Fakultät Maschinenbau
fortschritt studieren

RUHR-UNIVERSITÄT BOCHUM

RUB

RUHR – UNIVERSITÄT BOCHUM
FACULTY OF MECHANICAL ENGINEERING

Master's Programme Mechanical Engineering

Specialisation Sustainable Energy Systems & Circular Process Engineering

Module Catalogue

Valid from summer semester 2025

In addition to the course schedules the module catalogue includes summaries of the contents of the modules. Only the module catalogue published on the website of the Faculty of Mechanical Engineering at the Ruhr-Universität Bochum is valid. Older module catalogues are to be found in the archive. Regular revisions of the module catalogue are to be expected which is why the module description valid in the semester of the last lecture is always decisive for the module examination.

27 March 2025

Update: October 2025 (changes highlighted in yellow)

Value of the module grade for the final grade

Percentage of the final grade [%] = „CP of module“ * 100 * FAK / DIV

FAK = 1,0 for the modules of all study sections

DIV = 90

Modules

Index by areas of study

1) Specialisation M.Sc. Mechanical Engineering, ECTS: 40

2) STEM Modules M.Sc. Mechanical Engineering, ECTS: 15

Here you will only find the STEM modules offered by the Faculty of Mechanical Engineering. Module descriptions of other possible modules can be found in the corresponding areas/faculties.

3) Scientific Paper M.Sc. ME, ECTS: 30

4) non-STEM Module M.Sc. Mechanical Engineering, ECTS: 5

Here you will only find the non-STEM modules offered by the Faculty of Mechanical Engineering. Module descriptions of other possible modules can be found in the corresponding areas/faculties.

<table>
<tr><td colspan="6">3D-Simulation in Automation
3D-Simulation in der Automatisierungstechnik</td></tr>
<tr><td>Module number
139050</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Semester[s]
9. Sem.</td><td>Duration
1 Semester[s]</td><td>Group size
no limitation</td></tr>
<tr><td colspan="3">Courses
a) 3D Simulation in Automation</td><td>Contact hours
a) 4 WLH (60 h)</td><td>Self-study
a) 90 h</td><td>Frequency
a) each winter</td></tr>
</table>

Module coordinator and lecturer(s)
Prof. Dr.-Ing. Bernd Kuhlenkötter
a) Dr.-Ing. Alfred Hypki

Admission requirements
Recommended previous knowledge:
Prior successful participation in the module Grundlagen der Automatisierungstechnik is not a required prerequisite but may be helpful.

Learning outcome, core skills
After successful completion of this module the students

- know the basics of 3D simulation technology,
- have the ability to develop a 3D simulation
- can validate automation tasks before realisation
- are able to recognise the most important methods and software systems for solving simulation requirements in automation technology

Contents
a)
After a general introduction to the requirements and possibilities of 3D simulation in automation technology, the students learn the various steps that extend from the idea to the modelling of the work cell and programming the automation components through to virtual commissioning.

Special attention is paid in this lecture to industrial robotics, which is discussed in numerous examples and applications.

The lecture covers the following topics:

- Simulation in automation technology - requirements and possibilities
- Graphical 3D simulation
- CAD-based work cell modelling and 3D data exchange
- Robot programming
- Offline programming and virtual commissioning
- Fundamentals and features of graphical 3D simulation systems in industrial use

The accompanying exercise consists of the practical implementation of the modelling, programming and simulation tasks mentioned, modelling, programming and simulation tasks with a commercially available and industrially applied 3D robot simulation and offline programming system.

Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / German / English

Examination methods

• Written exam '3D Simulation in Automation' (90 min., Part of modul grade 100,0 %)
Requirements for the award of credit points Passed written exam (Note: The grade is based on the written exam only)
Module applicability • MSc. Mechanical Engineering • MSc. Sales Engineering and Product Management
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Advanced Systems Engineering (ASE)

Advanced Systems Engineering

Module number	Credits	Workload	Semester[s]	Duration	Group size
139270	5 CP	150 h	9. Sem.	Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Advanced Systems Engineering	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Detlef Gerhard
a) Prof. Dr.-Ing. Detlef Gerhard

Admission requirements

none

Learning outcome, core skills

After successful completion of the module

- students have a broad, integrated knowledge of the methods and tools of Advanced Systems Engineering
- have acquired a comprehensive understanding of the interaction of the relevant software systems and of integration concepts from the perspective of advanced systems engineering and can apply this in a situation-specific manner, e.g. to assess the CAx and PDM/PLM process chains in a differentiated manner.
- students are able to independently analyze and evaluate problems in the development of complex technical systems and develop a system architecture based on requirements management.
- have exemplary, interdisciplinary methodological competence in cross-domain modeling and can independently model and understand complex technical systems in an object-oriented modeling language (e.g. SysML) and evaluate the developed models
- can work cooperatively on modeling and simulation tasks in the field of advanced systems engineering in heterogeneous groups, justify processes and results and communicate about issues related to the development of models for complex technical systems. By working on practical case studies and tasks, they can transfer the skills they have learned in dealing with corresponding software systems to specific problems in model-based systems engineering.

Contents

a)
Digitalization opens up numerous potential benefits for new types of market services in industry based on technical systems that are characterized by a high degree of complexity and interdisciplinarity. One approach to overcoming the limitations of classic development methods is advanced systems engineering, which focuses on the model-based and integrative interaction of disciplines and aspects of product development in a development approach and thus represents a holistic product development methodology that incorporates systems engineering methods. The lecture deals with the methods and tools used in the development of complex technical systems from an overarching perspective of the overall process. In particular, the Model Based Systems Engineering (MBSE) concept and the system modeling language SysML are applied and deepened by the students through independent work on project tasks. The following topics are covered in the module

- Introduction Fundamentals and terms of Advanced Systems Engineering

- Model Based Definition (MBD) and Model Based Systems Engineering (MBSE)
- Methods of system definition and formal modeling,
- Modeling languages, e.g. Sys-ML
- Requirements management
- Verification & validation
- Advanced engineering applications
- MBSE and PLM integration aspects

Educational form / Language

a) Tutorial (2 WLH) / Lecture (2 WLH) / German / English

Examination methods

• Written exam 'Advanced Systems Engineering' (90 min., Part of modul grade 100,0 %)

• Course-related tasks: Term papers (if the term papers are completed before the final module examination, optional bonus points for the written examination are possible) (scope and submission deadlines will be announced at the beginning of the semester)

Requirements for the award of credit points

- Passed final module examination: Written exam
- Completed course-related assignments: Term papers (scope and deadlines will be announced at the beginning of the semester")

Module applicability

- M.Sc. Sales Engineering and Product Management
- M.Sc. Mechanical Engineering
- M.Sc. Applied Informatics

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents.

DIV: The values can be taken from the table of contents.

Further Information

The course "Advanced Systems Engineering" covers identical content in German.

<table>
<tr><td colspan="6">Computer Aided Process Design
Beispiele der simulationsgestützten Prozessentwicklung</td></tr>
<tr><td>Module number
138605</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Semester[s]
8. Sem.</td><td>Duration
1 Semester[s]</td><td>Group size
no limitation</td></tr>
<tr><td colspan="3">Courses
a) Computer Aided Process Design</td><td>Contact hours
a) 4 WLH (60 h)</td><td>Self-study
a) 90 h</td><td>Frequency
a) each summer</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Prof. Dr.-Ing. Marcus Grünewald
a) Dr.-Ing. Maria Polyakova</td></tr>
<tr><td colspan="6">Admission requirements
Recommended previous knowledge:
basic knowledge in Aspen Plus® or other flowsheet simulation tool in chemical engineering</td></tr>
<tr><td colspan="6">Learning outcome, core skills
After successful completion of the module, students are able to
• Develop processes for the manufacture of chemical products and assess their impact on the environment and society,
• Identify the necessary information needs for these tasks, find sources of information, and obtain the relevant information,
• Implement a complex process in common flowsheet simulation environment (Aspen Plus®), perform simulations and critically evaluate their results using parameter and sensitivity analysis, and derive further need for action from the results,
• Familiarize themselves independently and systematically with new tasks in a short period of time.</td></tr>
<tr><td colspan="6">Contents
a)
The course teaches simulation methods for complex processes in the chemical industry. In particular, the following topics are addressed:
• Tasks of and requirements for successfully implement and run process simulations,
• Simulation types and their advantages and disadvantages,
• Criteria for selecting models to represent common unit operations, as well as the required data basis
• and limitations of the models,
• Solution strategies for complex recycle loops,
• Process analysis tools such as sensitivity analysis, design specs and optimization,
• Simulation-based options for heat and resource integration,
• Analysis and preparation of simulation data for the presentation of relevant results.</td></tr>
<tr><td colspan="6">Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / German / English</td></tr>
<tr><td colspan="6">Examination methods
• Oral exam 'Computer Aided Process Design' (45 min., Part of modul grade 100,0 %, in small groups)</td></tr>
</table>

