INSTITUT FÜR NACHHALTIGE TECHNISCHE SYSTEME

M.Sc.
Sustainable Systems Engineering

Module Handbook

Subject-specific Examination Regulations 2021
Last edit on 30.03.2023

Institut für Nachhaltige Technische Systeme (INATECH)
Faculty of Engineering

universität freiburg

Content

The Master's Program

Overview

University	University of Freiburg (Albert-Ludwigs-Universität Freiburg)
Faculty	Faculty of Engineering
Institute	Department of Sustainable Systems Engineering (Institut für Nachhaltige Technische Systeme, INATECH)
Subject	Sustainable Systems Engineering (SSE)
Degree	Master of Science (M.Sc.)
Duration	4 semesters / 2 years, standard duration of studies
Type/Format	Consecutive, full-time studies on campus
ECTS	120 ECTS credits
Language(s)	English (no German skills necessary; however, a couple of elective modules can be offered in German)
Profile	The Master of Science program SSE, with its international diversity among the student body, is research-oriented and consecutive. It is designed for highly qualified graduate students holding a bachelor's degree in engineering or science. The English-taught master's program provides in-depth engineering skills in *Energy Systems Engineering, Resilience Engineering* and *Sustainable Materials Engineering*. Depending on the individual focus, students can acquire and deepen specific knowledge in these technical concentration areas. Complementing interdisciplinary knowledge in natural resources and climate change, sustainable economy, technology and society is also taught during the two-year-program.
Educational Goals/Professional Prospects	M.Sc. 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), • live in one of Germany's most appealing and green cities.

	Students are enabled to research, develop and apply sustainable systems engineering related solutions as well as consider and actively include aspects of sustainable development in their later engineering activities – for example in the areas of conventional and renewable energies, communication and semiconductor technologies or material development and testing. The program is designed to prepare graduates for a further academic career in research and development as well as for an engineering career in the industry, in particular with infrastructure operators for supply, mobility and energy, with engineering offices for urban and infrastructure planning or with state authorities.
Admission Requirements	• A bachelor's degree in engineering or science with a total of 180 ECTS and at least three years of duration • A minimum average grade of 2.5 on the German grading scale • At least 120 ETCS of the bachelor's degree must be in these three fields: 1. Mathematics and Informatics, 2. Chemistry and Physics, 3. Engineering, and in each of these fields at least 30 ETCS • Advanced English language skills at the level of B2 on the CEFR (Common European Framework of Reference for Languages)
Intake	Winter semester (no summer semester intake possible)
Further information	www.inatech.uni-freiburg.de

Department / 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 of Freiburg with an engineering research facility for research in sustainability. The three department of Microsystems Engineering (IMTEK), Computer Science (IIF) and INATECH form the Faculty of Engineering.

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

- *Energy Systems Engineering* – which can provide a reliable and efficient supply and storage of renewable energies.
- *Resilience Engineering* – which can secure the robustness and adaptability of systems toward environmental disasters and climate change.
- *Sustainable Materials Engineering* – which can provide the production and application of materials in an energy and resource friendly way.

Chairs at INATECH

Gips-Schüle Chair for Power Electronics / *Gips-Schüle Professur für Power Electronics (PEL)*	Prof. Dr. Dr. Oliver Ambacher
Walter-and-Ingeborg-Herrmann-Chair for Power Ultrasonics and Engineering of Functional Materials / *Walter-und-Ingeborg-Herrmann-Professur für Leistungsultraschall und Technische Funktionswerkstoffe (EFM)*	Prof. Dr.-Ing. Frank Balle
Eva-Mayr-Stihl Chair for Multi-Scale Characterization of Materials Systems / *Eva-Mayr-Stihl-Professur für Skalenübergreifende Materialcharakterisierung (CMC)*	Prof. Dr. Oana-Eugenia Cojocaru-Miredin
Chair for Photovoltaic Energy Conversion / *Professur für Photovoltaic Energy Conversion (PEC)*	Prof. Dr. Stefan Glunz
Chair for Solar Energy Systems / *Professur für Solar Energy Systems (SES)*	Prof. Dr. Hans-Martin Henning
Gips-Schüle Chair for Sustainable Systems Engineering / *Gips-Schüle-Professur für Sustainable Systems Engineering (SSE)*	Prof. Dr.-Ing. habil. Stefan Hiermaier

Fritz-Hüttinger Chair for Energy-Efficient High-Frequency Electronics / *Fritz-Hüttinger-Professur für Energieeffiziente Hochfrequenzelektronik (EEH)*	Prof. Dr. Rüdiger Quay
Chair for Monitoring of Large-Scale Structures / *Professur für Monitoring of Large-Scale Structures (MLS)*	Prof. Dr. Alexander Reiterer
Chair for Resilience Engineering for Technical Systems / *Professur für Resilienz Technischer Systeme (RTS)*	Prof. Dr. Alexander Stolz
Chair for Control and Integration of Grids / *Professur für Technologien der Energieverteilung (CIG)*	Prof. Dr. Anke Weidlich

Profile and Qualification Goals

Science and engineering are basic tools to achieve a sustainable development in domains like ecology, economics and society. The master's program *Sustainable Systems Engineering* (*SSE*) enables students to not just talk about sustainability, but actively contribute to how the materials, energy systems, and technologies of the future are developed. *SSE* is an interdisciplinary program that builds on fundamental knowledge in electrical and mechanical engineering as well as natural and material sciences. The program is designed on the basis of three Technical Concentration Areas (*Energy Systems Engineering, Resilience Engineering and Sustainable Materials Engineering*). Since there are no mandatory courses in the first semester, students can start concentrating on their favourite spezialisation area and research field from the beginning of their studies. In addition to an engineering's point of view of sustainability, interdisciplinary modules enhance the holistic understanding of sustainability.

The master's program *Sustainable Systems Engineering* consists of 120 ECTS credits. Further information are outlined in detail on the subsequent pages.

Technical qualification goals

Students

- are able to analyze technical questions and to develop, design, test, optimize and manufacture sustainable systems
- acquire an overview of the most important models, processes and methods of technologies for realizing sustainable systems and are able to select, apply and combine the processes and methods that are suitable for a given problem
- learn strategies for identifying and evaluating new applications of sustainable systems
- are able to prepare, plan, carry out and document experiments independently
- have an applicable overview of the most common techniques and measures used in practice as well as their extensions and new methods
- acquire in-depth knowledge in a special field of sustainable system engineering in the area of specialization they have chosen

General qualification goals

Students

- are able to draw up a laboratory diary, write scientific reports, give a scientific lecture and create a scientific poster
- can work on a given technical question largely independently and document the result in a scientific paper
- are able to team up in project groups, which can be made up of students from different master's courses in the specialization modules, to promote social and intercultural competences

Examination Regulations and Module Handbook

The content and organization of studies are defined in the respective **Subject-Specific Examination Regulations** (*Prüfungsordnung*, PO) for each program and the **General Examination Regulations** (*Rahmenordnung*). The latter provide the overarching regulatory framework of a certain degree, in our case all Master of Science programs at the University of Freiburg. You can find a German and English version on our website. The German version is the official version. The English version serves as a courtesy translation.

This Module Handbook has been compiled according to the **Subject-Specific Examination Regulations 2021** for the Master of Science *Sustainable Systems Engineering*. They define all the formal and legal aspects of this specific study program. In the case of the M.Sc. SSE Examination Regulations 2021, the framework of the program is based on three **Technical Concentration Areas** (*Energy Systems Engineering, Resilience Engineering, Sustainable Materials Engineering*), which contain a range of elective modules, an **Interdisciplinary Profile** and a **Master's Section**. The term Technical Concentration Area is not used in the Subject-Specific Examination Regulations, instead the three areas (*Bereiche*) are mentioned separately. However, for better comprehension, we specify the three areas as the three Technical Concentration Areas in this Module Handbook. The subsequent pages will provide detailed information about all areas and how to achieve the M.Sc. SSE degree. Students can focus on their preferred technical concentration area from the beginnging of their studies and select several interdisciplinary modules to enhance their holistic societal and scientific understanding.

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. A course is the smallest unit described in this Module Handbook. There are different types of courses, including lectures, exercises, laboratory courses and seminars. This Module Handbook describes the modules that constitute the curriculum of the SSE program. Module descriptions clarify elements such as the title, the qualification goals, the recommended requirements, the course content, the name of the offering institution/professor, the type of assessment, and how many ECTS credits according to the *European Credit Transfer and Accumulation System* (short: ECTS) the student will earn when completing the module successfully. These credits define the associated workload for the student. One credit is equivalent to a workload of 30 hours. The recommended number of ECTS credits to be completed per term is 30 ECTS credits. The ECTS credits define the weighting of a module within the entire master's program and its impact on the final overall grade (similar to the Grade Point Average, GPA).

Students of the master's program must complete 120 ECTS credits to earn their degree. This usually requires four terms, i.e.two years. The entire Faculty of Engineering has switched to a uniform ECTS system. This means that students can earn either three,six or nine ECTS credits in any courses. This makes inter-faculty studies much easier.

It is possible that courses offered for the SSE program by INATECH are also open for other degree programs. These assigned and associated study programs are shown in **HISinOne**, the Campus Management System.

Teaching and Learning Methods

Lectures and the corresponding exercises make up the largest part of the modules and courses within the master's program.

All *Mandatory Elective Modules* offered within the three Technical Concentration Areas *Energy Systems Engineering, Resilience Engineering* and *Sustainable Materials Engineering* consist of both a lecture and an exercise. These modules are open to all M.Sc. SSE students, and partially to other study programs, thus reaching a participant number of approx. 50 students or more.

Within the *Elective Modules* offered within the *Further Selection* as well as the *Interdisciplinary Profile*, the knowledge transfer is carried out additionally in seminars, practical exercises, laboratory courses, or even lecture series as well as partially in integrated project work and excursions. These modules are oftentimes more interactive due to the limited and smaller group sizes of approx. 25 – 30 students. Laboratory courses, for instance, allow seats for ten or 20 students.

Within the scope of the *Master's Project* as well as the *Master's Thesis*, students work on an individual and independent research project. They learn to define and work independently on a research topic and scientific questions within a given timeframe. In this, they are supported by a supervisor or module responsible in the case of the Master's Project and by two official supervisors in the case of the Master's Thesis.

Assessment Types

Generally speaking, students can complete a module/course in two ways: with a *Prüfungsleistung* (PL) or *Studienleistung* (SL). Whether a course completes with a PL or SL is defined in the Subject-Specific Examination Regulations and further outlined in the framework and in the module descriptions on the subsequent pages.

A **Prüfungsleistung** (PL) is a graded assessment. These assessments and their grades count into the final overall grade. A definition can be found in §14 of the General Examination Regulations. Written Prüfungsleistungen are written supervised exams (*Klausuren*) and written reports (*schriftliche Ausarbeitungen*). Oral Prüfungsleistungen are oral exams (*Prüfungsgespräche*) and oral presentations. Practical Prüfungsleistungen consist of conducting experiments as well as developing software programs or demonstrators. The duration of the written and oral assessments and the length of reports (e.g. number of pages) are usually defined in the module descriptions. Details are also provided by the lecturers in the respective courses in a timely manner. Generally, written PL can have a duration of min. 60 minutes and max. 240 minutes. Oral PL can have a duration of min. ten minutes and max. 45 minutes.

A **Studienleistung** (SL) is a pass/fail assessment and must be passed only(min. 4.0 on a German grading scale). These assessments do not count into the final overall grade, even if they may be graded. A definition can be found in §13 of the General Examination Regulations. Studienleistungen are individual written, oral or practical assessments that need to be completed by students in conjunction with the module/course. They can take the form of regular attendance (85% – 100% mandatory attendance), completion of exercises or project work, written reports (e.g. protocols, posters), written exams, oral exams, oral presentations, conducting experiments, developing software programs or demonstrators.

Studienleistungen and Prüfungsleistungen can also be taken as online exams, in accordance with the current Subject-Specific Examination Regulations and General Examination Regulations of the University of Freiburg.

Regulations Regarding Attendance

Attendance is not mandatory in lectures. Seminars and practical exercises require regular attendance as part of the Studienleistung (pass/fail assessment) because it is essential for reaching the learning targets of these courses. Exercises may require regular attendance as well, in which case this fact will be stated in the description of the specific module.

Framework

Technical Concentration Areas

The master's program is structured on the basis of three **Technical Concentration Areas**: *Energy Systems Engineering, Resilience Engineering, and Sustainable Materials Engineering*. The following rules apply:

1. Within each of the three areas, a minimum of 18 and a maximum of 42 ECTS credits must be earned.
2. In each area, students must select and complete a minimum of two modules out of the **Mandatory Electives Modules** shown in the table and illustration on the next two pages and listed in the chapter below. In the case of *Energy Systems Engineering*, students select a minimum of two out of four modules, in the case of *Resilience Engineering*, students select a minimum of two out of three modules, in the case of *Sustainable Materials Engineering*, students select a minimum of two out of three modules. This rule ensures that students participate in sufficient "basic" modules of the program before participating in "specialized" modules that build upon these "basic" modules.
3. To complete the above-mentioned 18 ECTS credits per Technical Concentration Area, it is necessary to complete at least six ECTS credits more from either the other Mandatory Elective Modules or from modules of the so-called **Further Selection** which are assigned to the respective concentration area and listed in the chapter below. The term *Further Selection* was chosen to better differentiate between the ten Mandatory Elective Modules defined in the Examination Regulations 2021 and all other modules from which students can choose.

