. The competence includes in-depth understanding and treatment of complex microwave systemsand of general system design including the treatment of complex modulated signal flows.

Inhalte Vorlesung / *Content of the lecture*

The Design Course: RF- and Microwave Systems deals with the analysis and creation of RF-devices, circuits and systems. It comprises three aspects: the detailed electromagnetic design of high-frequency/RFpassive and active structures, the modelling and layout and verification of active electronic RF-devices incircuit environments based on various semiconductor

technologies, and the high-level combination of morecomplex microwave systems. This includes the simulation of printed circuit boards, of integrated circuits andof devices in package including RF-interconnects, and of behavioural system simulation. Advanced analysisof RF-problems, characterisation, modelling and linear and nonlinear simulation techniques are introducedin order to combine knowledge from modern electronics (from various technologies such as silicon complementary MOS and GaAs), from component analysis, RF-circuit design principles, and system engineering.The examples include simple printed circuits boards, integrated circuits, advanced communication transceivers in mobile communication based on UMTS and LTE and modern radar.

Zu erbringende Prüfungsleistung / *Graded assessment*
The grade is calculated based on the average of the submitted exercises (5 out of 6). There is no exam. Die Note ergibt sich aus dem Durchschnitt der Abgaben (5 von 6). Es gibt keine Prüfung.

Zu erbringende Studienleistung / *Pass/fail assessment*
None

Literatur / *Literature*
• Keysight Design System User Manual www.keysight.com • Script: Design Course: RF- and Microwave Systems, R. Quay, (will be provided at the beginning of the lecture)

Modul / *Module*
RF- and Microwave Devices and Circuits

Nummer *Number*	11LE68MO-5215		
Modulverantwortlicher *Responsible person*	Prof. Dr. Rüdiger Quay	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 h	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 h (26 hours attendance + 64 hours self-study)		

Lernziele / *Learning objectives*

The students will be enabled to understand concepts, devices, design, and functioning of modern RF- andmicrowave transceiver subsystems. This includes the understanding of basic RF-concepts, passive andactive devices, circuits, functionalities, their critical figures-of-merrit, and the inclusion into modules. Thestudents will be competent to analyse passive and active RF-structures and circuits, which are relevant forany system with an RF-functionality. The competence includes the full understanding of a transmit/receivemodule needed for today's communcation and sensing.

Inhalte Vorlesung / *Content of the lecture*

The lecture RF- and Microwave Devices and Circuits deals with the fundamentals of RF-devices and circuits. It comprises three parts: high-frequency/RF concepts and passive structures, active electronic RF-devices, and RF-circuits and modules. At the interface of modern electronics, dielectric wave propagation,circuit design, and advanced communication and sensing, advanced analysis and characterisation techniques are introduced in order to bridge the gap from modern electronics and modern passive RF-technologyto the understanding of RF-communication and sensing systems. The methodologies of RF-analysis, designof devices and circuits, and their basic figures-of-merit, their modelling and characterisation are introducedalong with the demonstration of their relevance to modern RF-components and microsystems. This alsoincludes a discussion of the underlying technology and many examples supported by RF-design tools fromthe microwave oven to today's RF-applications in mobile communication in the iPod.

Zu erbringende Prüfungsleistung / *Graded assessment*
Oral examination, duration: 30 min.

Zu erbringende Studienleistung / *Pass/fail assessment*
None

Literatur / *Literature*
RF- and Microwave passives • Zinke/Brunswig, Hochfrequenztechnik, Band 1, Springer, 1999 RF-Devices • U.K. Mishra, J. Singh, Semiconductor Device Physics And Design, Springer, 2007

Modul / *Module*
Security and Privacy in Resilient Systems

Important: Due to the vacant chair, the module cannot be offered in summer term 2021!

Nummer *Number*	11LE68MO-9030		
Modulverantwortlicher *Responsible person*	tbd	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Students will need a Laptop with Microphone and ideally camera.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lectures + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	150 hours (56 hours full-time attendance course of study + 94 hours self-study)		

Lernziele / *Learning objectives*

Students should learn the basics of cryptology and their application in cryptographic protocols. Students will get to know current cyber security threats, countermeasures and their limitations. Furthermore, the issue of privacy protection in light of EU GDPR is discussed, also in its relation to security strategies, the goals of which are sometimes in opposition with privacy protection. The limits of technical concepts and models which enable privacy protection and how they differ from the security viewpoint will be reviewed. The lecture will handle security vs. privacy as well as the application of privacy enhancing and transparency enhancing techniques. Additionally the "right to be forgotten" will be discussed.

Inhalte Vorlesung / *Content of the lecture*

Topics discussed are:

- Basics of cryptology
- Current threats
- Security measures
- Privacy vs. security
- Privacy and transparency enhancing mechanisms
- Privacy engineering & assessment
- Security in the context of business processes and in complex systems

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination, exercises and volunteer presentations

Literatur / *Literature*
• Stallings, W. “Cryptography and Network Security: Principles and Practice”, 7th edition, Pearson, 2016. • Bishop, M. “Computer Security: Art and Science”, 2nd edition, Addison Wesley, 2017. • Troncoso, C., Danezis, G., Isaakidis, M., and Halpin, H. “Systematizing Decentralization and Privacy: Lessons from 15 years of research and deployments”, PoPETs 2017 (4):307–329, 2017. Available online: https://petsymposium.org/2017/papers/issue4/paper87-2017-4-source.pdf. • Wicker, S. “Cellular Convergence and the Death of Privacy”, Oxford University Press, 2013. • Schneier, B. “Click Here to Kill Everybody: Security and Survival in a Hyper-connected World”, Norton & Company, 2018. • Cavoukian, A. “Privacy by Design in Law, Policy and Practics”, Information and Privacy Commission Canada, 2011. Available online: http://www.ontla.on.ca/library/repository/mon/25008/312239.pdf.