Requirements for the award of credit points Passed final module exam: Oral examination in small groups
Module applicability • MSc. Mechanical Engineering • MSc. Sales Engineering and Product Management • MSc. Umweltingenieurwesen
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Carbon Dioxide Capture from Industrial Processes Carbon Dioxide Capture from Industrial Processes					
Module number 138330	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Carbon Dioxide Capture from Industrial Processes			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each summer
Module coordinator and lecturer(s) Prof. Dr.-Ing. V. Scherer a) Priv.-Doz. Dr.-Ing. Martin Schiemann					
Admission requirements					
Learning outcome, core skills Objective: The lecture provides a basic understanding of CO_2 as a greenhouse gas and associated CO_2 sources. The state of development and perspectives of separation processes are discussed. The influence of separation on transport and storage will be addressed and economic, legislative and social aspects will be discussed. Competences: Students acquire the ability to evaluate and critically classify the individual process steps of CO_2 capture and storage or use. You will be able to make references to other lectures and to apply what you have learned there. The newly acquired knowledge is applied in a smaller project work accompanying the lecture.					
Contents a) Based on the definition, causes and effects of climate change, types of CO_2 sources and alternative energy sources are considered. The concept of CO_2 capture and storage is explained. Technical measures for CO_2 capture such as post-combustion, oxy-fuel combustion and pre-combustion capture will be discussed. Legal aspects and costs are considered. Transport by pipeline and ship is dealt with. Risks, security aspects and monitoring are discussed for the mentioned procedures. Geological storage and storage in the ocean are considered as storage types. Carbonate formation and the material use of CO_2 are discussed. Finally, component costs and carbon capture-and-sequestration usage scenarios are considered.					
Educational form / Language a) Tutorial (2 WLH) / Lecture (2 WLH) / English					
Examination methods • Written exam 'Carbon Dioxide Capture from Industrial Processes' (90 min., Part of modul grade 100,0 %, if there are less than 10 registrations the examination mode can be switched to an oral examination)					
Requirements for the award of credit points • Passed final exam: Written exam					
Module applicability Msc. Umweltingenieurwesen					
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents.					

DIV: The values can be taken from the table of contents.
Further Information

Chemical Energy Storage and Carbon-Based Feedstock

Chemical Energy Storage and Carbon-Based Feedstock

Module number	Credits	Workload	Semester[s]	Duration	Group size
139250	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Chemical Energy Storage and Carbon-Based Feedstock	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Thomas Ernst Müller

a) Prof. Thomas Ernst Müller

Admission requirements

Recommended previous knowledge:

Previous knowledge of chemistry is recommended

Learning outcome, core skills

Today's energy and chemical feedstock supply and storage systems are based largely on fossil resources. They need to be converted in the next decades into energy supply and feedstock systems that rely to a large extend on renewable feedstock. Most renewable sources are of intermittent nature, and this will lead to completely new system design requirements to maintain reliable energy systems and a continuous feedstock supply for the chemical industry and other industries. Knowledge of these new systems and their development and implementation will be essential for graduates in the future.

Understanding that the reliability of the transformed energy systems and feedstock supply chain will rely on primarily on the three pillars energy storage, renewable (over)production, and carbon-based feedstocks

Ability to assess the different possibilities to deal with and balance the time-offset between power generation and power demand, know different technologies to store energy and distinguish different storage solutions and applying them to a given storage or feedstock

Understanding of the different types of carbon-based feedstocks and the application and industry where they

are most suitable.

Ability to do a basic life cycle assessment of chemical feedstock supplies and chemical storage systems and their respective chances and boundary conditions for large scale adoption and implementation.

After successful completion of the module students should be able to

- Have enhanced subject and method competences in the area of chemical energy storage and carbon-based feedstocks
- Be familiar with current developments and technical principles in the area of chemical energy storage and carbon-based feedstocks
- Compare different chemical energy storage concepts and carbon-based feedstocks and assess the suitability of these concepts in a process-chain analysis and under consideration of process technology aspects and applications
- Assess and discuss thermodynamic and kinetic aspects of chemical energy storage and carbon-based feedstocks

- Explain, estimate and calculate potentials, energy densities and efficiencies of storage technologies and concepts
- Be familiar with interdisciplinary thinking at the interface of engineering and chemistry and can tackle actual and future problem definitions in the chemical industry, regarding sustainability and use of renewable resources such as CO_2 and others
- Enter industrial R&D in a cutting-edge field in the area of the „Energiewende“ and „Wasserstoffrepublik Deutschland“

Contents

a)

Since the beginning, human beings have made use of energy storage; history of energy storage from the perspective of the carbon cycle

- Thermodynamic basics of chemical energy storage
- Overview of energy storage technologies (including non-chemical)
- Technology and characteristics of conventional power plants
- Biogenic energy carriers; photosynthesis as the first energy storage process; fossil energy as a form of ancient biomass; solid (wood, coal), fluid (oils, crude oil) and gaseous (natural gas) biogenic energy carriers
- Chemical energy carriers in the energy system, power-to-gas (e.g. methane) and power-to-liquid (e.g. methanol); energy storage via fuels
- Electrochemical basics and applications for electrochemical energy storage; systems for electrochemical energy conversion and storage (batteries, electrolysis, fuel cells)
- Hydrogen storage technologies (generation, compression, liquefaction, adsorption, chemical binding to a carrier)
- Energy storage as heat
- Energy scenarios and modelling; Life Cycle Assessment
- What is a Feedstock? Renewable vs. depleting feedstock; renewable carbon-based feedstocks, CO2, biomass, bio coal; current feedstock consumption
- Value chain of fuels and chemicals; agricultural and industrial applications
- Renewable carbon-based feedstock for energy; biofuels from first generation corn-based, ethanol, biodiesel; second generation biofuels, cellulosic, oils, grasses; third and fourth generation, biofuels, algae
- Chemical conversion of carbon dioxide
- Biorefinery; production of aromatics from lignin; renewables as feedstock for polymers

Educational form / Language

a) Tutorial (2 WLH) / Lecture (2 WLH) / English

Examination methods

• Written exam 'Chemical Energy Storage and Carbon-Based Feedstock' (120 min., Part of modul grade 100,0 %)

Requirements for the award of credit points

- Passed final module exam: written exam

Module applicability

M. Sc. Mechanical Engineering

M. Sc. Sales Engineering and Product Management

M. Sc. Umweltingenieurwesen
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Chemical Processes for Closed Carbon Cycles Chemical Processes for Closed Carbon Cycles					
Module number 138160	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Chemical Processes for Closed Carbon Cycles			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each summer

Module coordinator and lecturer(s)
Prof. Thomas Ernst Müller
a) Prof. Thomas Ernst Müller

Admission requirements
Recommended previous knowledge:
Basic understanding of chemical concepts is recommended, as well as previous knowledge of chemical reaction engineering or chemical process engineering

Learning outcome, core skills
Knowledge of the main chemical-technological conversion processes for closed carbon cycles, sustainable use and utilization of renewable raw materials and renewable raw material sources.

Ability to fundamentally simulate and evaluate reactor models with regard to boundary conditions and large-scale implementation.

Understanding of the use of (pseudo)homogeneous and heterogeneous catalytic reactions on a large-industrial scale and the applicable framework conditions.

After successful completion of the module, students

- Master the basics of the process engineering design of reactors for different chemical reactions, in particular heterogeneous catalytic reactions for chemical processes in closed carbon cycles,
- Determine kinetic data for the design of reactors from reaction engineering measurements,
- Competently apply (pseudo)homogeneous and heterogeneous reactor models for different reactions and accelerated approaches in order to optimally select and design chemical reactors in terms of process technology under production engineering specifications and economic boundary conditions,
- Can use simulation programs for this purpose and integrate them effectively into the engineering work flow.