Due to their interdisciplinary content, a few modules are assigned to more than just one concentration area. In such cases, students can select in which concentration area the module should be credited. The modules are mainly offered by INATECH and other institutes of the Faculty of Engineering, as well as by other departments and faculties of the University of Freiburg.

All modules are to be completed with a Prüfungsleistung (PL, graded assessment, part of the final overall grade). Depending on the module, it is possible that some also require to complete a Studienleitstung (SL, pass/fail assessment). Details are defined in the module descriptions.

Interdisciplinary Profile (IP)

This area includes **Modules related to the Subject Area** of SSE and the **Module outside the Subject Area**, which will help enhance the students' holistic societal and scientific understanding. Within the **Interdisciplinary Profile**, students must complete a minimum of six and a maximum of 24 ECTS credits. Courses can be selected from the catalog on the subsequent pages. If students decide to take only one course of a minimum of six ECTS credits to complete the Interdisciplinary Profile, it does not matter whether it is a Module related to the Subject Area or a Module outside the Subject Area. However, it is not allowed to choose more than one Module outside the Subject Area, even if the modules together would have six ECTS credits or less. Language courses are not recognized within the M.Sc. SSE. However, students are welcome to take a course on a voluntary basis.

While the catalog is already quite extensive, students still have the option to select modules from the university wide course catalog. For details on how to submit a request, please read the chapter below.
All modules within the IP are completed with a Studienleistung (SL, pass/fail assessment).

In all areas together, the Technical Concentration Areas and the Interdisciplinary Profile, a maximum of 84 ECTS credits can be earned.

Master’s Section

The **Master’s Section** with a total of 36 ECTS credits includes two mandatory modules: The **Master’s Project** (6 ECTS credits) and the **Master’s Module** consisting of the master’s thesis and the defense (27 + 3 ECTS credits). The Master’s Project must be completed with a Studienleistung (SL, pass/fail assessment); the Master’s Module must be completed with a Prüfungsleistung (PL, graded assessment).

Framework shown in a table

Recommended Term	Cycle	Area and Module	Type of Module	PL/SL	SWS	ECTS
Energy Systems Engineering						**min. 18, max. 42***
Within this Technical Concentration Area, a minimum of 18 and a maximum of 42 ECTS credits need to be achieved. In addition to this, a minimum of two out of the four below-mentioned Mandatory Elective Modules need to be completed. Example: Students can choose two of the below-mentioned modules (= 12 ECTS) and at least 6 ECTS from the Further Selection catalog in this Module Handbook (= 18 ECTS); alternatively, students can choose three or even four of the below-mentioned modules (= 18/24 ECTS) and if wanted, additional modules from the Further Selection (up to an overall maximum of 42 ECTS).						
1	Winter term	Solar Energy	Mandatory Elective	SL+ PL	4	6
1	Winter term	Energy System Operations		PL	4	6
2	Summer term	Energy Efficient Power Electronics		PL	4	6
2	Summer term	Energy Storage		PL	4	6
Resilience Engineering						**min. 18, max. 42***
Within this Technical Concentration Area, a minimum of 18 and a maximum of 42 ECTS credits need to be achieved. In addition to this, a minimum of two out of the three below-mentioned Mandatory Elective Modules need to be completed. Example: Students can choose two of the below-mentioned modules (= 12 ECTS) and at least 6 ECTS from the Further Selection catalog in this Module Handbook (= 18 ECTS); alternatively, students can choose even all three below-mentioned modules (= 18 ECTS) and if wanted, additional modules from the Further Selection (up to an overall maximum of 42 ECTS).						
1	Winter term	Fundamentals of Resilience	Mandatory Elective	PL	4	6
2	Summer term	Design and Monitoring of Large Infrastructures		PL	4	6
2	Summer term	Dynamics of Materials: Material Characterization		PL	4	6
Sustainable Materials Engineering						**min. 18, max. 42***
Within this Technical Concentration Area, a minimum of 18 and a maximum of 42 ECTS credits need to be achieved. In addition to this, a minimum of two out of the three below mentioned Mandatory Elective Modules need to be completed. Example: Students can choose two of the below-mentioned modules (= 12 ECTS) and at least 6 ECTS from the Further Selection catalog in this Module Handbook (= 18 ECTS); alternatively, students can choose even all three below-mentioned modules (= 18 ECTS) and if wanted, additional modules from the Further Selection (up to an overall maximum of 42 ECTS).						
1	Winter term	Material Life Cycles	Mandatory Elective	PL	4	6
1	Winter term	Materials Selection for Sustainable Engineering		PL	4	6
2	Summer term	Computational Materials' Engineering		SL+PL	4	6
Interdisciplinary Profile						**min. 6, max 24***
Within the Interdisciplinary Profile, a minimum of 6 and a maximum of 24 ECTS points need to be achieved. All Modules related to the Subject Area within the Interdisciplinary Profile can be found within this Module Handbook. Within the Interdisciplinary Profile, a maximum of 6 ECTS points can be assigned to one Module outside the Subject Area. The respective list can also be found in the Module Handbook.						
1 – 3	Winter/ Summer term	Module(s) *related to the Subject Area*	Elective	SL		
1 – 3	Winter/ Summer term	Module *outside the Subject Area (Just one!)*		SL		max. 6
Master's Section						**36**
3	Winter/ Summer term	Master's Project	Mandatory	SL		6
4	Winter/ Summer term	Master's Module: Master's Thesis + Defense		PL		27 + 3

Abbreviations:
PL=*Prüfungsleistung*/graded assessment; SL= *Studienleistung*/pass/fail assessment; V=*Vorlesung*/lecture; Ü=*Übung*/exercise; S=*Seminar*/seminar; Pr=*Praktikum*/practical exercise; SWS=*Semesterwochenstunden*/hours per week per semester

***In all areas together – Technical Concentration Areas and the Interdisciplinary Profile – a maximum of 84 ECTS credits can be earned.**

Framework shown in an illustration

	Technical Concentration Areas*			
	Energy Systems Engineering (min. 18, max. 42 ECTS)	**Resilience Engineering** (min. 18, max. 42 ECTS)	**Sustainable Materials Engineering** (min. 18, max. 42 ECTS)	**Interdisciplinary Profile*** (min. 6, max. 24 ECTS)
Term/ Semester 1	**Mandatory Elective Modules** **(min. two out of four, min. 12 ECTS)** Solar Energy (Winter term) Energy System Operations (Winter term)	**Mandatory Elective Modules** **(min. two out of three, min. 12 ECTS)** Fundamentals of Resilience (Winter term)	**Mandatory Elective Modules** **(min. two out of three, min. 12 ECTS)** Material Life Cycles (Winter term) Materials Selection for Sustainable Engineering (Winter term)	**Module(s) <u>related</u> to the Subject Area** and/or **Module <u>outside</u> the Subject Area** **(max. one, max. 6 ECTS)**
Term/ Semester 2	Energy Efficient Power Electronics (Summer term) Energy Storage (Summer term) **Further Selection**	Design and Monitoring of Large Infrastructures (Summer term) Dynamics of Materials: Material Characterization (Summer term) **Further Selection**	Computational Materials' Engineering (Summer term) **Further Selection**	
Term/ Semster 3				
	Master's Project (6 ECTS)			
Term/ Semster 4	**Master's Thesis + Defense** (27 + 3 ECTS)			

***In all areas together –Technical Concentration Areas and the Interdisciplinary Profile – a maximum of 84 ECTS credits can be earned!**

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 master's program *Sustainable Systems Engineering* 120 ECTS credits are awarded. One ECTS credit equals on average 30 hours of workload. For more information, see the **Subject-Specific** and **General Examination Regulations.** They both set the legal framework for the studies. The available modules/courses are listed and described in detail in the **Module Handbook**.

Study Organization

Course Information and Registration

The **Course Catalog** (*Vorlesungsverzeichnis*) in **HISinOne,** the university's **Campus Management System** shows the offered courses and the corresponding modules for every semester. Additionally, the course catalog provides information on course registration/sign up procedures, important dates during the semester and the content of the respective courses. For an overview of all SSE relevant courses we strongly recommend using the **Study Planer** (*Studienplaner*) tool in HISinOne. For further information see the step-by-step guide for the registration/sign up process.

Courses offered by INATECH, IMTEK or IIF (all institutes at the Faculty of Engineering) are available for registration in HISinOne. Usually there is no limitation of seats in lectures, however, there are a few exceptions with limited capacity. For example, the *Photovoltaic Laboratory (PV Lab)* and *Energy System Modeling with Python* have limited seats available every semester, but such limitations might apply to 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 automated 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.

If a course is not offered by INATECH, it is the students' responsibility to look for further information about the course. Normally, all information about courses are in HISinOne or on the respective websites of the faculties offering the courses. The different faculties and departments may have different registration requirements, periods and procedures. It is important that you ensure that you will inform yourself in time and – if necessary – get in touch with the faculties and departments. Please note that some courses are not offered regularly.

Within the Interdisciplinary Profile, the University College Freiburg (UCF) offers courses regularly. SSE students register online through HISinOne. Courses can be found under *Liberal Arts and Sciences Wahlmodul I, II,* and *III*. There are limited seats available in UCF courses. UCF reserves the right to allocate seats.

For the Module outside the Subject Area within the Interdisciplinary Profile, every student is welcome to select further courses from the extensive course catalog offered by the University of Freiburg. However, before students register for new courses (i.e. courses not listed below), each course must be checked regarding its suitability for the M.Sc. SSE master's program. This is done by the dean of academic affairs. Students 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 by the semester start (April 1/October 1)! The necessary information includes: course number, name, content outline of the course, ECTS credits, required Prüfungsleistung, required Studienleistung, link to further information if available, name of offering institution, and/or contact person. Deadlines are strictly enforced! Please note that all incoming inquiries are collected throughout the semester and will be checked once per semester only before the lecture start. Registering first and/or participating in the course and asking for the recognition of the course later is considered inappropriate and will lead to non-recognition of the course. It is important that students also clarify independently in parallel whether they can participate or not. Please contact the respective professors or program coordinators of the course offering department directly.

Examination Registration

To take a Prüfungsleistung and/or Studienleistung, students must register the PL/SL through HISinOne within the registration periods. The deadlines for the registration (and de-registration) for exams, the modalities, and the actual exam periods are listed on the website of the Faculty of Engineering. Please note that courses from other faculties – this concerns those within the Interdisciplinary Profile – may have different registration rules and periods.

A few Mandatory/Elective Modules require both a PL and an SL. If this is the case, students must register for both. The completion of the SL is not a requirement for the registration and completion of the PL. The SL and PL can be completed independently from each other. However, from a practical and study-efficient perspective, it is highly recommended to complete both the SL and PL within the same semester, within the semester when the course is actually offered.

Repeat of Examinations

Prüfungsleistungen that are graded "not adequate" (5.0) or considered as failed can be repeated once. Additionally, a maximum of two failed Prüfungsleistungen can be repeated twice. For further information and the modalities for improving the grade see the Subject-Specific Examination Regulations. Studienleistungen can be repeated as many times as needed until they are passed.

Modules Descriptions

Overview of all Modules

By clicking on the page number given next to the module name, you will be directed to the module description. If it says IMTEK, IIF, or something else, you will find the module description online, in HISinOne.