Modul / *Module*
Structural Robustness: Resilient Designs

Nummer *Number*	11LE68MO-4109		
Modulverantwortlicher *Responsible person*	Dr. A. Stolz	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module Type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	SSE Modul Fundamentals of resilience SSE Modul Design of large urban infrastructures		

Empfohlenes Fachsemester:: *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS: *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand: *Workload*	90 hours (32 Full-time attendance course of study + 58 Self-study)		

Lernziele / *Learning objectives*
Es besteht ein starkes Bedürfnis, die Menschen, die gesellschaftliche Gemeinschaft und kritische Infrastrukturen und Versorger vor schädigenden Naturereignissen oder von Menschen herbeigeführten außergewöhnlichen Ereignissen zu schützen. Lösungen müssen abgeleitet werden, um eine ausreichende Robustheit und Resilienz der städtischen Infrastruktur für diese außergewöhnlichen Ereignisse mit minimaler Wirkung auf die Normalität zu realisieren. Bisher berücksichtigen normale Regularien und Baurichtlinien diese außergewöhnlichen Ereignisse nicht im Detail. Das erforderliche Fachwissen steht aber zur Verfügung. Daher sollten die Grundlagen dieses Wissens, welche erforderlich sind um Lösungen abzuleiten, in diesem Kurs beleuchtet werden. There is strong need to protect people, the societal community and critical infrastructures and utilities against being damaged, destroyed or disrupted by natural disasters or deliberate acts of terrorism. Solutions have to be derived to realize sufficient resilience of the urban infrastructure for rare occasions with minimum effect on normality. Hitherto, normal regulations and building guidelines do not take into account such extraordinary events in detail. But the required specialist knowledge is available. Hence the basics of this knowledge to derive the required solutions will be explored within this course.

Inhalte Vorlesung / *Content of the lecture*
Vorlesung und Übung

Im Detail sollen die Studierenden folgendes lernen:
• Ingenieurverfahren zur Grenztragfähigkeit von Strukturen
• Druck-Impulsdiagramme zur Schadensbewertung
• Schädigungsmodelle
• Grundlagen der Verwendung numerischer Simulation zur Schadensbewertung
• Überblick numerische Methoden
• Beispiele zum Einsatz numerischer Simulation, Anwendung der Verfahren auf vorhandene Bausubstanz
• Redundanzen, Resttragfähigkeit
• Verfahren und Methoden zur Risikominderung durch Schutzmaßnahmen
• Umsetzungsbeispiele zu Schutzmaßnahmen
• Retrofit: Konzepte, Planungsdesign

Lecture and exercise

In detail students will learn about
- Engineering methods for the assessment of the ultimate bearing capacity of structures
- Pressure-Impulse diagrams for the damage assessment
- Damage models in general
- Fundamentals of numerical simulations for damage assessment
- Overview of numerical methods
- Use cases of numerical Simulations on build infrastructures
- Redundancy and Residual bearing capacity
- Processes and methods for risk reductions
- Examples for effective countermeasures
- Retrofit: Concepts and plan design

Zu erbringende Prüfungsleistung / *Course-based assessment*
Schriftliche Prüfungsleistung / written examination; Referat, Vortrag / presentation

Literatur / *Literature*
tba

Modul / *Module*
The science of complex systems - fundamentals and applications

Nummer *Number*	11LE68MO-5560		
Modulverantwortlicher *Responsible person*	Dr. Mirko Schäfer	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	• Basic knowledge of the programming language Python • Basic knowledge of matrix and probability theory and differential equations		

Empfohlenes Fachsemester *Recommended term of study*	4	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180h (in class + preparation of classes)		

Lernziele / *Learning objectives*

After the completion of the course the student is expected to be able to
- identify and explain characteristic properties of complex systems
- discuss problems occuring in different fields (technical, societal, economic, etc.) from an interdisciplinary complex systems perspective
- describe and compare various concepts and models from the science of complex systems
- implement and analyse mathematical complex systems models in the programming language Python

Inhalte Vorlesung / *Content of the lecture*

Theory:
- Fundamentals of complex networks theory
- Bifurcations and chaos in dynamical systems
- Collective phenomena and swarm intelligence

- Fundamentals of game theory
- Agent-based modelling

Applications:
- Market models
- Economics of climate change
- Complexity theory and financial regulation
- The structure and dynamics of cities

Zu erbringende Prüfungsleistung / *Course-based assessment*
None (because interdisciplinary profile)

Zu erbringende Studienleistung / *Coursework*
Written supervised exam **and** exercises

Literatur / *Literature*

- Claudius Gros, "Complex and Adaptive Dynamical Systems, Fourth Edition" (Springer, 2015)
- David Easley, Jon Kleinberg, "Networks, Crowds and Markets" (Cambridge University Press, 2010)

Further literature will be announced in class

13th Edition, as of Febuary 10, 2021
Slightly updated version 13.1, as of April 16, 2021

Publisher:

Issued by:
The Dean of Academic Affairs,
Sustainable Systems Engineering
Faculty of Engineering
INATECH – Institut für Nachhaltige Technische Systeme
Emmy-Noether-Strasse 2
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Editor of 13th and updated version: Ellen Schmidt (maternity leave replacement of Eva Hein)
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