Contents
a)

- Resources for closed carbon cycles, use and utilization of renewable raw materials and sustainable raw material sources.
- Renewable raw materials, including CO_2, biomass, biochar as a feedstock for chemical production.
- Renewable carbon-based feedstock for energy generation.
- Chemical processes for closed carbon cycles, industrial applications, processes and value chains, selected processes.
- Transport phenomena in heterogeneous catalytic reactions and in multiphase systems.
- Micro- and macro-kinetics of different reaction systems, especially heterogeneous catalytic reactions.
- Apparatus for (pseudo)homogeneous and heterogeneous catalytic reactions.

- Setting up of calculation modules with MATLAB or comparable software for calculating, graphically representing and optimizing physicochemical processes in chemical reactors.

Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / English

Examination methods
• Written exam 'Chemical Processes for Closed Carbon Cycles' (120 min., Part of modul grade 100,0 %)

Requirements for the award of credit points
Passed final module examination: written exam

Module applicability
- MSc. Mechanical Engineering
- MSc. Sales Engineering and Product Management
- MSc. Environmental Engineering

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information

Circular Process Engineering Circular Process Engineering					
Module number 138320	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** no information	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Circular Process Engineering			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each summer

Module coordinator and lecturer(s)
Prof. Dr.-Ing. Manfred Renner
a) Dr.-Ing. Philip Biessey

Admission requirements

Learning outcome, core skills
After successful completion of the module, students will be able to

- understand the basic principles and boundary conditions of the Circular Economy and to identify interdisciplinary challenges for circular process engineering
- describe the basic principles and operation modes of sustainable technologies and processes for closing material cycles in the process industry
- apply the methods presented in the lecture for process balancing and scaling in relation to selected processes and evaluate them regarding established sustainability indicators
- identify boundary conditions and limitations of the sustainable technologies and processes considered and derive scenarios for large-scale implementation

Contents
a)
The course addresses technologies and processes for closing material cycles in the process industry and thus the transformation of this sector towards a sustainable Circular Economy. For this purpose, recycling technologies for plastics are discussed as examples in-depth. Within the lectures, basic ideas and operation modes of the considered technologies and processes will be presented; based on this, relevant material and heat transfer phenomena as well as the balancing of selected processes will be considered in detail in order to derive scaling strategies and design approaches and to be able to evaluate the technologies in terms of suitable sustainability indicators.

- Motivation, concepts and boundary conditions of the Circular Economy for closed material cycles in the process industry
- current technologies and processes especially for mechanical, physical and chemical plastics recycling as enablers for a circular economy of plastics
- balancing of selected processes and scaling strategies for design
- Key figures and methods for sustainability assessment of technologies and processes

Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / English

Examination methods
• Portfolio exam in the form of two assignments during the semester (each accounting for 10% of the module grade) and a group project including written documentation (accounting for 60% of the module grade) and

a final presentation (accounting for 20% of the module grade). The individual components are assessed separately for each participant. All components must be passed. Compulsory attendance (80% attendance required to pass).
Requirements for the award of credit points • Passed module exam: Portfolio exam. • All semester excercises must be passed. • Sufficient attendance.
Module applicability • MSc. Mechanical Engineering • MSc. Sales Engineering and Product Management • MSc. Umweltingenieurwesen
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Computational Fracture Mechanics

Computational Fracture Mechanics

Module number	Credits	Workload	Semester[s]	Duration	Group size
440108	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Computational Fracture Mechanics	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr. Alexander Hartmaier

a) Prof. Dr. Alexander Hartmaier

Admission requirements

Recommended previous knowledge:

Basic knowledge about solid mechanics and plasticity

Learning outcome, core skills

The students attain the ability to independently simulate fracture including plasticity for a wide range of materials and geometries. Based on the acquired understanding of the different types of brittle fracture and ductile failue of materials, they are enabled to choose appropriate fracture mod-els and to implement them in a finite element environment.They gain suffiecient knowledge about the theoretical background of the diffrent types of fracture models, to study the relevant literature independently. On an engineering level, the students are able to discriminate between situations, where cracks in a structure or component can be tolerated or under which conditions cracks are not admissible, respectively.

Contents

a)

Subject aims

- Phenomenology of fracture/Fracture on the atomic scale
- Concepts of linear elastic fracture mechanics
- Concepts of elastic-plastic fracture mechanics
- R curve behavior of materials
- Concepts of cohesive zones (CZ), extended finite elements (XFEM) and damagemechanics
- Finite element based fracture simulations for static and dynamic cracks
- Application to brittle fracture & ductile failure for different geometries and loadingsituations

Educational form / Language

a) Tutorial (2 WLH) / Lecture (2 WLH) / English / German

Examination methods

• Portfolio exam including reports on assignments, seminar and self-evaluation report

Requirements for the award of credit points

Passed final module examination: Portfolio exam

Module applicability

MSc. Computational Engineering

MSc. Maschinenbau

MSc. Materials Science and Simulation

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Computational Microstructure Analysis - NEW

Computational Microstructure Analysis

Module number	Credits	Workload	Semester[s]	Duration	Group size
139130	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Computational Microstructure Analysis	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Sebastian Weber

a) Dr.-Ing. Santiago Benito

Admission requirements

Recommended previous knowledge:

none

Learning outcome, core skills

After completing this course, students will be able to:

- Recognize and illustrate the advantages and limitations of popular 2D imaging techniques such as optical, atomic force, and electron microscopy, including the contrast mechanisms they provide.
- Select and apply appropriate sampling strategies (e.g., random sectioning) and image processing techniques (e.g., spatial filtering, segmentation).
- Perform automated image analysis using established tools (e.g., ImageJ, MATLAB, Python-based libraries) and develop custom analysis scripts in scientific programming environments.
- Quantify and interpret key microstructural descriptors such as grain size, shape, orientation, phase fraction, and texture.
- Understand and apply concepts of stochastic and statistical modeling of metallic microstructures, linking processing, structure, and properties.
- Employ computational methods, including pattern recognition, dimensionality reduction, and supervised learning, for extracting structure-property relationships from imaging data.
- Critically assess the reliability and interpretability of data-driven microstructure analysis approaches.

Contents

a)

The microstructure is at the heart of all Materials Science and Engineering endeavors. It connects a material's chemistry and processing history with the emerging properties ultimately responsible for system performance. Only with a comprehensive understanding of its features, formation, and evolution, and of the mechanisms that govern thermomechanical property emergence, can we strive to design materials in a top-down way.

The importance of microstructure has led to a constant search for new technologies and methodologies that enable the systematic collection, processing, and interpretation of digital, quantitative, high-resolution information. Prominent examples include microscopy, X-ray diffraction, and X-ray microtomography. Coupled with advances in image and signal processing, computer vision, and spatial statistics, these tools offer unprecedented access to the fundamental properties and interrelationships within complex microstructures.

Today, computational techniques under the umbrella of Computer Vision play an increasingly important role in microstructure analysis. These methods allow for automatic interpretation and a deeper understanding of processing-structure-property relationships.

This course provides a comprehensive overview of the information-based nature of metallic microstructures, with a focus on their imaging, processing, quantitative description, and computational analysis. In detail, the course covers:

- Microstructures as random fields
- Imaging techniques and contrast mechanisms
- Digital image processing
- Automatic image analysis and segmentation
- Stereology and quantitative microstructural descriptors
- Fundamentals of computational microstructure analysis

Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / German

Examination methods
• The tasks to be solved during the exercises constitute a self-contained project work integrated in the module. The module note (100%) will be defined by a 15-minute presentation on the results of said project work, followed by a 15-minute discussion of the employed methods and obtained results.

Requirements for the award of credit points

- Passed examination
- Fulfilment of all exercises

Module applicability
M.Sc. Mechanical Engineering

M.Sc. Materials Science and Simulation

M.Sc. CompEng

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information
Literature for the lecture will be announced at the beginning of the semester.