Technical Concentration Areas

<u>Energy Systems Engineering</u>

Mandatory Electives Modules (min. 12 ECTS)

min. two out of four:

- Energy Efficient Power Electronics (p.43)
- Energy Storage (p.49)
- Energy System Operations (p.53)
- Solar Energy (p.120)

Further Selection (min. 6 ECTS)

- Characterization of Solar Cells: From Feedstock Quality to Final Cell Efficiency (p.23)
- Electrochemical Energy Applications (IMTEK, changing technical focus)
- Electrochemical Methods for Engineers (IMTEK)
- Energy Efficient Power Electronics (p.43)
- Energy in Buildings: Components and Systems for Energy Supply (p.45)
- Energy in Buildings: Energy Demand and Building Physics (p.47)
- Energy Storage (p.49)
- Energy System Modeling with Python (p.51)
- Energy System Operations (p.53)
- Forecasting for Energy Systems (p.60)
- From the Principles of Re-Design to New Products (p.62)
- Industrial Manufacturing and Application of Solar Cells and Modules (p.71)
- Methods of Material Characterization for Waste Management (p.90, INATECH/ Freiburger Materialforschungszentrum)
- Modellprädiktive Regelung für erneuerbare Energiesysteme / Model Predictive Control for Renewable Energy (IMTEK)
- Optimization for Energy Systems (p.96)
- Photovoltaic Laboratory (p.98)
- Power Electronics for E-Mobility (p.102)
- Power Electronics for Photovoltaics and Wind Energy (p.104)
- RF- and Microwave Circuits and Systems (p.112)
- RF- and Microwave Systems - Design Course (p.114)
- RF- and Microwave Devices and Circuits (p.116)
- Smart Grids (p.118)
- Solar Energy (p.120)
- Thermoelektrik und thermische Messtechnik (IMTEK)
- Wind Energy Systems (IMTEK)

Resilience Engineering

Mandatory Electives Modules (min. 12 ECTS)

min. two out of three:

- Design and Monitoring of Large Infrastructures (p.37)
- Dynamics of Materials: Material Characterization (p.39)
- Fundamentals of Resilience (p.69)

Further Selection (min. 6 ECTS)

- Bionic Sensors (IMTEK)
- Continuum Mechanics I with Exercises (p.33)
- Continuum Mechanics II with Exercises (p.35)
- Design and Monitoring of Large Infrastructures (p.37)
- Dynamics of Materials: Material Characterization (p.39)
- Functional Safety, Security and Sustainability: Active Resilience (p.65)
- Fundamentals of Resilience (p.69)
- Hardware Security and Trust (IIF)
- Laser Scanning for Mapping Large Structures (p.74)
- Machine Learning Approaches in Structural Mechanics (IMTEK)
- Mechanical Properties and Degradation Mechanisms (IMTEK)
- Optical Metrology for Quality Assurance in Sustainable Production (p.94)
- Physics of Failure (p.100)
- Quantification of Resilience (p.106)
- Reliability Engineering (IMTEK)
- Resilience of Supply Networks (p.110)
- Structural Robustness: Resilient Designs (p.122)

Sustainable Materials Engineering

Mandatory Electives Modules (min. 12 ECTS)

min. two out of three:

- Computational Materials' Engineering (CME) (p.31)
- Material Life Cycles (MLC) (p.85)
- Materials Selection for Sustainable Engineering (p.87)

Further Selection (min. 6 ECTS)

- Bioinspired Functional Materials (IMTEK)
- Bionic Sensors (IMTEK)
- Ceramic Materials for Microsystems (IMTEK)
- Composite Materials (p.29)
- Computational Materials' Engineering (CME) (p.31)
- Contact, Adhesion, Friction (IMTEK)
- Continuum Mechanics I with Exercises (p.33)
- Continuum Mechanics II with Exercises (p.35)
- Disposable Sensors (IMTEK)
- Electrochemical Energy Applications (IMTEK, changing technical focus)
- Electrochemical Methods for Engineers (IMTEK)
- Engineering of Functional Materials/Technische Funktionswerkstoffe (p.55)
- From the Principles of Re-Design to New Products (p.62)
- 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.71)
- Lightweight Design and Materials (p.76)
- Material Flow Analysis (p.82)
- Materials for Electronic Systems (IMTEK)
- Material Life Cycles (MLC) (p.85)
- Materials Selection for Sustainable Engineering (p.87)
- Mechanical Properties and Degradation Mechanisms (IMTEK)
- Methods of Material Analysis (IMTEK)
- Methods of Material Characterization for Waste Management (p.90, INATECH/Freiburger Materialforschungszentrum)
- Nanomaterials – Lecture (IMTEK)
- Optical Metrology for Quality Assurance in Sustainable Production (p.94)
- Physics of Failure (p.100)
- Surface Analysis (IMTEK)
- Surface Analysis Lab (IMTEK)

Interdisciplinary Profile (IP)

The following list shows various courses recognized for the *Interdisciplinary Profile* sorted by the faculties of the University of Freiburg.

IP – Modules related to the Subject Area

Faculty of Engineering

- Advanced Database and Information Systems (IIF)
- Advanced Microcontroller Laboratory (IMTEK)
- Artificial Intelligence Planning (IIF)
- BioMEMS (IMTEK)
- Climate Change: Impact, Key Technologies, and Policymaking (p.25)
- Compiler Construction (IIF)
- Complex Networks (p.27)
- Cyber-Physical Systems – Discrete Models (IIF)
- Cyber-Physical Systems – Program Verification (IIF)
- Distributed Systems (IIF)
- Energy and Digitalization (p.41)
- Finance, Climate Change, and the Global Energy Transition (p.58, Faculty of Economics and Behavioral Sciences/INATECH)
- Foundations of Artificial Intelligence (IIF)
- Functional Programming (IIF)
- High-Performance Computing: Fluid Mechanics 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)
- Model Thinking for Complex Systems (p.92)
- Modelling and System Identification (IMTEK)
- MST Design Lab (IMTEK)
- Nanotechnology (IMTEK)
- Network Algorithms (IIF)

- Neuroscience for Engineers (IMTEK)
- Numerical Optimal Control in Engineering – Project (IMTEK)
- Numerical Optimal Control in Science and Engineering (IMTEK)
- Practical Course on High-Through Put Data Analysis with Galaxy (IIF)
- Project Management for Engineers (IMTEK)
- Real-Time Operating Systems and Worst-Case Execution Times (IIF)
- Scientific Writing and Presentation (IMTEK)
- Sensors and Actuators Circuit Technology (IMTEK)
- Signal Processing (IMTEK)
- Statistical Pattern Recognition (IIF)
- Verification of Digital Circuits (IMTEK)
- Wireless Sensor Networks (IIF)

Faculty of Biology

- Ökologische Perspektiven einer nachhaltigen Entwicklung

Faculty of Environment and Natural Resources

- Atmosphäre und Hydrosphäre (formerly Klima und Wasser)
- Bioenergy
- Crystal Growth Methods II
- Ecosystem Management
- Epitaxy
- Hydropower
- Klimawandelanpassung in Ländern des globalen Südens
- Life Cycle Management
- 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 Faculty of Environment and Natural Resources/Chair of Industrial Ecology/Prof. S. Pauliuk)
- Umweltwahrnehmung und Umweltbildung

Faculty of Mathematics and Physics

- Laser-based Spectroscopy and Analytical Method
- Multi-junction Solar Cell Technology and Concentrator Photovoltaic
- Photovoltaic Energy Conversion
- Theory and Modeling of Materials

University College Freiburg

- Climate Change and Biodiversity
- Computational Modeling
- Ecology
- Energy Transitions and Policy
- Environment, Risks, and Us
- Environmental Chemistry
- Environmental Impacts: Measurement and Political Use
- Environmental Psychology
- Geographic Information Systems (GIS) Seminar

- Introduction to Earth and Environmental Sciences
- Knowledge for Change? Low-Carbon Transitions and Environmental Justice
- Natural Resource Policy and Environmental Governance Studies
- Resources and Sustainability

IP – Modules outside the Subject Area (One module, max. 6 ECTS)

Faculty of Economics and Behavioral Sciences

- Advanced Microeconomics I
- Basic Income and Social Justice (Seminar "SoCoLab")
- 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

- Environmental Statistics

University College Freiburg

- Advanced Statistics
- Basic Chemistry and Biochemistry
- Environmental Humanities
- Human Physiology
- Journalism: Natural Science, Social Science, and the Humanities
- Pedosphere to Lithosphere – Resources Beneath Our Feet
- Political Theory
- Quantitative Genomics: Genetics, Epigenetics and Bio-informatic analysis
- Sustainable Food Systems Transitions
- The Earth in the Universe
- The Ecological History and Nature of Human Nutrition

Master's Section

- Master's Module (p.78)
- Master's Project (p.80)

Module Descriptions in Alphabetical Order

MODULE
Characterization of Solar Cells: From Feedstock Quality to Final Cell Efficiency

NUMBER	11LE68MO-4104 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLES	Dr. Martin Schubert	**LECTURERS**	Dr. Martin Schubert
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture + seminar	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Module *Solar Energy*		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h seminar	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS

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.

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

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 realization 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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
Written supervised exam on the content of the lecture and seminar, duration: 120 min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
Oral presentation: approx. 15 min scientific presentation on topic related to lecture content. Regular attendance of the seminar according to §13 (2) of the General Examination Regulations for the Master of Science.

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.

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Climate Change: Impact, Key Technologies, and Policymaking

NUMBER	11LE68MO-5566 PO 2021	**INSTITUTION**	INATECH/IMTEK
MODULE RESPONSIBLE	Prof. Dr. Stefan Hiermaier	**LECTURERS**	Leonhard Probst, Miriam von Holst The lecturers are an interdisciplinary and experienced team from the University of Freiburg, Fraunhofer ISE, the Institute for Applied Ecology Freiburg and experienced scientists from external partners.
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture series	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	2	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Summer term
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

QUALIFICATION GOALS
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.

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 and Industrial Ecology
9. Policymaking II: Energy Policy I
10. Policymaking III: Energy Policy II
11. Finances I: Market Development for Negative Emissions
12. Finances II: Decarbonization of the Financial Market

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

None (because *Interdisciplinary Profile*)

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Written supervised examination, duration: 90 min.
The final exam at the end of the semester covers written comprehension questions related to the lecture (no calculations).

LITERATURE

Information will be given during the lectures.

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the *Interdisciplinary Profile – Modules related to the Subject Area*

MODULE
Complex Networks

NUMBER	11LE68MO-5559 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Dr. Mirko Schäfer	**LECTURER**	Dr. Mirko Schäfer
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with integrated exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic knowledge of matrix and probability theory. Basic knowledge of Python recommended.		
RECOMMENDED TERM	3	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	4 h	**TERM CYCLE**	Winter term
WORKLOAD	180 h (45 h attendance + 135 h self-study)		

QUALIFICATION GOALS

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

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 aspects of the electricity system (power flows, representation of the transmission grid in electricity markets, flow tracing and emission accounting,…)

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

None (because *Interdisciplinary Profile*)

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

The final written supervised exam is a graded *Studienleistung* at the end of the semester which covers the content of the lecture and exercises. Duration: 120 min.

LITERATURE

- A.L. Barabási, *Network Science*, available at networksciencebook.com
- M. Newman, *Networks: An Introduction*, Second Edition, Oxford University Press, 2018

Further literature will be announced in class.

USABILITY OF THE MODULE

Elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the *Interdisciplinary Profile – Modules related to the Subject Area*

MODULE
Composite Materials

NUMBER	11LE68MO-4209 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Prof. Dr. Stefan Hiermaier	**LECTURER**	Dr. Michael May
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Module *Physics of Failure* Module *Dynamics of Materials*		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 60 h self-study)		

QUALIFICATION GOALS

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.

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.

Prüfungsleistung (Graded Assessment)
Written supervised examination, duration: 90 min.

Studienleistung (Pass/Fail Assessment)
None

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

Usability of the Module

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Sustainable Materials Engineering*

MODULE
Computational Materials' Engineering (CME)

NUMBER	11LE68MO-8050 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Dr. Gianpietro Moras	**LECTURER**	Dr. Gianpietro Moras
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic knowledge in classical mechanics, analysis and vector calculus.		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS
Students will become familiar with the various methods of computational materials science: quantum-mechanical and classical molecular dynamics, semi-empirical interatomic potentials, coarse grained models, continuum models. Students will be able to set up simple molecular dynamics simulations to understand and design sustainable materials.

CONTENT OF THE LECTURE
The lecture introduces the basic concepts of computational materials science. 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 main method explored in the lecture will be molecular dynamics. The lecture will begin with a brief introduction of its quantum-mechanical fundamentals and will continue with an in-depth study of various technical aspects ranging from the integration of the equations of motion of atoms to the control of temperature and pressure. In the final part of the lecture, various classes of interatomic potentials for simulating materials with different types of chemical bonds will be explored. Throughout the lecture, theoretical aspects will be complemented by the discussion of case studies relevant to sustainability and, in particular, concerning the minimization of losses due to friction and wear.

Content of the Exercise
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.

Prüfungsleistung (Graded Assessment)
Written supervised exam, duration: 90 min.

Studienleistung (Pass/Fail Assessment)
Regular attendance of the exercise according to §13 (2) of the General Examination Regulations for the Master of Science. A molecular dynamics exercise will be carried out by each student towards the end of the tutorials and corrected by the lecturer.

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 • Martin H. Müser, Sergey V. Sukhomlinov, Lars Pastewka, Interatomic potentials: Achievements and challenges, Advances in Physics: X 8 (2023), https://doi.org/10.1080/23746149.2022.2093129

Usability of the Module
Mandatory elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Sustainable Materials Engineering*

MODULE
Continuum Mechanics I with Exercises

NUMBER	11LE68MO-4302 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Dr. Dirk Helm	**LECTURER**	Dr. Dirk Helm
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Advanced mathematics; engineering mechanics		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS
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.

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 structure 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.

CONTENT OF THE EXERCISE

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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
Oral examination (one-on-one, *Prüfungsgespräch*) with a max. duration of 45 min. The oral examination covers the content of the lecture and exercises.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
None

LITERATURE
M. Itskov, Tensor Algebra and Tensor Analysis for Engineers, Springer, 2013

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering* or *Sustainable Materials Engineering*

MODULE
Continuum Mechanics II with Exercises

NUMBER	11LE68MO-4304 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Dr. Dirk Helm	**LECTURER**	Dr. Dirk Helm
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Module *Continuum Mechanics I with Exercises*		
RECOMMENDED TERM	3	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Winter term
WORKLOAD	180 h (60 h attendance + 120 h self-study)		

QUALIFICATION GOALS

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.