Demand and Supply in Energy Markets

Demand and Supply in Energy Markets

Module number	**Credits**	**Workload**	**Semester[s]**	**Duration**	**Group size**
138190	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	**Contact hours**	**Self-study**	**Frequency**
a) Demand and Supply in Energy Markets	a) 4 WLH (60 h)	a) 90 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr. rer. pol. Valentin Bertsch
a) Prof. Dr. rer. pol. Valentin Bertsch

Admission requirements

Recommended previous knowledge:
Recommended prior knowledge: Basic knowledge of energy economics, such as that covered in the B.Sc. module Energy Economics. Furthermore, solid prior knowledge of investment appraisal is advantageous. For participation in the exercises, a (mobile) computer with a spreadsheet program (e.g. Excel) is advantageous.

Learning outcome, core skills

After successful completion of this module the students are able to:

- name different types of energy markets and explain their purpose and functionality.
- name the main technological, socio-economic and political drivers of energy demand and explain how they each change energy demand over time or between energy carriers.
- assess how the expansion of renewable energy sources, energy efficiency and energy systems integration across sectors and scales impact energy demand and supply within and across energy carriers.
- apply the concepts learnt to complex case studies, analyse and interpret the corresponding results and draw conclusions for the transformation of the energy system.
- work independently in project groups and present results of their group work in an understandable way.

Moreover, the students will have

- developed the ability to think in a networked and critical way and are able to select and apply established methods and procedures,
- acquired in-depth and interdisciplinary methodological competence and are able to apply it in a situationally appropriate manner.

The students practice scientific learning and thinking and can

- develop complex problems in technical systems in a structured way and solve them in an interdisciplinary way using suitable methods,
- transfer knowledge/skills to concrete systems engineering problems.

Contents

a)
- Basics of economics
- Fundamentals of energy markets
- Energy demand:

- Energy demand by sector and energy carriers at global and regional level

- Bottom-up analysis of energy demand
- Top-down analysis of energy demand

- Energy supply:

- Investment appraisal
- Investing in supply expansion

- Group work on complex case studies focussing on how policy, regulation and markets affect energy demand (between sectors, over time) and supply

During the lecture and exercise, students work in project groups on concrete case studies, prepare a written paper and present their results at the end of the term.

Educational form / Language
a) Tutorial (1 WLH) / Lecture (3 WLH) / English

Examination methods
• Written exam 'Demand and Supply in Energy Markets' (90 min., Part of modul grade 100,0 %, onsite or online)
• Course-related tasks: Group work (40 hours, deadlines will be announced at the beginning of the semester) (If the group work is completed before the final module exam, optional bonus points are possible for the exam).

Requirements for the award of credit points

- Passed written exam (Note: The grade is based on the written exam only)
- Successful completion of the group work (details will be announced at the beginning of the semester)

Module applicability

- MSc. Mechanical Engineering
- MSc. Sales Engineering and Product Management
- MSc. Umweltingenieurwesen

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information

Dynamic Structures and Active Control Dynamic Structures and Active Control					
Module number 126602	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Dynamic Structures and Active Control			**Contact hours** a) 3 WLH (45 h)	**Self-study** a) 105 h	**Frequency** a) each summer

Module coordinator and lecturer(s)
Prof. Dr. Tamara Nestorovic
a) Prof. Dr. Tamara Nestorovic

Admission requirements
Basic knowledge of control systems is of advantage

Learning outcome, core skills
The students acquire an overall competence in fundamental methods of active structural

control. After successfully completing the course, the students are able to recognize the problems in practice and to apply the acquired knowledge in solving engineering problems in the field active control of mechanical structures, with the focus on active vibration control. In particular, the students:

- have basic knowledge in behavior and modeling of piezoelectric materials for applications in smart structures and active systems
- have knowledge in model development of mechanical structures for the control system design (linear time invariant systems in the state-space and transfer function form)
- are able to perform the model-based system analysis in time and frequency domain
- are able to design basic control structures with compensator and feedback gain systems
- are able to independently simulate control systems (PID and pole placement controller)
- have knowledge in discrete-time control systems
- are able to use Matlab/Simulink software and toolboxes for the control system analysis, design and simulation

Contents
a)
The course presents an overall insight in the modeling and control of active structures and systems. Basic terms and definitions are introduced along with presentation of the potential application fields. For the purpose of the controller design for active structural control, the basics of the control theory are introduced: development of linear time invariant models, representation of linear differential equations systems in the state-space form, controllability, observability and stability conditions of control systems. The parallel description of the modeling methods in structural mechanics enables the students to understand the application of control approaches. For actuation/sensing purposes multifunctional active materials (piezo ceramics) are introduced as well as the basics of the numerical model development for structures with active materials. Control methods include time-continuous and discrete-time controllers in the state-space for multiple-input multiple-output systems, as well as methods of the classical control theory for single-input single output systems. Differences and analogies between continuous and discrete time control systems are specified and highlighted on the basis of a pole placement method. Closed-loop controller design for active structures is explained. Different application examples and problem solutions will show the feasibility

and importance of the active structural systems development. The students also get insight into basics of active structural health monitoring. Within this course the students learn computer aided controller design and simulation using Matlab/Simulink software. Students will implement the acquired knowledge in the framework of a seminar paper related to the controller design supported by Matlab Software.
Educational form / Language a) Lecture with tutorial / English
Examination methods • Written exam 'Dynamic Structures and Active Control' (90 min., Part of modul grade 100,0 %) • Homework – Seminar paper based on the computer exercises; deadlines will be announced at the beginning of the semester
Requirements for the award of credit points • Passed final module examination and passed Seminar paper
Module applicability MSc Maschinenbau
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information Lectures with exercises, computer exercises and tutorials (3h / week) / English

Embedded Systems Embedded Systems					
Module number 137040	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Embedded Systems			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Martin Mönnigmann

a) Prof. Dr.-Ing. Martin Mönnigmann

Admission requirements

Recommended previous knowledge:

Undergraduate course on frequency space control, undergraduate or graduate course on state-space control methods

Learning outcome, core skills

After successfully completing the module

- Students can classify types of embedded systems hardware and assess the complexity of various control and automation tasks.
- Students can select an appropriate hardware and software development tool for a given task that is to be solved with an embedded system.
- Students can design embedded systems and select and use techniques for automated and functional testing.
- Students can design interfaces and protocols for implementing real-time capable embedded systems.
- Students can select, apply, and combine methods for discrete-time systems for the modeling and programming of embedded systems.
- Students can assess the importance of new scientific results in the field of embedded systems and control.
- Students are capable of life-long learning in the field of embedded systems.

Contents

a)

- Overview of commercially available hardware for implementing embedded systems and discussion of the lack of standardization in the field of embedded systems
- Classification of different types of hardware such as microcontrollers or programmable logic circuits, with respect to their computational performance, electrical power consumption, physical size, reliability, and cost
- Methods for assessing the complexity of various control and regulation tasks and deriving decision-making aids for selecting suitable embedded systems
- Design approaches and tools in the context of validation techniques
- Interfaces, protocols, and real-time requirements
- Methods and tools for discrete-time systems for the modeling and programming of embedded systems

Educational form / Language

a) Tutorial (2 WLH) / Lecture (2 WLH) / German / English

Examination methods • Written exam 'Embedded Systems' (120 min., Part of modul grade 100,0 %)
Requirements for the award of credit points Passed final module exam: written exam
Module applicability • MSc. Mechanical Engineering • MSc. Sales Engineering and Product Management
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information This module is equivalent to the module Embedded Systems in the German course catalogue.

Energy Systems Analysis

Energy Systems Analysis

Module number	Credits	Workload	Semester[s]	Duration	Group size
139170	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Energy Systems Analysis	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr. rer. pol. Valentin Bertsch

a) Prof. Dr. rer. pol. Valentin Bertsch

Admission requirements

Recommended previous knowledge:

Recommended prior knowledge: Basic knowledge of energy economics, such as that covered in the B.Sc. module Energy Economics. Furthermore, solid prior knowledge in operations research as well as investment appraisal are advantageous.

Exercises are organised as computer tutorials. If possible, these take place in the CIP pool(s) on campus. If students want to work on the exercises outside the CIP pool hours, they need a (mobile) computer on which they can install an open-source energy system model, which is provided by the chair.

Learning outcome, core skills

After successful completion of this module the students are able to

- name categories of energy systems models and explain the methodological concepts behind the different categories.
- explain and apply approaches for generating energy systems model input data in a structured way.
- apply selected methods and models to practical problems (e.g. unit commitment optimisation).
- interpret results from energy systems models and draw conclusions to support decision making.
- discuss strengths and weaknesses of the methods and models used and to discuss and derive potential for improvement.