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. linear-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

CONTENT OF THE EXERCISE

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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
Oral examination (one-on-one, *Prüfungsgespräch*) with a max. duration of 45 min. The oral examination covers the content of the lecture and exercises.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
None

LITERATURE
P. Haupt, Continuum Mechanics and Theory of Materials, Springer Verlag, 2002

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering* or *Sustainable Materials Engineering*

MODULE
Design and Monitoring of Large Infrastructures

NUMBER	11LE68MO-9020 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLES	Prof. Dr. Alexander Reiterer, Prof. Dr. Alexander Stolz	**LECTURERS**	Prof. Dr. Alexander Reiterer, Prof. Dr. Alexander Stolz
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS

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 interdependencies between systems also the amount of considerable threats in terms of natural hazards or manmade deliberated attacks rises.
In general, the network performance and reliability relies for a large portion on the robustness of the networks built infrastructure elements like windmills transformer station and 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 for the given infrastructure.
- 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

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

CONTENT OF THE EXERCISE

- 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

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised examination at the end of the semester covering both the content of the lecture (50%) and the content of the exercises (50%), duration: 90 min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

LITERATURE

Literature will be provided at the beginning of the lecture.

USABILITY OF THE MODULE

Mandatory elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering*

MODULE
Dynamics of Materials: Material Characterization

NUMBER	11LE68MO-5118 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Stefan Hiermaier	**LECTURER**	Prof. Dr. Stefan Hiermaier
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS

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.

CONTENT OF THE LECTURE

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

Content of the Exercise
Exercises will utilize freely available Finite-Element codes (currently: Ansys Student) to study specific applications of the theoretical knowledge established in the lectures. We will work through a series of applied examples demonstrating different material behaviour, e.g. reversible elastic or permanent plastic deformation. Different solution methods for quasi-static and time-dependent phenomena will be explored. The need for simulation as a tool to interpret experimental data will be demonstrated in case of elastic wave propagation for the Split-Hopkinon Bar Method. Students are expected to present solutions to exercises in front of the class.

Prüfungsleistung (Graded Assessment)
Written supervised exam on the content of the lecture and the exercise, duration: 90 min.

Studienleistung (Pass/Fail Assessment)
None

Literature
S. Hiermaier, "Structures under Crash and Impact", Springer, 2008

Usability of the Module
Mandatory elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering* Elective module for students of the study program • M.Sc. in Microsystems Engineering or Mikrosystemtechnik (PO 2021) in the concentration area *Materials and Fabrication* (= *Materialien und Herstellungsprozesse*)

MODULE
Energy and Digitalization

NUMBER	11LE68MO-5571 PO 2021	INSTITUTION	INATECH; external lecturer
MODULE RESPONSIBLE	Dr. Stephan Schnez	LECTURER	Dr. Stephan Schnez
TYPE	Elective Module	DURATION	1 term
FORMAT	Lecture	LANGUAGE	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic knowledge in thermodynamics, electro-dynamics, and solid-state/semiconductor physics are useful, however, not mandatory.		
RECOMMENDED TERM	2	ECTS CREDITS	3
SEMESTER WEEK HOURS	2 h lecture	TERM CYCLE	Summer term
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

QUALIFICATION GOALS
The students will be enabled to understand the trade-offs between computing resources and the consumption of energy. Classical computer concepts, alternative computer concepts, and their functioning will be analyzed with respect to their breakdown in energy consumption. This includes the understanding of basic concepts and principles of computing, processors, data transmission concepts, algorithms etc. Aspects of typical evolutions of technical developments are discussed, such as, Moore's law and related scaling laws. Based on these rather fundamental concepts, the students will acquire knowledge how these impact today's large-scale data centers and how this can be dealt with.

CONTENT OF THE LECTURE
The lecture "Energy and Digitization" deals with the fundamentals and concepts of digital information systems and how they use and dissipate energy. For this the fundamental scaling laws, e.g. Moore's Law, and their implications are reviewed, as well as the connection to thermodynamics (Landauer's Limit). Based on that, today's conventional computing structure and its limitations are discussed and alternatives, e.g. analog, optical, and quantum computing, are presented. The impact of software and, particularly, algorithms on runtime and energy consumption is shown with some examples. This part is concluded with an outlook on computation complexity theory. Then, the consequences of the massive buildup of data centers

is discussed, e.g. in the context of integration of data centers into an energy system for providing grid flexibility, but also feeding the waste heat into a district heating network. The lecture is concluded with an outlook on other aspects of relevance which cannot be discussed in more detail in the lecture, including the impact of behavioral aspects on the energy consumption of the digital infrastructure.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

None (because *Interdisciplinary Profile*)

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Oral examination, max. 30 minutes per student.
(In case of more than 15 students, it will be a written examination instead of an oral examination.)

LITERATURE

The lecture intends to be self-contained and is not based on a particular textbook. Materials will be provided during the lecture. One example with a focus on data centers is "Energy-Efficient Computing and Data Centers" by Luigi Brochard et al.

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the *Interdisciplinary Profile – Modules related to the Subject Area*

MODULE
Energy Efficient Power Electronics

NUMBER	11LE68MO-9010 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Oliver Ambacher, Prof. Dr. Rüdiger Quay	**LECTURERS**	Prof. Dr. Oliver Ambacher, Prof. Dr. Rüdiger Quay, Dr. Sönke Christian Rogalla
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic knowledge of electric and electronic circuits.		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS

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 converters 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.

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.

Content of the Exercise

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.

Prüfungsleistung (Graded Assessment)

Written supervised exam, duration: 120 min.
The final written exam covers the content of the lecture (70%) and exercise (30%).

Studienleistung (Pass/Fail Assessment)

None

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

Usability of the Module

Mandatory elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Energy in Buildings: Components and Systems for Energy Supply

NUMBER	11LE68MO-4113 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Hans-Martin Henning	**LECTURERS**	Prof. Dr. Hans-Martin Henning, Dr. Manuel Lämmle, Beatrice Rodenbücher
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture + practical exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Modules *Energy Storage*, *Solar Energy*, *Energy in Buildings: Energy Demand and Building Physics*		
RECOMMENDED TERM	3	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h practical exercise	**TERM CYCLE**	Winter term
WORKLOAD	180 h (60 h attendance + 120 h self-study incl. preparation)		

QUALIFICATION GOALS
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).

CONTENT OF THE LECTURE

Covered technologies:

- Burners, condensing boiler technology
- Combined heating and power (CHP) units for buildings
- Heat pumps: heat pump systems and operation principles
- 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 analyzed 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.

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).

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised exam, duration: 120 min.
The final exam covers both the content of the lecture and the practical exercises.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Exercise sheets have to be completed on a regular basis and 7 reports about the exercise sheets have to be handed in. These will be scored and awarded with points. A report counts as passed if 60% of points have been reached. The Studienleistung counts as passed if

- at least 6 out of 7 reports have been passed,
- the course has been attended regularly according to §13 (2) of the General Examination Regulations for the Master of Science.

LITERATURE

- Ursula Eicker: Solar Technologies for Buildings. Springer. ISBN-13: 978-0471486374
- Solar Cooling Handbook 3rd revised and enlarged Edition. By Hans-Martin Henning (Editor), Mario Motta (Editor), Daniel Mugnier (Editor). Ambra. ISBN-13: 978-3990434383

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Energy in Buildings: Energy Demand and Building Physics

NUMBER	11LE68MO-4112 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Hans-Martin Henning	**LECTURERS**	Prof. Dr. Hans-Martin Henning, Dr. Manuel Lämmle, Beatrice Rodenbücher
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture + practical exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Modules *Energy Storage* and *Solar Energy*		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h practical exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study incl. preparation)		

QUALIFICATION GOALS

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.

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

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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised exam, duration: 120 min.
The final exam covers both the content of the lecture and the practical exercises.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Students have to submit 3 exercises (calculations) and 3 reports about the conducted experiments. These will be scored and awarded with points. A report or an exercise counts as passed if 60% of points have been reached. The Studienleistung counts as passed if

- all 6 submissions have been passed,
- the course has been attended regularly according to §13 (2) of the General Examination Regulations for the Master of Science.

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

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Energy Storage

NUMBER	11LE68MO-8010 PO 2021	INSTITUTION	INATECH; external lecturer
MODULE RESPONSIBLE	Dr.-Ing. Peter Schossig	LECTURERS	Andreas Georg, Dr.-Ing. Peter Schossig, Dr. Tom Smolinka
TYPE	Mandatory Elective Module	DURATION	1 term
FORMAT	Lecture + exercise	LANGUAGE	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic understanding of Engineering Physics and Engineering Chemistry		
RECOMMENDED TERM	2	ECTS CREDITS	6
SEMESTER WEEK HOURS	3 h lecture + 1 h exercise	TERM CYCLE	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS

- 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

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. Mechanical (pumped hydro, CAES, fly wheels)
3. Electric (SuperCaps)

4. Electrochemical - Basics (Lead-acid, NiCd, NiMh, Lithium-ion, Sodium-ion, NaS /NaNiCl, Redox-flow)
5. 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)
6. 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
7. Thermal storage: 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

CONTENT OF THE EXERCISE

The lecture includes exercises to deepen the understanding of the lecture's content and to discuss further details.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised examination, duration: 120 min.
The final written exam at the end of the semester covers both the content of the lecture and exercise.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

LITERATURE

- T. Letcher: Storing Energy
- G. Pistoia: Lithium-Ion Batteries Advances and Applications
- 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

USABILITY OF THE MODULE

Mandatory elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Energy System Modeling with Python

NUMBER	11LE68MO-6002 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Anke Weidlich	**LECTURERS**	Ramiz Qussous, Tim Fürmann
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Computer lab + lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	Attendance during the first lecture is obligatory for those who want to keep their seat.		
RECOMMENDED REQUIREMENTS	Module *Energy System Operations*		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	4 h computer lab + integrated lecture	**TERM CYCLE**	Summer term; max. 20 participants
WORKLOAD	180 h (45 h attendance, 60 h preparation, 75 h project)		

QUALIFICATION GOALS

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

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)

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

- Practical assessment (development of software programs in Python): 25 %;
- Report (description of the research challenge addressed by the implemented model, including details on the chosen approach, data inputs used, output plots, result discussion and bibliography): 50 %
- Oral presentation (Students present their project in the class. The oral presentation includes answering questions by the lecturer and a discussion about the implementation): 25%

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Five modelling assignments have to be completed on a regular basis and the respective model script and report have to be handed in. These will be evaluated as sufficient or insufficient. If insufficient, students have a second attempt to complete the assignment. The *Studienleistung* counts as passed if all 5 assignments are evaluated as sufficient.

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)

USABILITY OF THE MODULE

Elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Energy System Operations

NUMBER	11LE68MO-8090 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Anke Weidlich	**LECTURER**	Prof. Dr. Anke Weidlich
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Fundamentals of Electrical Engineering or Engineering Physics		
RECOMMENDED TERM	1	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	3 h lecture + 1 h exercise	**TERM CYCLE**	Winter term
WORKLOAD	180 h (60 h attendance + 120 h self-study)		

QUALIFICATION GOALS

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.

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

Content of the Exercise
The lecture includes exercises to deepen the understanding of the lecture's content and to discuss further details.

Prüfungsleistung (Graded Assessment)
Written supervised examination, duration: 90 min.

Studienleistung (Pass/Fail Assessment)
None

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

Usability of the Module
Mandatory elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Engineering of Functional Materials/Technische Funktionswerkstoffe

NUMBER	11LE68MO-4222 PO 2021	INSTITUTION	INATECH
MODULE RESPONSIBLE	Prof. Dr.-Ing. Frank Balle	LECTURERS	Dr.-Ing. Michael Becker
TYPE	Elective Module	DURATION	1 term
FORMAT	Lecture + laboratory	LANGUAGE	German
MANDATORY REQUIREMENTS	Keine		
RECOMMENDED REQUIREMENTS	Grundlagenwissen im Bereich der Materialwissenschaft und Werkstoffkunde (Bachelor-Studium)		
RECOMMENDED TERM	2	ECTS CREDITS	6
SEMESTER WEEK HOURS	4 h	TERM CYCLE	Summer term; max. 20 participants
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS
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 kennen, incl. den Vor- und Nachteilen ausgewählter technischer Funktionswerkstoffe, und sind in der Lage Möglichkeiten zur gezielten Beeinflussung (multi-) funktionaler Werkstoffeigenschaften zu erläutern. Darüber hinaus 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.

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. Funktionsschichten hinsichtlich Korrosionsschutzes, Oxidationsschutzes und Verschleißschutzes, 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.

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 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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Mündliches Prüfungsgespräch über die Inhalte aus der Vorlesung und der praktischen Übung. Es sind keine Hilfsmittel zugelassen. Dauer: 30 Min. pro Student*in.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Regelmäßige Teilnahme an der praktischen Übung gemäß §13 (2) der Rahmenprüfungsordnung Master of Science und erfolgreiches Absolvieren der 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.

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 der Elektrotechnik, Carl Hanser Verlag, 2013
- E. Macherauch, W. Zoch: Praktikum in Werkstoffkunde, Springer Vieweg Verlag, 2014

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Sustainable Materials Engineering*

MODULE
Finance, Climate Change, and the Global Energy Transition

NUMBER	11LE68MO-5567 PO 2021	**INSTITUTION**	INATECH/Faculty of Economics and Behavioral Sciences
MODULE RESPONSIBLES	Dr. Mirko Schäfer; Prof. Dr. Eva Lütkebohmert- Holtz	**LECTURERS**	Dr. Mirko Schäfer; Prof. Dr. Eva Lütkebohmert- Holtz
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Seminar	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	3	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Irregular; max. 10 seats available for M.Sc. SSE students
WORKLOAD	180 h (30 h attendance + 150 h self-study)		

QUALIFICATION GOALS

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

CONTENT OF THE SEMINAR

- 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

Prüfungsleistung (Graded Assessment)
None (because *Interdisciplinary Profile*)

Studienleistung (Pass/Fail Assessment)
The graded *Studienleistung* consists of • Oral presentation (approx. 45 min): 60% • Written report (approx. 10 pages): 30% • Discussion of another students' presentation: 10%

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.

Literature
• „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 during the course.

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the *Interdisciplinary Profile – Modules related to the Subject Area*

MODULE
Forecasting for Energy Systems

NUMBER	11LE68MO-5575 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Anke Weidlich	**LECTURER**	Prof. Dr. Anke Weidlich
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with integrated exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	2	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Summer term
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

QUALIFICATION GOALS

The students understand the background of different forecasting methods and can carry out typical forecasting tasks in energy system modeling. Time series-based forecasts like decomposition, exponential smoothing or ARIMA modeling and regression techniques, such as multiple linear regression and machine learning-based approaches are equally covered. Students are experienced in implementing the discussed methods in a computer tool, and can interpret the results.

CONTENT OF THE LECTURE

- Naïve approaches & time series decomposition
- Statistical modeling (multiple linear regression, exponential smoothing, ARIMA & SARIMAX modeling)
- Machine learning algorithms (multi-layer perceptron, recurrent neural networks, LSTM, k-nearest neighbor regression, random forest regression, support vector regression)

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised exam, duration: 60 min.

Studienleistung (Pass/Fail Assessment)
None

Literature
• Hyndman, R. J. and G. Athanasopoulos: *Forecasting: principles and practice*, Online, Open-Access Textbooks Otexts, available under https://www.otexts.org/book/fpp3, 2021.

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
From the Principles of Re-Design to New Products

NUMBER	11LE68MO-5573 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Oana Cojocaru-Mirédin	**LECTURER**	Prof. Dr. Oana Cojocaru-Mirédin
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS

The objective of the module "From Principles of re-design to New products" is to teach the product development process starting from the atomistic phenomena and to present the huge diversity in product design available nowadays.

After this lecture the students will:

- explain the working principles of energy conversion and storage devices (batteries, solar cells, thermoelectrics etc)
- understand the importance of controlling the Nanostructuring down to the nanometer level,
- recognize the most important fundamental factors for the Re-Design of the Energy Materials,
- analyse and evaluate pros and cons for future viability of energy materials for provision, conversion and storage

CONTENT OF THE LECTURE

The module consists of lecture, practical exercise and lecture exercise focused on various examples of energy materials and systems.
Lecture chapters are:

- Introduction: Sustainable energy materials and systems
- Absorber Materials: from nanostructuring to novel solar cells
- Thermoelectrics by Design
- Battery Matterils: Seeing the Unseen
- Green Hydrogen

Content of the Exercise

The proposed exercises will be closely linked with the theoretical concepts proposed. Besides the classical numerical exercises crated to consolidate the knowledge in working principles of energy conversion and storage devices, very recent methods and concepts available in recent high-impact factor publications will be studied in details.

Prüfungsleistung (Graded Assessment)

Oral presentation, max. 30 minutes per student.
The oral presentation covers the content of the lecture and the exercise.

Studienleistung (Pass/Fail Assessment)

Exercise sheets have to be completed and handed in on a regular basis. These will be scored and awarded with points. The *Studienleistung* counts as passed if

- at least 55% of the overall number of achievable points for the semester has been reached,
- the course has been attended regularly according to §13 (2) of the General Examination Regulations for the Master of Science.

Literature

- M. Ashby, Materials and the Environment: Eco-informed Material Choice: Second Edition, 2012. https://doi.org/10.1016/C2010-0-66554-0.
- B. Dunn, H. Kamath, J.M. Tarascon: Electrical Energy Storage for the Grid: A Battery of Choices, Science (2011), 334 (6058), 928-935.
- P.C. Vesborg, T.F. Jaramillo: Addressing the Terawatt Challenge: Scalability in the Supply of Chemical Elements for Renewable Energy, RSC Adv. (2012), 2 (21), 7933-7947.
- A.C.H. Allwood, J. M. Cullen, J. M. Carruth, M. A. Cooper, D.R. McBrien, M. Milford, R.L. Moynihan, M.C. Patel, S. Bauer, Sustainable materials: With both eyes open, UIT Cambridge Ltd, Cambridge, England, 2012. https://doi.org/10.1016/s1369-7021(12)70169-4.
- D. Raabe, C.C. Tasan, E.A. Olivetti, Strategies for improving the sustainability of structural metals, Springer US, 2019. https://doi.org/10.1038/s41586-019-1702-5.
- J.-P. Birat, Sustainable Materials Science - Environmental Metallurgy, Volume 1: Origins, basics, resource and energy needs, In: Science des matériaux, EDP Sciences | 2020, DOI: https://doi.org/10.1051/978-2-7598-2443-4.

Usability of the Module

Elective module for students of the study program:

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering* or *Sustainable Materials Engineering*

MODULE
Functional Safety, Security and Sustainability: Active Resilience

NUMBER	11LE68MO-5120 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Dr. Ivo Häring	**LECTURER**	Dr. Ivo Häring
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with integrated exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	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 • Machine Learning/Artificial Intelligence (ML/AI) methods		
RECOMMENDED TERM	2	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Summer term
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

QUALIFICATION GOALS
Main learning targets include: 1. Know main (emerging) application domains, e.g. digitalized production, autonomous transport, aerospace, safety of self-learning systems, and renewable energy systems 2. Knowledge how to achieve acceptable overall safety (risk control), security, sustainability, and resilience of socio-technical (safety relevant and critical) systems through reliable functions 3. Knowledge and tailoring of definitions, types and effects of reliability functions 4. Relation of functional safety to related concepts for security and sustainability generation 5. Knowledge and tailoring of safety life cycle, development processes and process steps to plan, develop, verify and validate reliability or safety functions

6. Knowledge, tailoring, process-driven application, quantification and evaluation, executive conclusions development, and litigable documentation of mainly quantitative system analysis methods
7. Knowledge of required development methods and how to combine and tailor them for achieving functional safety
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 reliable functions, e.g. safety integrity level (on demand or continuous), hardware failure tolerance, diagnostic coverage, safe failure fraction, complexity level
10. Understanding of the role of Machine Learning (ML) and artificial intelligence (AI) approaches as part of considered systems or of the functional safety process and methods, and related emerging options
11. Knowledge of reliability prediction methods and related standards
12. Applicable knowledge of related standardization landscape

CONTENT OF THE LECTURE

Main content:

1. Definition of functional safety, safety functions, safety integrity level (SIL), safety related systems and related key quantities, e.g. hardware failure tolerance (HFT), complexity, diagnostic coverage (DC), safe failure fraction (SFF)
2. Relation and transfer of functional safety to reliability, availability, security, IT-security, sustainability, and resilience
3. Functional safety, security, sustainability and resilience life cycle models (management and development processes): general and phase-specific requirements
4. System definition and graphical/semi-formal modelling for system analysis, e.g. with UML and SysML
5. Inductive analytical tabular system analysis methods: e.g. hazard analyses (PHL, PHA, SSH, O and SHA, HAZOP), hazard log, failure mode and effects analysis (FMEA, FMEDCA), double failure matrix
6. (Deductive) Graphical system analysis methods: Fishbone diagram, Event Tree Analysis, Reliability block diagram (RBDs), Fault tree analysis (FTA, TDFTA)
7. Markov models and Petri nets
8. (Semi) Quantification and evaluation of system analysis methods, e.g. using risk priority numbers, parts count and parts stress, reliability prediction standards, Boolean algebra and importance measures for FTA, quantitative measures for graph-based methods, computation and simulation approaches for Markov and Petri models
9. Overview on methods for requirements determination, e.g. SIL: graphical, numerical, analytical, statistical, simulation based using individual and collective risk criteria
10. Safety and reliability function architecture allocation, e.g. MooN, MooND
11. Overview on techniques and measures for hardware and software to avoid and control systematic errors of hardware and software 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 generation, systems with ML/AI, e.g. autonomous driving
14. Use for ML/AI for safety assessment and development
15. Standardization landscape, e.g. functional safety standards IEC 61508, ISO 26262 and safety of intended functionality ISO/PAS 21448
16. Emerging standards, future risk control and resilience generation challenges, e.g. AI and superintelligence control

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
Written supervised exam, duration: 90 min. The exam covers both the content of the lecture and the embedded exercises

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
Presentation and critical review of selected publications or of chapter of the lecture manuscript (approx. 20 minutes including questions and answers).

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. Hazard analysis techniques for system safety, Clifton A. Ericson, Wiley, 2015
5. FRAM: the functional resonance analysis method, Erik Hollnagel, Ashgate, 2012
6. Synesis: The Unification of Productivity, Quality, Safety and Reliability, Erik Hollnagel, Ashgate, 2020
7. Control systems safety evaluation and reliability, William M. Gobe, 2010
8. System reliability theory: models, statistical methods and applications, Marvin Rausand, Arnljot Hoyland, Wiley-Interscience, 2004
9. Risk assessment: theory, methods, and application, Marvin Rausand, Wiley, 2011
10. Reliability of safety-critical systems: theory and applications, Marvin Rausand, Wiley, 2014
11. Risk and resilience: methods and application in environment, cyber and social domains, Eds.: Igor Linkov, Jose Manuel Palma-Oliviera, Springer, 2017
12. Functional safety for road vehicles: new challenges and solutions for e-mobility and automated driving, Hans-Leo Ross, Springer, 2016
13. Functional Safety of Machinery: Sample Questions and Solutions, Jagadeesh-Pandiyan, author’s edition, 2019
14. Functional safety in practice, Harvey T Dearden, CreateSpace Independent Publishing Platform, 2018
15. 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
16. 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
17. Reliability engineering: theory and practice, Alessandro Birolini, Springer, 2013
18. Electronic safety systems: hardware concepts, models, calculations, Josef Börcsök, Hüthig, 2004
19. Functional Safety: Basic Principles of Safety-related Systems, Josef Börcsök, Hüthig, 2020
20. Zuverlässigkeitstechnik, Arno Meyna and Bernhard Pauli, Hanser, 2010
21. The safety critical systems handbook, David J. Smith, Butterworth-Heinemann, 2010
22. Reliability and availability engineering: modeling, analysis, and applications, Kishor S. Trivedi, Andrea Bobbio, Cambridge University Press, 2017

23. Embedded Software Development for Safety-Critical Systems, Chris Hobbs, CRC Press, 2019
24. Dynamic Probabilistic Systems, Volume I: Markov Models, Ronand A. Howard, Dover publications, 2012
25. Dynamic Probabilistic Systems, Volume II: Semi-Markov and Decision Processes, Ronand A. Howard, Dover publications, 2013
26. Fault-Tolerant Systems, Israel Koren, C. Mani Krishna, Morgan Kaufmann Publisher, 2020
27. Semi-Markov Processes: Applications in System Reliability and Maintenance, Franciszek Grabski, Elesevier, 2014
28. Risk analysis and management: engineering resilience, Ivo Häring, Springer 2015
29. A Primer in Petri Net Design, Wolfgang Reisig, Springer, 1992
30. Ereignisdiskrete Systeme: Modellierung und Analyse dynamischer Systeme mit Automaten, Markovketten und Petrinetzen, Jan Lunze, De Gruyter, 2017
31. System Modeling and Control with Resource-Oriented Petri Nets, MengChu Zhou, Routledge, 2017
32. Formal Methods in Computer Science, Jiacun Wang, William Tepfenhart, Taylor & Francis, 2019
33. Technical Safety, Reliability and Resilience: Methods and Processes, I. Häring, Springer, 2021
34. From event to performance function-based resilience analysis and improvement processes for more sustainable systems, I. Häring, J. Schäfer, et al., International Journal of Sustainable Materials and Structural Systems, 5(1/2), 2021, pp.90 – 120
35. Functional safety assessment of distributed predictive heating and cooling systems for electric delivery vehicles, Y. Satsrisakul, I. Häring, et al., ESREL 2021

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
Recent publications: https://scholar.google.com/citations?user=luyHvrkAAAAJ&hl=en

Usability of the Module

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering*
- M.Sc. in Microsystems Engineering or Mikrosystemtechnik (PO 2021) in the concentration area *Materials and Fabrication* (= *Materialien und Herstellungsprozesse*)

Module
Fundamentals of Resilience

Number	11LE68MO-8020 PO 2021	**Institution**	INATECH
Module Responsible	Prof. Dr. Stefan Hiermaier	**Lecturer**	Prof. Dr. Stefan Hiermaier
Type	Mandatory Elective Module	**Duration**	1 term
Format	Lecture + exercise	**Language**	English
Mandatory Requirements	None		
Recommended Requirements	Basic understanding of Engineering Physics		
Recommended Term	1	**ECTS Credits**	6
Semester Week Hours	2 h lecture + 2 h exercise	**Term Cycle**	Winter term
Workload	180 h (60 h attendance + 120 h self-study)		

Qualification Goals

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.