Moreover, the students will have

- developed the ability to think in a networked and critical way and are able to select and apply established methods and procedures,
- acquired in-depth and interdisciplinary methodological competence and are able to apply it in a situationally appropriate manner.

The students practice scientific learning and thinking and can

- develop complex problems in technical systems in a structured way and solve them in an interdisciplinary way using suitable methods,
- transfer knowledge/skills to concrete systems engineering problems.

Contents

a)

Modelling and Simulation of Energy Systems

- Introduction and overview of energy systems analysis

- Fundamental optimisation models for power systems analysis
  - Optimal unit commitment (short-term planning)
  - Optimal capacity expansion (long-term planning)
- Scenario planning approaches
  - Introduction to scenario planning
  - Combination of scenario planning and power systems analysis
- Investment appraisal
- Selected case studies

Decision Analysis and Assessment of Strategies

- Types of decision environments and models
- Structuring decision problems
  - Generating objectives and hierarchies
  - Generating and preselecting alternatives
- Preference elicitation
- Aggregation functions and sensitivity analysis
- Selected case studies

During the exercises, students work on concrete case studies using an open source energy systems model to be installed on their (mobile) computers, and practise preparing input data, processing model results and drawing conclusions.

Educational form / Language
a) Tutorial (1 WLH) / Lecture (3 WLH) / English

Examination methods
• Written exam 'Energy Systems Analysis' (90 min., Part of modul grade 100,0 %, onsite or online)
• Assignments accompanying the course: Computer tutorials / exercises (details will be announced at the beginning of the semester).

Requirements for the award of credit points
- Passed written exam (Note: The grade is based on the written exam only
- Successful completion of the computer exercises (details will be announced at the beginning of the semester)

Module applicability
- MSc. Mechanical Engineering
- MSc. Sales Engineering and Product Management
- MSc. Umweltingenieurwesen

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
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Further Information

Specialized Laboratory Energy Technology

Fachlabor Energietechnik

Module number	Credits	Workload	Semester[s]	Duration	Group size
139403-138830	5 CP	150 h	8./9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Specialized Laboratory Energy Technology	a) 2 WLH (30 h)	a) 120 h	a) each sem.

Module coordinator and lecturer(s)

Dr.-Ing. David Engelmann

a) Prof. Dr.-Ing. V. Scherer, Prof. Dr. Francesca di Mare, Prof. Romuald Skoda, Prof. Dr. rer. pol. Valentin Bertsch

Admission requirements

none

Learning outcome, core skills

After successful completion of the module, students are able to

- explain the functionality, the field of application as well as the underlying physics of the setups presented in the experiments
- analyse and proof gathered experimental data
- prepare, illustrate and present experimental results
- independently work out solutions to questions related to the particular experiments

Contents

a)

The chairs Energy Technology (LEAT), Thermal Turbomachinery and Aero Engines (TTF), Energy Systems and Energy Economics (EE) as well as Hydraulic Fluid Machinery (HSM) offer a specialized laboratory to students of the master's programme Mechanical Engineering in each winter and summer semester. By participating in five experiments within one semester, students are taught interesting and innovative techniques in the energy sector. The portfolio includes, among others, the following experiments, which can change from summer to winter semester:

- Determination of the calorific value of a solid fuel using a calorimeter (LEAT)
- Flow measurement using Laser Doppler Anemometry (LEAT)
- Elemental analysis (LEAT)
- Experimental determination of flow parameters of a compressor profile (TTF)
- Determination of the engine characteristics of a radial compressor stage (TTF)
- Function and possible field of application of a gas engine driven combined heat and power plant (EE)
- Cavitation in centrifugal pumps (HSM)
- Numerical test rig for centrifugal pumps (HSM)
- Measurement oft pressure distribution around a NACA profile (HSM)

Educational form / Language

a) Internship / German

Examination methods

• Compulsory attendance

Requirements for the award of credit points

- Confirmation of active participation and acceptance of the rules in Moodle
- Participation in all 5 experiments offered within one semester
- Passed pre-tests for all 5 experiments offered within one semester
- Passed detailed report of the first assigned experiment
- Passed presentation of the second assigned experiment

Module applicability

MSc. Mechanical Engineering

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents.

DIV: The values can be taken from the table of contents.

Further Information

Interested students register for the specialized laboratory in FlexNow within 6 weeks before the beginning of the semester and additionally in the corresponding Moodle course.

Process Technology Laboratory
Fachlabor Verfahrenstechnik

Module number	Credits	Workload	Semester[s]	Duration	Group size
139404	5 CP	150 h	8./9. Sem.	1 Semester[s]	40

Courses	Contact hours	Self-study	Frequency
a) Process Technology Laboratory	a) 2 WLH (30 h)	a) 120 h	a) each sem.

Module coordinator and lecturer(s)
Prof. Dr.-Ing. Andreas Kilzer
a) Dr.-Ing. Stefan Pollak

Admission requirements
Recommended previous knowledge:
All students with admission to the master's program in mechanical engineering are eligible to participate.

Learning outcome, core skills
Subject-specific laboratories in the Master's program generally serve to acquire the skills necessary for entry into experimental (subject-specific) scientific work. Since the relevant practical skills depend to a large extent on the chosen focus, subject-specific laboratories are offered. In the specialised Process Technology Laboratory, the focus is on basic unit operations and the acquisition and evaluation of measurement data.

After the successful completion of the module, the students

- practice scientific thinking, learning and working in a more in-depth form.
- are familiar with the comprehensive engineering fundamentals in the area of their major field of study and are able to apply these to subject-specific problems.
- have practical skills in the use of measurement setups and experimental equipment.
- present their own experimental results and are proficient in recording and processing measurement results.
- possess both disciplinary and interdisciplinary methodological competence and are able to apply these in a manner appropriate to the situation.

Contents
a)
In the specialised laboratory, students of the master's program in mechanical engineering with a specialization in energy and process engineering, learn basic operations of process engineering and the associated measurement and analysis technology.

The laboratory consists of 6 experiments, which are regularly updated and can therefore vary. Which experiments are offered depends on the availability of equipment and supervisors. The experiments are different in summer and winter semesters. Currently available experiments are:

Vapor Pressure / Particle Image Velocimetry / Orifice Flow / Bubble Column
Viscosimetry / Particle Technology / Heat Exchangers / Density Measurement
Fluidised Bed / Spray Drying / Boiling Equilibrium / Rectification

The laboratory is absolved in groups. A group ideally consists of four students. All experiments must be prepared using the script provided. At the beginning of each experiment, this preparation will be checked in an oral entrance examination. As a follow-up, each group prepares a protocol or gives a presentation for each experiment.

Educational form / Language

a) Internship / German / English

Examination methods

• Internship 'Process Technology Laboratory' (6 mth., Part of modul grade 100,0 %, Experimental protocols or presentation of the results)
• Anwesenheitspflicht - Vorbereitung, Versuchsbeteiligung und Nachbereitung

Requirements for the award of credit points

Preparation, participation in the experiment and follow-up are prerequisites for receiving a grade. To pass the laboratory, all 6 experiments must be passed. The student will receive an overall grade for all 6 protocols or presentations.

Module applicability

MSc. Mechanical Engineering

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information

Fundamental Aspects of Materials Science and Microengineering

Fundamental Aspects of Materials Science and Microengineering

Module number	Credits	Workload	Semester[s]	Duration	Group size
138520	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Fundamental Aspects of Materials Science and Microengineering	a) 4 WLH (60 h)	a) 90 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Gunther Eggeler

a) Prof. Dr.-Ing. Gunther Eggeler, Prof. Dr. Tong Li, Prof. Dr.-Ing. Alfred Ludwig

Admission requirements

Recommended previous knowledge:

keine

Learning outcome, core skills

The students will learn:

- to evaluate the thermodynamic parameters which stabilize solid solutions and which lead to the formation of ordered phases and heterogeneous particle/matrix systems.
- to appreciate the role of microstructure in determining functional and structural materials properties in four case studies.
- to use the methodology of combinatorial materials research to assess material libraries with the objective to identify new alloy compositions and to invent new materials. They will appreciate the important role of micro engineering in this respect.
- to appreciate the applied side of fields like high temperature materials (lifetime of components in high temperature service) and shape memory alloys (acceptance criteria for shape memory actuators and shape memory implants).
- that there is plenty of space for improving existing and inventing new materials, and that progress in this area is vital for progressing the field and for technological success in materials science and technology.
- to familiarize themselves with the English language, which is used in the academic and technical literature of materials science and microengineering. The lecture will also develop communication skills in English.