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

CONTENT OF THE EXERCISE

In the exercises, students will apply some of the more abstract concepts taught in the lecture to a variety of specific problems. The exercises work to incorporate real world problems and extend the students' knowledge of resilience and its application. Students will work in small groups and cover topics that include a resilience analysis of the Fukushima disaster, a risk assessment of earthquakes in California utilizing real historical data, creating a stress strain curve from experimental data and assessing the overpressure of a historical World War 2 bomb found in Freiburg in 2016. After completion of the exercises, students will have a better understanding of how resilience can be applied through various lenses to improve critical infrastructure and society.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised exam, duration: 90 min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

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.

USABILITY OF THE MODULE

Mandatory elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering*

MODULE
Industrial Manufacturing and Application of Solar Cells and Modules

NUMBER	11LE68MO-4114 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Dr. Dirk Holger Neuhaus	**LECTURER**	Dr. Dirk Holger Neuhaus
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with integrated exercise	**LANGUAGE**	English or *German*
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic understanding of physics and chemistry Module *Solar Energy*		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 60 h self-study)		

QUALIFICATION GOALS

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 estimate or 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.

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 eingeschätzt oder berechnet werden. Der Student bekommt einen Überblick über weltweite Märkte und Produktionskapazitäten sowie neu aufkommende Märkte der integrierten Photovoltaik.

CONTENT OF THE LECTURE

- Global markets and production capacities / *Weltweite Märkte und Produktionskapazitäten*
- Manufacturing of crystalline silicon solar cells and solar modules with focus on state-of-the-art production processes, equipment and materials / *Herstellung von kristalline Silizium Solarzellen und Solarmodulen mit dem Fokus auf die heute dominierenden Prozesstechnologien, Anlagen und Materialien*
- Loss mechanisms in solar modules (optical gains, optical losses, module operation temperature, electrical losses) / *Verlustmechanismen in Solarmodulen (optische Gewinne, optische Verluste, Modultemperatur, elektrische Verluste)*
- Material and energy consumption required for the production of solar modules, total manufacturing cost as well as generated greenhouse gas emissions / *Material- und Energieverbrauch bei der Herstellung von Solarmodulen, Herstellungskosten sowie verursachte Treibhausgasemissionen*
- Technology trends / *Technologietrends*
- Module reliability and failure mechanisms, qualification and test procedures / *Modulzuverlässigkeit und Ausfallmechanismen, Qualifizierung, Testverfahren*
- Modelling of the solar energy yield considering the local solar insulation, the local ambient temperature as well as module and system parameters / *Berechnung des solaren Energieertrages unter Berücksichtigung der solaren Einstrahlung, der Umgebungstemperatur, Modul- und Systemeigenschaften*
- Calculation of the power generation cost of solar modules (LCOE) / *Berechnung der Stromgestehungskosten von Solarmodulen (LCOE)*
- Integrated photovoltaics, with solar cells integrated into constructional elements that carry additional functionalities (building-integrated photovoltaics, vehicle-integrated photovoltaics, …) / *Integrierte Photovoltaik, bei der Solarzellen in Bauteile integriert werden und zusätzliche Funktionen übernehmen (Gebäude-integrierte Photovoltaik, Vehikel-integrierte Photovoltaik, …)*

The lecture must be followed up in self-study. To deepen the content of the lecture, exercises are given that can be worked on individual aspects. The solution will be discussed in the lecture. A tour of Fraunhofer's module laboratory is offered. Here, a solar module is manufactured on modern production facilities.

Die Vorlesung muss im Selbststudium nachbereitet werden. Zur Vertiefung der Vorlesungsinhalte werden Übungsaufgaben ausgegeben, die zur Vertiefung einzelner Aspekte bearbeitet werden können. Die Lösung wird in der Vorlesung besprochen. Es wird eine Besichtigung eines Labors des Fraunhofer ISE angeboten. Hier wird gemeinsam auf modernen Produktionsanlagen ein Solarmodul hergestellt.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Supervised written examination, which covers the entire content of the lecture in form of short questions. Duration: 90 min.

Klausur (schriftliche Aufsichtsarbeit), die den gesamten Vorlesungsinhalt in Form von kurzen Fragen behandelt. Dauer: 90 Min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

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/ • *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 and Practice, University of New South Wales, Kensington 1995, ISBN 0-7334-0994-6 • Polysun Simulation Software, User Manual, Vela Solaris AG, Winterthur/Switzerland 2017, https://www.velasolaris.com

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering* or *Sustainable Materials Engineering*

MODULE
Laser Scanning for Mapping Large Structures

NUMBER	11LE68MO-4205 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Alexander Reiterer	**LECTURER**	Prof. Dr. Alexander Reiterer
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic understanding of optical measurement techniques; Basics of Optics and Physics		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 90 h self-study)		

QUALIFICATION GOALS

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.

CONTENT OF THE LECTURE

- 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)

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Oral examination/presentation, duration: approx. 30 min. The final oral examination at the end of the semester covers the content of the lecture

Studienleistung (Pass/Fail Assessment)
None

Literature
Literature will be provided at the beginning of the lecture.

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering*

Module
Lightweight Design and Materials

Number	11LE68MO-4221 PO 2021	**Institution**	INATECH
Module Responsible	Prof. Dr.-Ing. Frank Balle	**Lecturer**	Prof. Dr.-Ing. Frank Balle
Type	Elective Module	**Duration**	1 term
Format	Lecture	**Language**	English
Mandatory Requirements	None		
Recommended Requirements	B.Sc. Mechanical Engineering, Materials Science, Production Engineering, Materials Design		
Recommended Term	3	**ECTS Credits**	3
Semester Week Hours	2 h	**Term Cycle**	Winter term
Workload	90 h (30 h attendance + 60 h self-study incl. preparation)		

Qualification Goals

The students are able:

- 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

Content of the Lecture

- Basics and motivation of lightweight design by materials engineering

- Lightweight strategies and criteria for materials selection
- Light alloys: Aluminum, 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)

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Oral examination on the content of lecture, duration: 30 min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

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

USABILITY OF THE MODULE

Elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Sustainable Materials Engineering*

MODULE
Master's Module

NUMBER	11LE68MO-8700-672 PO 2021	INSTITUTION	INATECH
MODULE RESPONSIBLES	Prof. Dr. Anke Weidlich	LECTURER	Examiners of the Department of Sustainable Systems Engineering
TYPE	Mandatory Module	DURATION	1 term
FORMAT	Written thesis	LANGUAGE	English or *German*
MANDATORY REQUIREMENTS	Admission for the thesis can be granted once at least 72 ECTS credits have been acquired within the degree program.		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	4	ECTS CREDITS	Master's Thesis: 27 Defense: 3
SEMESTER WEEK HOURS		TERM CYCLE	Each term
WORKLOAD	900 h (self-study)		

QUALIFICATION GOALS
Students show with the master's 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. Students have proven their ability to apply methods and knowledge as well as research and development competencies in the project, the scientific documentation and the defense.

CONTENT
The master's module is an independent research project. It consists of a written documentation and a defense (oral presentation/colloquium) with discussion. The student works on a given topic for a given timeframe and has to deliver a scientific documentation.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
The module consists of a written documentation of the thesis and a defense of the results of the thesis (oral presentation/colloquium). The final module grade is made up of the grade of the

written thesis (27 ECTS = 90% of the grade) and the grade of the defense (3 ECTS = 10% of the grade).

Studienleistung (Pass/Fail Assessment)
None

Usability of the Module
Mandatory module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021)

MODULE
Master's Project

NUMBER	11LE68MO-7160 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Oliver Ambacher	**LECTURER**	Prof. Dr. Oliver Ambacher
TYPE	Mandatory Module	**DURATION**	1 term
FORMAT	Individual project with colloquium	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	3	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	4 h	**TERM CYCLE**	Each term
WORKLOAD	180 h (30 h attendance + 150 h self-study)		

QUALIFICATION GOALS

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

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's project in winter

term. However, they are allowed to also conduct it in summer term. Students, who conduct their master's project during the summer term, will present their results during the examinations phase.

Prüfungsleistung (Graded Assessment)
None

Studienleistung (Pass/Fail Assessment)
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's project exam (*Studienleistung*)!

Grading
The grading of the master's 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).

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

Usability of the Module
Mandatory module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021)

MODULE
Material Flow Analysis

NUMBER	11LE68MO-4224 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Stefan Hiermaier	**LECTURER**	Dr. Sebastian Kilchert
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with integrated exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Module *Material Life Cycles*		
RECOMMENDED TERM	2	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Summer term
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

QUALIFICATION GOALS

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

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, aluminum, 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.

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.

Prüfungsleistung (Graded Assessment)

The *Prüfungsleistung* is to be completed in the form of a written report. Each report is written by a group of 3–5 students. The report consists of a quantitative and qualitative part. The quantitative part counts for 40 %, the qualitative part counts for 60 % of the final grade of the *Prüfungsleistung*.

The quantitative part covers the following topics:

- Introductory exercise (same for all)
- System redefinition (same for all)
- Mathematical modelling incl. error propagation and sensitivity analysis
- Lifetime estimation.

A task is assigned to each topic.

The qualitative part is to be completed in the form of an essay with a scope of ~3000 words (excluding abstract and references). The essay is also to be created within the defined group of students. The essay consists of: Abstract, introduction, methods, results/discussion, conclusion, references.

Studienleistung (Pass/Fail Assessment)
None

Literature
Information will be given during the lecture.

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Sustainable Materials Engineering*

MODULE
Material Life Cycles (MLC)

NUMBER	11LE68MO-8030 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Stefan Hiermaier	**LECTURER**	Dr. Sebastian Kilchert
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Fundamental knowledge of Materials Science and Technology		
RECOMMENDED TERM	1	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Winter term
WORKLOAD	180 h (60 h attendance + 120 h self-study)		

QUALIFICATION GOALS

The aim of the lecture is to introduce a framework within which a student can form critical, independent assessments of "Sustainable Developments". With a focus on the adoption of industrial ecology methods to assess environmental impacts the students are introduced to the complexity inherent in discussions of sustainability and shows how to deal with it in a systematic way.
Within that context, the lecture addresses questions such as "How do we achieve sustainable development? How do we measure progress in achieving it? How can environmental impact be quantified? 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 different environmental aspects of a technological change.

CONTENT OF THE LECTURE

Starting from the key drivers for sustainable development the students are introduced to the concepts of life cycle thinking, the circular economy, and environmental management. The methodology of life cycle assessment (LCA) and its theory are explained and applied by means of simplified LCA and case studies (from science and industry). Within that scope relevant concepts and methods, such as the product Leontief Inverse, contribution analysis, multifunctionality and impact calculation are considered. An overview on the principles and (simple) application of input-output analysis and its adoption to life cycle assessment is given. The students learn different aspects of the closed-loop economy and end of life respectively, and are introduced to the consideration of uncertainties in the LCA data. At the end of the lecture, future perspectives in LCA research will be presented and discussed.

Content of the Exercise

In the exercises the students practice the independent application of the methods learned in the lecture. Using different scenarios, students learn to apply the basic steps of the LCA process and critically evaluate its outcomes. Another focus is to enable students to write simple software solutions for the fundamental numerical concepts of LCA themselves and to apply them on the basis of case studies.

Prüfungsleistung (Graded Assessment)

Written supervised exam, duration: 90 min.
The final written exam covers the content of the lecture and exercises.

Studienleistung (Pass/Fail Assessment)

None

Literature

- Hauschild, Michael, Rosenbaum, Ralph K., Olsen; Life Cycle Assessment - Theory and Practice, Springer, 2018. (ISBN: 978-3-319-56475-3)
- Heijungs, Reinout, Suh, Sangwon; The Computational Structure of Life Cycle Assessment, Springer, 2012. (ISBN: 978-94-015-9900-9)

Usability of the Module

Mandatory elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Sustainable Materials Engineering*

MODULE
Materials Selection for Sustainable Engineering

NUMBER	11LE68MO-4220 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr.-Ing. Frank Balle	**LECTURER**	Dr.-Ing. Michael Becker
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	B.Sc. in Mechanical Engineering, Materials Science, Production Engineering, Materials Design or similar areas		
RECOMMENDED TERM	1	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Winter term
WORKLOAD	180 h (60 h attendance + 120 h self-study incl. preparation/follow-up)		

QUALIFICATION GOALS

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

CONTENT OF THE LECTURE

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)

CONTENT OF THE EXERCISE

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 (Ansys Granta, 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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised examination on the content of lectures and exercises, duration: 90 min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

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

Usability of the Module

Mandatory elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Sustainable Materials Engineering*

Module
Methods of Material Characterization for Waste Management

Number	11LE68MO-5562 PO 2021	**Institution**	FMF
Module Responsible	Prof. Dr. Michael Fiederle	**Lecturer**	Prof. Dr. Michael Fiederle
Type	Elective Module	**Duration**	1 term
Format	Lecture + exercise	**Language**	English
Mandatory Requirements	None		
Recommended Requirements	Basics in the area of materials science and engineering (Bachelor studies)		
Recommended Term	3	**ECTS Credits**	6
Semester Week Hours	2 h lecture + 1 h exercise	**Term Cycle**	Winter term
Workload	180 h (45 h attendance + 135 h self-study)		

Qualification Goals

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.