Contents

a)

The students will learn to apply basic materials science concepts (elements of microstructure, phase diagrams, diffusion, strength, physical properties) to four material classes, which are in the focus of todays materials research and feature fascinating structural and functional properties: high entropy alloys (HEAs), intermetallic phases (IPs), single crystal Ni-base superalloys (SX) and shape memory alloys (SMAs). These four material classes have quite different microstructures and properties, but these can be understood on the basis of the concept toolbox, which the students have learned in their basic studies.

Key materials science concepts from the fields of solid state physics (crystal structures and crystal defects), thermodynamics (thermodynamics of mixtures), kinetics (diffusion) and mechanics (uniaxial testing, fracture mechanics) will be reviewed. Emphasis is placed on the importance of the strong link between elementary atomistic, crystallographic, thermodynamic/kinetic and microstructural processes and the functional and structural properties of materials/components on the macro scale. The following subtopics will receive special attention:

- Importance of atoms and electrons in materials engineering and the transition from atoms to alloys and from alloys to components
- Thermodynamic concepts in materials engineering and fundamentals of alloy design (with a special focus on ternary phase diagrams)
- Combinatorial materials research
- Kinetic concepts in materials science and engineering (with a focus on microstructural evolution)
- Basic concepts of solid state phase transformations
- Understanding and application of knowledge to four materials classes: high entropy alloys, intermetallic phases, single crystal superalloys and shape memory alloys
- Acquisition of knowledge about high temperature strength (example: superalloys), fracture mechanics and fatigue (example: shape memory alloys), structure and properties of alloys and compounds (chemistry, crystallography and physical properties) and methods for the invention of new materials (micro engineering and combinatorial materials research)

Educational form / Language

a) Lecture with tutorial / English / German

Examination methods

• Written exam 'Fundamental Aspects of Materials Science and Microengineering' (120 min., Part of modul grade 100,0 %)

Requirements for the award of credit points

Passing the exam

Module applicability

- MSc. Maschinenbau
- MSc. Sales Engineering and Product Management
- MSc. Materials Science and Simulation

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents.

DIV: The values can be taken from the table of contents.

Further Information

Gasdynamics Gasdynamics					
Module number 139310	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Gasdynamics			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Romuald Skoda
a) Dr.-Ing. Maximilian Paßmann

Admission requirements
Recommended previous knowledge:
Bachelor degree in Mechanical Engineering

Fundamental of Fluid Mechanics (Grundlagen der Strömungsmechanik), ideally also Advanced Fluid Mechanics (Fortgeschrittene Strömungsmechanik).

Learning outcome, core skills
After attending this module the student will understand state-of-the-art concepts and methods of gasdynamics and its applications in engineering sciences. The student will be in a position to analyse complex problems by selecting an appropriate approach to solving the problem and by applying well established solution methods. Additionally, the student will have the ability to transfer the learned skills into solving new problems.

Contents
a)

- Recapitulation of the basic concepts of fluid mechanics and thermodynamics
- Conservation laws
- Speed of sound and Mach-number
- Normal and oblique shock waves
- Expansion waves
- Lift and drag in supersonic flow
- Method of characteristics
- Compressible potential flow
- Numerical results

Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / English

Examination methods
• Oral exam 'Gasdynamics' (20 min., Part of modul grade 100,0 %, Oral exam in English or optionally in German)

Requirements for the award of credit points
Passed module exam: Oral exam

Module applicability
MSc. Mechanical Engineering

Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information Manuscripts for lecture and exercise are available in both English and German. Also, the entire module will be made available in German as a video stream via Moodle. Further literature will be recommended during the lecture.

Geothermal Drilling Engineering and Subsurface Technologies

Geothermal Drilling Engineering and Subsurface Technologies

Module number	Credits	Workload	Semester[s]	Duration	Group size
139080	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Geothermal Drilling Engineering and Subsurface Technologies	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)

Prof. Dr. rer. nat. Rolf Bracke

a) Prof. Dr. rer. nat. Rolf Bracke

Admission requirements

Recommended previous knowledge:

English language skills: "Test of English as a Foreign Language" (TOEFL): the test result in the internet version (iBT) should be at least 80 points, or "International English Language Testing System" (IELTS): minimum overall score "6" ("academic").

Learning outcome, core skills

The course provides an introduction to the principles of resource geology, deep drilling technologies, reservoir production and subsurface technologies. Students will learn how to evaluate a resource and propose suitable utilization concepts, plan a drilling project including well design, and select tools and equipment for reservoir production and monitoring. The lecture is accompanied by an exercise with practical examples and two excursions

Students will be able to:

- explain resource geology methods and parameters,
- define conceptual reservoir models
- tell principles of resource management
- compute thermal power outputs,
- explain the main methods and parameters of drilling technology
- develop drilling and production concepts,
- calculate casing designs,
- describe potential drilling problems,
- define the composition of the cost structure of a drilling project
- describe reservoir test principles,
- calculate production parameters

Contents

a)

- Introduction to subsurface technologies and applications
- Geothermal resource characterization: temperature, pressure, and, fluid flow in the geological subsurface + 1 excursion
- Geological and mininig law act

- Deep drilling basics (drilling rig, strings, and, bits) + 1 excursion
- Drilling techniques and processes (conventional and advanced drilling technologies);
- Casing design and calculation;
- Drilling fluid/mud system;
- Cementation and well control;
- Health safety and environment;
- Economics and Reporting;
- Well integrity and Logging technologies
- Monitoring techniques
- Reservoir production technologies
- Deep geothermal heat exchangers

Educational form / Language
a) Tutorial (1 WLH) / Lecture (3 WLH) / English

Examination methods
• Written exam 'Geothermal Drilling Engineering and Subsurface Technologies' (90 min., Part of modul grade 100,0 %)
• Semester-accompanying exercises

Requirements for the award of credit points

- Passed final module examination: written exam
- Passed semester-accompanying exercises

Module applicability
MSc. Mechanical Engineering

MSc. Geosciences

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information

Geothermal Energy Systems and Downstream Technologies Geothermal Energy Systems and Downstream Technologies					
Module number 138620	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Geothermal Energy Systems and Downstream Technologies			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each summer
Module coordinator and lecturer(s) Prof. Dr. rer. nat. Rolf Bracke a) Prof. Dr. rer. nat. Rolf Bracke					
Admission requirements Recommended previous knowledge: English language skills: "Test of English as a Foreign Language" (TOEFL): the test result in the internet version (iBT) should be at least 80 points, or "International English Language Testing System" (IELTS): minimum overall score "6" ("academic").					

Learning outcome, core skills

The course provides an introduction to downstream geothermal development, focusing on the direct use of geothermal energy for heating and cooling and/or its conversion to electricity. Students will learn to identify useful geothermal utilization options, understand the thermodynamics of fluid and steam cycles, describe the components and functions of a power plant, and understand how a heat pump works and how to evaluate its efficiency. The course also focuses on the opportunities and challenges of geothermal energy in industrial and agricultural applications and in district heating systems and the basics of economic calculations. The students will be able to specify steps for district heating planning, understand the significance of thermal storage and calculate levelized costs of heat.