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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised examination, duration: 90 min.; 60% of final grade
Oral presentation, duration: approx. 20 min. and 10 min. questions; 40% of final grade

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Exercise sheets have to be completed and handed in on a regular basis. These will be scored and awarded with points. The *Studienleistung* counts as passed if at least 50% of points have been reached per exercise sheet.

LITERATURE

- 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 and 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

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering* or *Sustainable Materials Engineering*

MODULE
Model Thinking for Complex Systems

NUMBER	11LE68MO-5560 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Dr. Mirko Schäfer	**LECTURER**	Dr. Mirko Schäfer
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic knowledge of matrix and probability theory and differential equations		
RECOMMENDED TERM	4	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	4 h	**TERM CYCLE**	Summer term
WORKLOAD	180 h (35 h attendance and 145 h self-study)		

QUALIFICATION GOALS

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

- identify and explain characteristic properties of complex systems
- implement and analyze stylized complex systems models in the modelling environment NetLogo
- discuss problems occurring in different fields (technical, societal, economic, etc.) from an interdisciplinary complex systems and modelling perspective
- describe and compare various modelling concepts in different fields and discuss their inherent assumptions, limitations, explanatory power and applicability

CONTENT OF THE LECTURE

- Systems thinking and stock-and-flow diagrams
- Local interaction models
- Collective motion
- Synchronization phenomena
- Fundamentals of complex networks theory

- Agent-based modelling
- Modelling the spread of infectious diseases
- Energy system optimization models
- Electricity market models
- Integrated assessment models and Energy-Environment-Economy models

Prüfungsleistung (Graded Assessment)
None (because *Interdisciplinary Profile*)

Studienleistung (Pass/Fail Assessment)
Written supervised exam **and** exercises • The final written supervised exam is a graded *Studienleistung* at the end of the semester which covers the content of the lecture and exercises, duration: 3 h. • Exercises: 4 homework exercises. 3 out of 4 need to be passed in order to be admitted to the final written exam.

Literature
• S.E. Page, *The Model Thinker*, Basic Books, 2018 • E. Thompson*, Escape from Model Land. How Mathematical Models Can Lead Us Astray and What We Can Do About It*, Basic Books, 2022 • D.H. Meadows and D. Wright, *Thinking in Systems: A Primer*, Chelsea Green Publishing, 2008 • S.F. Railsback and V. Grimm, *Agent-Based and Individual-Based Modeling: A Practical Introduction,* Princeton University Press, Second Edition, 2019 Further literature will be announced in class

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the *Interdisciplinary Profile – Modules related to the Subject Area*

MODULE
Optical Metrology for Quality Assurance in Sustainable Production

NUMBER	11LE68MO-4305 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Dr. Daniel Carl	**LECTURER**	Dr. Daniel Carl
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Fundamental knowledge about photonics		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Irregularly
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

QUALIFICATION GOALS

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

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.

Prüfungsleistung (Graded Assessment)
Final written supervised exam, 90 min. 5 topics with 3-5 questions on each topic.

Studienleistung (Pass/Fail Assessment)
None

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.

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering* or *Sustainable Materials Engineering*

MODULE
Optimization for Energy Systems

NUMBER	11LE68MO-5574 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Anke Weidlich	**LECTURER**	Prof. Dr. Anke Weidlich
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with integrated exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 60 h self-study)		

QUALIFICATION GOALS
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. They are able to understand goal conflicts and can formulate multi-criteria decision analysis models. They are experienced in implementing the discussed methods in a computer tool, and can interpret the results.

CONTENT OF THE LECTURE

- Optimization problems in energy systems (e. g. unit commitment, optimal dispatch)
- Linear and mixed-integer linear programming
- Stochastic optimization
- Dynamic programming
- Multi-criteria decision analysis
- Exercises with computational tools

Prüfungsleistung (Graded Assessment)
Written supervised exam, duration: 60 min.

Studienleistung (Pass/Fail Assessment)
None

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.

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Photovoltaic Laboratory (PV Lab)

NUMBER	11LE68MO-4108 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Stefan Glunz	**LECTURERS**	Prof. Dr. Stefan Glunz, Dr. Wolfram Kwapil
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Module *Solar Energy*		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	3 h	**TERM CYCLE**	Each term; max. 10 participants
WORKLOAD	180 h (45 h attendance + 135 h self-study)		

QUALIFICATION GOALS
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.

CONTENT OF THE EXERCISE

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

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written protocols of performed laboratory experiments and an oral presentation of the experimental results within a poster conference. Approx. 10 min. presentation + 5 min. questions = 15 min in total.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Students need to attend all laboratory sessions regularly according to §13 (2) of the General Examination Regulations for the Master of Science (100%) and to conduct the experiments.

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

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
Physics of Failure

NUMBER	11LE68MO-5121 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Stefan Hiermaier	**LECTURER**	Prof. Dr. Stefan Hiermaier
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 60 h self-study)		

QUALIFICATION GOALS

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.

CONTENT OF THE LECTURE

Fracture mechanics

- crack propagation and opening modes
- energy release rate
- crack tip stress state (stress intensity factors, J integral)
- cohesive zone model

Failure of materials

- failure criteria models (Tresca, Hill…)
- failure surfaces
- stress triaxiality (e.g. Johnson-Cook)

Damage mechanics

- strength degredation
- damage accumulation models

The theoretical, experimental, numerical and empirical approaches to the topics are accompanied with many examples from science and industry.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
Oral examination *(Prüfungsgespräch)*, duration: approx. 20 min. per student. The oral exam covers the content of the lecture.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
None

LITERATURE
Information will be given during the lecture.

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering* or *Sustainable Materials Engineering*

INATECH

MODULE
Power Electronics for E-Mobility

NUMBER	11LE68MO-4106 PO 2021	**INSTITUTION**	INATECH; external lecturer
MODULE RESPONSIBLE	Stefan Reichert	**LECTURER**	Stefan Reichert
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with embedded exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Module *Energy Efficient Power Electronics*; Basic knowledge in (Power) Electronics and Control		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 60 h self-study)		

QUALIFICATION GOALS

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.

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 are included in the lecture (3 exercises x 2 h)

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
Oral examination *(Prüfungsgespräch)*, approx. 30 min. The examination takes place at the end of the winter semester.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
None

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

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

Module
Power Electronics for Photovoltaics and Wind Energy

Number	11LE68MO-4107 PO 2021	**Institution**	INATECH; external lecturer
Module Responsible	Prof. Dr. Bruno Burger	**Lecturer**	Prof. Dr. Bruno Burger
Type	Elective Module	**Duration**	1 term
Format	Lecture	**Language**	English
Mandatory Requirements	None		
Recommended Requirements	Knowledge in Electrical Components (Semiconductors, Inductors, Capacitors)		
Recommended Term	3	**ECTS Credits**	3
Semester Week Hours	2 h	**Term Cycle**	Winter term
Workload	90 h (30 h attendance + 60 h self-study)		

Qualification Goals
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.

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

Prüfungsleistung (Graded Assessment)
Oral examination, duration: approx. 30 min.

Studienleistung (Pass/Fail Assessment)
None

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

Usability of the Module
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

Module
Quantification of Resilience

Number	11LE68MO-4110 PO 2021	**Institution**	INATECH; external lecturer
Module Responsible	Dr. Ivo Häring	**Lecturer**	Dr. Ivo Häring
Type	Elective Module	**Duration**	1 term
Format	Lecture with embedded exercise	**Language**	English
Mandatory Requirements	None		
Recommended Requirements	Basic knowledge in any single or more of the following domains would be helpful, without being mandatory: • system theory, modeling, analysis and simulation • finite state machine modelling, discrete system models • graphical/ semi-formal system modelling languages • failure, damage and physics of failure modelling • statistics, probability theory, stochastic processes • engineering models for adverse, damaging, disruptive or extreme loads or events • network and graph modeling, graph theory • physical-engineering modelling of critical infrastructure structures, components and systems, e.g. of electricity, water, wastewater, and green gas grids • coupled physical models • modeling and simulation of cyber-physical socio-technical systems, world models		
Recommended Term	3	**ECTS Credits**	3
Semester Week Hours	2 h	**Term Cycle**	Winter term
Workload	90 h (32 h attendance + 58 h self-study)		

Qualification Goals
Main learning targets include: 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 of applying and tailoring methods for resilience quantification

CONTENT OF THE LECTURE

Main contents comprise:

1. Context, basic definitions, objectives and options of resilience quantification: resilience management processes, resilience quantification and development processes
2. System (service) performance-based resilience quantification
3. Method types for resilience quantification, resilience dimensions, and resilience method taxonomy
4. Qualitative and semi-quantitative resilience assessments: ontologies, process schemes, quantification and evaluation
5. Resilience dimensional order expansions and resulting quantification bounds
6. Application of classical system analysis approaches, e.g. deterministic inductive and deductive system analysis methods
7. Advanced system analysis methods, in particular time, system phase and system trajectory dependent methods such as TDFT, non-classical Markov models, Petri nets and stochastic processes
8. System graph-based and topological approaches: system definition, identification of disruption vector, response and recovery determination and response strategy optimization
9. Resilience quantification based on multiple event propagation through resilience analysis layers: heuristics vs. formalization, resilience transition matrix elements, related statistical-empirical, probabilistic, engineering and physical-simulative methods, forward and backward propagation methods
10. Input-output models, operability models: discrete and continuous
11. Coupled agent-supported engineering grid-model approaches for overall system modelling, simulation and resilience determination: operator, prosumer and consumer models; organizational, policy and framing models
12. Combination of resilience quantification approaches
13. Optimization problems in resilience engineering
14. For all resilience quantification approaches: model assumptions, application domains, application examples, typical input and output data, acceptance of modeling approach
15. Use of Machine Learning (ML) and artificial intelligence (AI) as support and stand-alone approaches for resilience quantification of systems
16. Standards, emerging standards and ongoing standardization efforts

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised exam, duration: 90 min
The final exam covers both the content of the lecture and the embedded exercises.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Presentation and critical review of a selected publication or of a chapter of the lecture manuscript (approx. 20 minutes including questions and answers).

LITERATURE

Sample literature includes:

1. Vulnerable systems, Wolfgang Kröger and Enrico Zio, Springer, 2011

2. Catalogue of risks: natural, technical, social and health risks, Dirk Proske, Springer, 2008
3. Resilience engineering: models and analysis, Nii O. Attoh-Okine, Cambridge University Press, 2016
4. Exploring Resilience: A Scientific Journey from Practice to Theory, Siri Wiig, Springer, 2018
5. Urban resilience for emergency response and recovery: fundamental concepts and applications, Gian Paolo Cimellaro, Springer, 2016
6. Resilience quantification of urban areas: An integrated statistical-empirical-physical approach for man-made and natural disruptive events, Kai Fischer, Dissertation, Fraunhofer Verlag, 2018
7. Risk assessment and decision analysis with Bayesian networks, Norman Fenton and Martin Neil, CRC Press, 2013
8. Risk analysis and management: engineering resilience, Ivo Häring, Springer 2015
9. Principles of cyber-physical systems, Rajeev Alur, MIT Press, 2015
10. Cyber-physical systems: from theory to practice, Danda B. Rawat, Joel J.P.C. Rodrigues, and Ivan Stojmenovic (eds.), CRC Press, 2016
11. Cyber-physical systems: integrated computing and engineering design, Fei Hu, CRC Press, 2013
12. Agent-based modelling of socio-technical systems, Koen H. van Dam, Igor Nikolic and Zoifia Lukszo (eds.), 2012, Springer
13. Introduction to agent-based modeling, Uri Wilenski, Springer, 2015
14. Transdisciplinary Systems Engineering: Exploiting Convergence in a Hyper-Connected World, Azad M. Madni, Springer, 2018
15. Optimization Under Uncertainty with Applications to Aerospace Engineering, Massimiliano Vasile (editor), Springer, 2020
16. The science and practice of resilience, Igor Linkov, Benjamin Trump, Springer, 2020
17. Design of coastal hazard mitigation alternatives for rising seas, David Basco, World Scientific Publishers, 2020
18. Resilience and risk, methods and application in environment, cyber and social domains,
    a. Editors: Igor Linkov, José Manuel Palma-Oliveira, Springer, 2017
19. Resilience Engineering for Urban Tunnels, Editors: Michael Beer, Hongwei Huang, Bilal M. Ayyub, Dongming Zhang, Brian M. Philips, American Society of Civil Engineers, 2018
20. Resilience of Critical Infrastructure Systems: Emerging Developments and Future Challenges, Editors: Zhishen Wu, Xilin Lu, Mohammad Noori, CRC Press, 2020
21. Mathematical Modelling of System Resilience, Kanchan Das, Mangey Ram, River Publishers, 2019
22. Technical Safety, Reliability and Resilience: Methods and Processes, Ivo Häring, Springer, 2021
23. Critical Information Infrastructure Protection and Resilience in the ICT Sector, Editors: Sandro Bologna, Paul Theron, Information Science Reference, 2013
24. Industrial Control Systems Security and Resiliency: Practice and Theory, Editors: Craig Rieger, Indrajit Ray, Quanyan Zhu, Michael A. Haney, Springer 2019
25. Critical Infrastructures Resilience: Policy and Engineering Principles, Auroop Ratan, Ganguly, Udit Bhatia, Stephen E. Flynn, Taylor and Francis, 2018