The lecture is accompanied by an exercise with practical examples: The students will acquire the following skills:

- Describe the main technical solutions for direct, indirect and combined electricity and heat production uses
- Propose possible applications for available resource temperatures
- Describe the interactions of geothermal energy conversion systems: reservoir-well-piping-plant-reinjection
- Match the different power plant types and technical applications to corresponding reservoir conditions
- Identify the components of heat conversion technologies
- Develop technical solutions for given reservoir conditions, and regional or local energy demands
- Compare the different cooling energy sources and choose the right cooling system for a site
- Name the main elements for transmission and urban underground pipeline systems
- Estimate the environmental and social impacts of geothermal projects
- Illustrate the phases and cumulative costs at various stages of development

Contents

a)

- Geothermal energy systems and utilization options
- Thermodynamics of fluid and steam cycles, fluid mechanics, and heat transfer applied to geothermal energy conversion systems
- Power plant technologies based on flash steam, direct steam, binary conversion systems, and hybrid systems
- Cooling technologies
- Operation principle of heat pumps and thermodynamic reference cycle,
- COP / efficiency evaluation
- Compressors and refrigerants
- District heating networks and industrial and agricultural applications
- Heat storage
- Corrosion and scaling processes
- Social and environmental impacts
- Case studies
- Economics, finance, and risk analysis of a geothermal project

Educational form / Language

a) Tutorial (1 WLH) / Lecture (3 WLH) / English

Examination methods

• Written exam 'Geothermal Energy Systems and Downstream Technologies' (90 min., Part of modul grade 100,0 %)
• Semester-accompanying tasks: exercises

Requirements for the award of credit points

Passed final module examination: Written exam and module exercises

Module applicability

MSc. Mechanical Engineering

M.Sc. Sales Engineering and Product Management

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information

Hydrogen Technologies
Hydrogen Technologies

Module number	Credits	Workload	Semester[s]	Duration	Group size
138020-139260	5 CP	150 h	8./9. Sem.	2 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Hydrogen Technologies I: Production and Storage b) Hydrogen Technologies II: Synthetic Fuels and Basic Chemicals	a) 2 WLH (30 h) b) 2 WLH (30 h)	a) 45 h b) 45 h	a) each summer b) each winter

Module coordinator and lecturer(s)
Prof. Thomas Ernst Müller
a) Prof. Dr.-Ing. Ralf Peters
b) Prof. Dr.-Ing. Ralf Peters

Admission requirements
Recommended previous knowledge:
none

Learning outcome, core skills
After successfully completing the module, students can

- describe the basic principles and functionality of current technologies and processes for the production and use of hydrogen,
- apply the methods presented in the lecture for the design of electrolysis systems.
- identify the necessary boundary conditions, possible applications and limits of the technologies and processes under consideration and, within the framework of the energy transition, derive possible scenarios for large-scale implementation,
- assess the contribution of water electrolysis to the energy transition from technological, ecological and economic aspects.
- describe the basic principles and functionality of current technologies and processes for the production and use of synthetic fuels and chemicals in the Power-to-X process chains,
- apply the methods presented in the lecture for the design of Power-to-X systems,
- identify the necessary boundary conditions, possible applications and limits of the technologies and processes under consideration and, within the framework of the energy transition, derive possible scenarios for large-scale implementation

Contents
a)
The hydrogen technologies course includes the theoretical foundations and technical development for topics such as electrolysis, chemical energy conversion and fuel cells in the field of electrochemical and chemical process engineering, which are crucial for the successful implementation of the energy transition in research and development in the coming decades.

The ***Hydrogen Technologies I*** course focuses on the topics of hydrogen production, storage, transport and direct use of hydrogen.

As part of the lecture, the underlying concepts and basic functionality of the technologies and processes under consideration are presented. Building on this, the electrochemical and chemical conversion steps are discussed in detail, relevant material and heat transfer phenomena are considered, initial model equations are derived in order to derive design approaches for technical implementation and to evaluate the technologies in terms of future value chains for hydrogen. The components electrolysis and fuel cells play an important role.

- Motivation, concepts and boundary conditions for the production and use of hydrogen and synthesis gas as well as other electrochemically produced intermediate products as part of the energy transition
- Balancing electrochemical conversion processes and deriving relevant equations for the design of electrolysers and fuel cells
- Scaling of processes and technical structures from electrocatalyst and component research, process engineering analysis and process development to the technical representation of subsystems and systems on a technical scale up to integration into pilot plants
- Scientific and technical fundamentals of SOC technology for electrolysis and fuel cell operation including design, construction and operation as well as scale-appropriate integration into existing real-world laboratories
- Storage technologies and transport options for hydrogen
- Methodical approaches from modeling and simulation, analytics as well as manufacturing methods and apparatus technology that can be derived from the system technology orientation

b)
The ***Hydrogen Technologies II*** course focuses on the topics of hydrogen use for power-to-fuel and power-to-chemicals process chains.

As part of the lecture, the basic ideas and functionality of the technologies and processes under consideration are presented. Building on this, the chemical conversion steps are discussed in detail, relevant material and heat transfer phenomena are considered, initial model equations are derived in order to derive design approaches for technical implementation and to evaluate the technologies in terms of future value chains for synthetic fuels and sustainably produced chemicals.

Possible process chains are: the use of hydrogen and CO_2 for dynamic and decentralized methanol production (CH_3OH), the transport of CH_3OH and H_2 from preferred regions to Europe, the refining there using processes such as MtG (methanol-to-gasoline) and MtO (methanol-to-gasoline). to-olefins) to alkenes (chemical industry) and higher alcohols. Methanol-to-kerosene and methanol-to-diesel processes will provide liquid but sustainably produced fuels for various transport applications in the future

- Motivation, concepts and boundary conditions for the production and use of hydrogen, synthetic fuels and sustainably produced chemicals as part of the energy transition
- Process engineering aspects of the use of hydrogen and synthesis gas as well as other electrochemically produced intermediate products and CO_2 to produce synthetic fuels and chemicals. This may be done using CO_2 from biomass, from industrial process gases and, in the long term, by separating it from the air. Keywords: Power-to-X, Power-to-Fuel, Power-to-Chem.
- Balancing chemical conversion processes and deriving relevant equations for the design of synthesis reactors and peripheral components such as pumps, compressors and heat exchangers
- Process conditions and reactor design to achieve relevant throughputs with high thermomechanical integrity of components in thermocatalytic (membrane) reactors with elevated process temperatures and under high pressure. Increased integration of the development of membrane and multiphase reactors for process intensification

- Scaling of processes and technical structures from catalyst and component research, process engineering analysis and process development to the technical representation of subsystems and systems on a pilot scale to integration into pilot plants.
- Methodical approaches from modeling and simulation, analytics as well as manufacturing methods and apparatus technology that can be derived from the system technology orientation.

Educational form / Language
a) Lecture (2 WLH) / English
b) Lecture (2 WLH) / English

Examination methods
• Written exam 'Hydrogen Technologies' (90 min., Part of modul grade 100,0 %, in case of number of participants lower than 10 the examination may be conducted orally)

Requirements for the award of credit points
Passed final module exam: Written exam or oral exam

Module applicability
M. Sc. Maschinenbau

M. Sc. Umweltingenieurwesen

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information
In addition to the classic form of in-person lectures, short practical examples are offered as part of the lecture. In addition, at the end of the lecture, smaller mini-projects will be worked on - possibly as group work - which will then be presented online to the entire lecture course. Consultation by appointment.
The lecture counts as online lecture according to HDVO.

Introduction to Fluid-Flow Measurement Techniques

Introduction to Fluid-Flow Measurement Techniques

Module number	Credits	Workload	Semester[s]	Duration	Group size
138260	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Introduction to Fluid-Flow Measurement Techniques	a) 4 WLH (60 h)	a) 90 h	a) each summer

Module coordinator and lecturer(s)
Prof. Romuald Skoda
a) Dr.-Ing. Maximilian Paßmann

Admission requirements
Recommended previous knowledge:
Fundamental of Fluid Mechanics (Grundlagen der Strömungsmechanik), ideally also Advanced Fluid Mechanics (Fortgeschrittene Strömungsmechanik).

Learning outcome, core skills
After attending this module the student will understand state-of-the-art concepts and methods of fluid flow measurement techniques and their applications in engineering sciences. The student will be in a position to select an appropriate measurement technique for a given problem. Through mandatory laboratory exercises the student will gain hands-on experience in setting up the measurement system and performing the measurements. Additionally, the student will have the ability to perform a thorough data analysis of the acquired measurement signals including an analysis of the associated measurement uncertainties.

Contents
a)

- Introduction / motivation / scope of module
- Flow visualization techniques (e.g. Surface flow visualization, tracer based visualization, optical methods: shadowgraphy, schlieren, interferometry)
- Pressure measurements (e.g. pressure sensors and transducers, surface pressure measurements, pressure probes)
- Velocity measurements (e.g. multi-hole probes, hotwire anemometry, optical methods: Laser-Doppler-Anemometry, Particle-Image-Velocimetry)
- Temperature measurements (e.g. thermocouples, resistance thermometers, surface temperature measurements)
- Signal-/ Data analysis including error analysis
- Test facilities

Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / German

Examination methods
• Oral exam 'Introduction to Fluid-Flow Measurement Techniques' (40 min., Part of modul grade 100,0 %, Presentation (20 min) in English plus oral exam (20 min) in English or optionally in German)

Requirements for the award of credit points

- Participation in all laboratory exercises.