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
https://ascelibrary.org/ajrua6/resilience_quantification_modeling_decision_making

Search for the term resilience on the following web sites of standardization organizations: http://www.din.de/en/, http://www.iso.org, http://www.iec.ch, https://ansi.org
Recent publications:
https://scholar.google.com/citations?user=luyHvrkAAAAJ&hl=en

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering*
- M.Sc. in Microsystems Engineering or Mikrosystemtechnik (PO 2021) in the concentration area *Materials and Fabrication* (= *Materialien und Herstellungsprozesse*)

MODULE
Resilience of Supply Networks

NUMBER	11LE68MO-5564 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Alexander Stolz	**LECTURER**	Prof. Dr. Alexander Stolz, Dr. Mirjam Fehling-Kaschek
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	2	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	2 h lecture + 2 h exercise	**TERM CYCLE**	Summer term
WORKLOAD	180 h (52 h attendance + 128 h self-study)		

QUALIFICATION GOALS

- 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

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

CONTENT OF THE EXERCISE

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.

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: approx. 30-40 min. per student; 50 %

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

LITERATURE

Information will be given during the lecture.

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering*

MODULE
RF- and Microwave Circuits and Systems

NUMBER	11LE68MO-5232 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Rüdiger Quay	**LECTURER**	Prof. Dr. Rüdiger Quay
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 60 h self-study)		

QUALIFICATION GOALS

The students will be enabled to understand concepts, functioning, and design of modern complex RF-and microwave circuits and systems. This includes the understanding of basic RF-concepts, of more complex passive and active circuits, of modern antennas, of combined functionalities, data acquisition, and aspects of 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 concepts and data acquisition. System concepts for communication, such as for a full transmit-receive system, for remote sensing including imaging and radar, are presented and several examples discussed in detail.

CONTENT OF THE LECTURE

The lecture RF- and Microwave circuits and systems deals with the fundamentals and concepts of RF-circuits and systems. It comprises three parts: fundamental RF-concepts with focus on communications and sensing, more complex RF-circuits, and actual RF systems. At the interface of modern electronics, wave propagation, 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 to real 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.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Oral examination, duration: approx. 30 min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

LITERATURE

RF- and Microwave passives
- Zinke/Brunswig, Hochfrequenztechnik, Band 1, Springer, 1999

Further literature for systems is presented during the lecture.

USABILITY OF THE MODULE

Elective module for students of the study program
- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
RF- and Microwave Systems - Design Course

NUMBER	11LE68MO-5344 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Rüdiger Quay	**LECTURER**	Prof. Dr. Rüdiger Quay
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	The prior or parallel participation in either module *RF- and Microwave Devices and Circuits* or *RF- and Microwave Circuits and Systems* is highly recommended.		
RECOMMENDED TERM	2	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Summer term
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

QUALIFICATION GOALS
The students will be enabled to understand, design and layout modern RF- and microwave components and systems by means of the electronic design environment Agilent Advanced Design System including the two- and three-dimensional electromagnetic simulators Momentum and EMPro 3D. The detailed use of a 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, and their 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 everyday communication and sensing. The competence includes in-depth understanding and treatment of complex microwave systems and of general system design including the treatment of complex modulated signal flows.

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/RF passive and active structures, the modelling and layout and verification of active electronic RF-devices in circuit environments based on various semiconductor technologies, and the high-level combination of more complex microwave systems. This includes the simulation of printed circuit boards, of integrated circuits and of devices in package including

RF-interconnects, and of behavioural system simulation. Advanced analysis of RF-problems, characterisation, modelling and linear and nonlinear simulation techniques are introduced in 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 LTE and modern radar.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
The grade is calculated based on the average of the submitted exercises (5 out of 6). There is no exam.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
None

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)

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

MODULE
RF- and Microwave Devices and Circuits

NUMBER	11LE68MO-5215 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Rüdiger Quay	**LECTURER**	Prof. Dr. Rüdiger Quay
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	None		
RECOMMENDED TERM	2	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Summer term
WORKLOAD	90 h (26 h attendance + 64 h self-study)		

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

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-technology to the understanding of RF-communication and sensing systems. The methodologies of RF-analysis, design of devices and circuits, and their basic figures-of-merit, their modelling and characterisation are introduced along with the demonstration of their relevance to modern RF- components and microsystems. This also

includes a discussion of the underlying technology and many examples supported by RF-design tools from the microwave oven to today's RF-applications in mobile communication in the iPod.

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Oral examination, duration: approx. 30 min.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

None

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

USABILITY OF THE MODULE

Elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

Module
Smart Grids

Number	11LE68MO-5576 PO 2021	**Institution**	INATECH
Module Responsible	Prof. Dr. Christof Wittwer	**Lecturer**	Prof. Dr. Christof Wittwer, Dr. Bernhard Wille-Haussmann, Dr. Robert Kohrs
Type	Elective Module	**Duration**	1 term
Format	Lecture + Excercise	**Language**	English
Mandatory Requirements	None		
Recommended Requirements	Python Programming Skills; Electrotechnical & Controls Basics		
Recommended Term	3	**ECTS Credits**	6
Semester Week Hours	2 h lecture + 3 h exercise	**Term Cycle**	Winter term
Workload	180 h (75h attendance lecture & exercise + 105 h self-study)		

Qualification Goals

Students will learn to use the basics of designing grid integrated energy systems; fundamental aspects of power and energy definition, overview on plant and smart grid technologies, calculation and simulation of energy systems; fundamental aspects of power flow calculation and grid theory.

Content of the Lecture

- Introduction to smart grids
- Fundamentals of power system and power flow
- Net zero emission energy systems; energy system transition
- Grid bounded transport: gas; heat; electricity
- Power system analysis: sankey diagrams; efficiency; duration curves
- Grid structure; distribution and transmission grid
- Components; power plants; storage, loads
- Grid integration; flexibility; cross energy management; demand response
- Economics: liberalized energy market; grid operation; production costs

- System modeling and simulation
- DC and AC power flow; circuits
- Grid integration: reactive and active power flow control, grid codes
- Static and dynamic stability of Power Systems; transient and stationary power flow
- Control and communication systems for smart grids
- Metering, Agents, Blockchain for energy trading

CONTENT OF THE EXERCISE

Each lecture will be accompanied by an exercise.

- Energy system analysis
- AC and DC Circuits, grid calculation
- Reactive and active power flow
- Optimal control, energy management, cost functions
- Grid codes; stability
- Communication and smart metering
- Agent based trading

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)

Written supervised exam, duration 90 min.
The final exam covers both the content of the lecture and the exercises.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)

Exercise sheets have to be completed and handed in on a regular basis. These will be scored and awarded with points. The *Studienleistung* counts as passed if at least 80% of the overall number of achievable points for the semester has been reached.

LITERATURE

- Duffie and Beckman: Solar Engineering of Thermal Processes. ISBN: 978-0-470-87366-3
- Volker Quaschning: Renewable Energy and Climate Change: ISBN 978-0-470-74707-0.
- European SmartGrids technology platform: http://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf
- Smart Grid Communications and Networking; Ekram Hossain isbn: 9781107014138
- Modelling and Analysis of Electric Power Systems: Göran Andersson: https://www.yumpu.com/en/document/view/4227429/modelling-and-analysis-of-electric-power-systems-eeh-eth-zurich

USABILITY OF THE MODULE

Elective module for students of the study program:
- M.Sc. in Sustainable Systems Engineering (PO 2021) in *Energy Systems Engineering*

MODULE
Solar Energy

NUMBER	11LE68MO-8060 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Stefan Glunz	**LECTURERS**	Prof. Dr. Stefan Glunz, Dr. Manuel Lämmle, Dr.-Ing. Peter Schossig, Dr. Anna Heimsath
TYPE	Mandatory Elective Module	**DURATION**	1 term
FORMAT	Lecture + exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Basic understanding of physics		
RECOMMENDED TERM	1	**ECTS CREDITS**	6
SEMESTER WEEK HOURS	3 h lecture + 1 h exercise	**TERM CYCLE**	Winter term
WORKLOAD	180 h (60 h attendance + 120 h self-study)		

QUALIFICATION GOALS
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.

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, condenser 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)

Content of the Exercise

The lecture will be accompanied by exercises and simulation workshops to deepen the lecture's content and to apply state-of-the-art simulation software to design and describe complete energy systems.

Prüfungsleistung (Graded Assessment)

Written supervised exam, duration: 120 min.

Studienleistung (Pass/Fail Assessment)

Regular attendance of the exercise workshops according to §13 (2) of the General Examination Regulations for the Master of Science and submission of exercise sheets.

Literature

- 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

Usability of the Module

Mandatory elective module for students of the study program

- M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Energy Systems Engineering*

Elective module for students of the study program

- M.Sc. in Microsystems Engineering or Mikrosystemtechnik (PO 2021) in the concentration area *Materials and Fabrication* (= *Materialien und Herstellungsprozesse*)

MODULE
Structural Robustness: Resilient Designs

NUMBER	11LE68MO-4109 PO 2021	**INSTITUTION**	INATECH
MODULE RESPONSIBLE	Prof. Dr. Alexander Stolz	**LECTURER**	Prof. Dr. Alexander Stolz
TYPE	Elective Module	**DURATION**	1 term
FORMAT	Lecture with embedded exercise	**LANGUAGE**	English
MANDATORY REQUIREMENTS	None		
RECOMMENDED REQUIREMENTS	Module *Fundamentals of Resilience* Module *Design and Monitoring of Large Infrastructures*		
RECOMMENDED TERM	3	**ECTS CREDITS**	3
SEMESTER WEEK HOURS	2 h	**TERM CYCLE**	Winter term
WORKLOAD	90 h (30 h attendance + 60 h self-study)		

QUALIFICATION GOALS
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.

CONTENT OF THE LECTURE/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

PRÜFUNGSLEISTUNG (GRADED ASSESSMENT)
Oral examination *(Prüfungsgespräch)*, duration: approx. 30 min. The final oral examination at the end of the semester covers the content of the lecture and the exercise.

STUDIENLEISTUNG (PASS/FAIL ASSESSMENT)
None

LITERATURE
• Unified Facilities Criteria (UFC): Design of Buildings to Resist Progressive Collapse UFC 4-023-03, 2009 • Unified Facilities Criteria (UFC): Structures to Resist the Effects of Accidental Explosions UFC 3-340-02, 2008 • Chopra, A. K., Dynamics of structures. Theory and applications to earthquake engineering. 3. ed. Upper Saddle River, N.J: Pearson/Prentice Hall (2007) • Starossek, Uwe (2007): Typology of progressive collapse. In: Engineering Structures 29 (9), S. 2302–2307. DOI: 10.1016/j.engstruct.2006.11.025

USABILITY OF THE MODULE
Elective module for students of the study program • M.Sc. in Sustainable Systems Engineering (PO 2021) in the technical concentration area *Resilience Engineering*

Glossary

English	Deutsch
Content of the Lecture/Exercise	Inhalt der Veranstaltung/Übung
Duration	Moduldauer
ECTS Credits	ECTS Punkte
Format	Zugehörige Lehrveranstaltung
Institution	Einrichtung
Language	Sprache
Qualification Goals	Lernziele
Lecturer	Lehrperson
Literature	Literatur
Mandatory Requirements	Zwingende Voraussetzungen
Module	Modul
Module Responsible	Modulverantwortlicher
Number	Nummer
Prüfungsleistung (Graded Assessment)	Prüfungsleistung (zählt in die Endnote)
Recommended Requirements	Empfohlene Voraussetzungen
Recommended Term	Empfohlenes Fachsemester
Semester Week Hours	Semesterwochenstunden
Studienleistung (Pass/Fail Assessment)	Studienleistung (zählt nicht in die Endnote)
Term Cycle	Angebotsfrequenz
Type	Modultyp
Usability of the Module	Verwendbarkeit des Moduls
Workload	Arbeitsaufwand

EDITION NOTICE

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Program Coordination *Sustainable Systems Engineering*
Ester Gnandt (maternity leave replacement of Eva Hein)

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