- Presentation of allocated laboratory exercise.
- Passed module exam.

Module applicability

MSc. Mechanical Engineering

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents.

DIV: The values can be taken from the table of contents.

Further Information

Manuscripts for lecture and laboratory exercises are available in English. Further literature will be recommended during the lecture.

Introduction to Three-dimensional Materials Characterization Techniques

Introduction to Three-dimensional Materials Characterization Techniques

Module number	Credits	Workload	Semester[s]	Duration	Group size
139100	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Introduction to Three-dimensional Materials Characterization Techniques	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)
Prof. Dr. Tong Li
a) Prof. Dr. Tong Li

Admission requirements
Recommended previous knowledge:
Für die Teilnahme an der Vorlesung sind keine formalen Voraussetzungen zu erfüllen. Grundlagen zum Aufbau fester Stoffe, zu Kristalldefekten und zu den chemischen und mikroskopischen Untersuchungsmethoden werden kurz wiederholt, eventuell muss aus dem Grundlagenbereich ergänzend nachgearbeitet werden.

Learning outcome, core skills
By completing the course, students gain insight into a range of three-dimensional nanoscale and atomic scale material characterization techniques, e.g. 3D x-ray microscopy, electron tomography and atom probe tomography. They can describe the working principles of each technique in detail, summarize applications in a vast of applications, such as engineering alloys, catalyst materials, semiconductors, etc. and solve scientific questions related to material science by using three-dimensional material characterization techniques. Additionally, students will understand three-dimensional nanoscale and atomic scale material characterization methods, which are currently extremely important in both industry and academia, and achieve some basic hands-on experience on sample preparation and sample analysis on one of these techniques (depends on the availability of instrument).

Contents
a)
- 3D Energy-dispersive X-ray spectroscopy
- 3D-Field ion microscopy
- Atom probe tomography
- Electron tomography
- X-ray tomography
- Focused ion beam slicing/scanning electron microscopy

Educational form / Language
a) Seminar / Lecture with tutorial / English / German

Examination methods
• During the semester each student will be assigned a current topic on which the student has to write a five-page report and give a talk (Percentage of the module grade 100 %)

Requirements for the award of credit points
passed module examination: semester assignments (Submission of report and holding of seminar talk)

Module applicability • MSc. Mechanical Engineering • MSc. Sales Engineering and Product Management • MSc. Materials Science and Simulation
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Master's Thesis Masterarbeit					
Module number	**Credits** 30 CP	**Workload** 900 h	**Semester[s]** 3. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Master's Thesis			**Contact hours**	**Self-study** a) 900 h	**Frequency** a) each sem.

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Andreas Kilzer

a) Prof. Dr.-Ing. Andreas Kilzer

Admission requirements

Compulsory, compulsory elective and elective modules amounting to at least 50 LP (a maximum of 40 LP is still missing for a successful degree) from the Master's degree programme and any conditions imposed upon admission must have been passed.

Learning outcome, core skills

The Master's thesis should show that the candidate is able to independently work on a challenging problem in mechanical engineering using scientific methods within a given period of time.

On a higher level the Master's thesis pursues the following objectives:

- The students are familiar with the current state of modern engineering research in the area of their major field of study.
- The students are familiar with the most modern methods and procedures of engineering sciences/ mechanical engineering in the area of their major field of study and know application examples.
- The students are able to model and solve complex engineering problems (if necessary interdisciplinary), as well as develop and implement their own approaches.
- The students can transfer knowledge/skills to concrete mechanical engineering/engineering problems.
- Students can transfer knowledge/skills to concrete and new problems.
- Students possess enhanced social competences relevant to their training, with a particular focus on independence and initiative

Contents

a)

Various topics from the Master's programme, typically based on the chosen focus or the research areas of the supervising university teacher. Assignments are always formulated by university teachers and should reflect the scientific standard of the degree programme; if necessary, suggestions for topics from students can be taken into account. Both theoretical and experimental tasks can be worked on.

Educational form / Language

a) Final thesis / German / English

Examination methods

• Final thesis 'Master's Thesis' (900 h., Part of modul grade 100,0 %)

• Intemediate or final presentation (approx. 30 minutes)

Requirements for the award of credit points

- Passed final module examination: Final paper
- Successful intermediate or final presentation

Module applicability

MSc. Mechanical Engineering
Weight of the mark for the final score Percentage of total grade [%] = 30,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information The Master's thesis can also be written in English.

Materials for Aerospace Applications Materials for Aerospace Applications					
Module number 137017	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Materials for Aerospace Applications			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Dr.-Ing. Marion Bartsch
a) Prof. Dr.-Ing. Marion Bartsch

Admission requirements
Recommended previous knowledge:
recommended are basics in materials science and solid mechanics and english skills B1

Learning outcome, core skills
After successful completion of the module students can

- recapitulate which high performance materials and material systems are used for aerospace applications, how they are manufactured, and which microscopic mechanisms control their properties
- explain and apply procedures for selecting and developing material systems for aerospace components, considering the specific requirements
- decide which characterization and test methods to apply for qualifying materials and joints for aerospace applications and know how lifetime assessment concepts work
- draft work flows from data acquisition to certification of aerospace components
- communicate, using technical terms in the field of aerospace engineering in English

Contents
a)
The substantial requirements on materials for aerospace applications are „light and reliable“, in most cases for extreme service conditions. Therefore, specially designed materials and material systems are in use. Manufacturing technologies and characterization methods for qualifying materials and joints for aerospace applications will be discussed. Topics are:

- loading conditions for components of air- and space crafts (structures and engines)
- selecting and developing materials and material systems for service conditions in aerospace applications (e.g. aero-engines, rocket engines, thermal protection shields for reentry vehicles, light weight structures for airframes, wings, and satellites)
- degradation and damage mechanisms of aerospace material systems in service
- characterization and testing of materials and joints for aerospace applications
- concepts and methods for lifetime assessment
- data handling from acquisition to certification of aerospace components

Educational form / Language
a) Lecture with tutorial / English / German

Examination methods
• Written exam 'Materials for Aerospace Applications' (120 min., Part of modul grade 100,0 %)

Requirements for the award of credit points

Bestandene Modulabschlussprüfung: Klausur
Module applicability • MSc. Maschinenbau • MSc. Sales Engineering and Product Management
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information script in English, additional literature announced during lecture

Modelling and Design of Dynamic Systems
Modellierung und Entwurf dynamischer Systeme

Module number	Credits	Workload	Semester[s]	Duration	Group size
139070	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Modelling and Design of Dynamic Systems	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)
Prof. Dr.-Ing. Martin Mönnigmann
a) Dr.-Ing. Sebastian Leonow

Admission requirements
Recommended previous knowledge:
Prior participation in the control engineering courses of the BSc Mechanical Engineering program (Fundamentals of Control Engineering and Advanced Methods of Control Engineering) is recommended.

Learning outcome, core skills
Upon successful completion of the module, students will be able to:

- Classify systems, derive subsystems, and construct optimal system boundaries and interfaces for model derivation.
- Develop and verify parametric dynamic models (white-box models) of mechanical, thermodynamic, fluid dynamic, and electrical systems using both current state-of-the-art, and novel methods. Students will be able to establish design and selection criteria for interdisciplinary system design and derive analogies between different system classes.
- Apply, evaluate, and verify empirical models (black-box models).
- Select numerical solvers for differential equations, create an analog computer solution of a system, assess numerical stability, and evaluate numerical errors.
- Design state observers and parameter estimators and assess their accuracy.
- Demonstrate the ability for interconnected, scientific thinking, enabling them to apply learned approaches to novel problems and communicate competently on this topic (including in English).
- Organize their own learning process, utilize digital media for their studies, and connect with workgroups (including digital collaboration).

Contents
a)
The course builds on the knowledge acquired during the bachelor's degree, particularly in the fields of mechanics, thermodynamics, fluid dynamics, electrical engineering, mathematics, and control engineering. Specifically, the following topics are covered:

- Review of mathematical fundamentals for modeling and system description, such as differential and difference equations and state-space representation.
- System categorization, (non-)linear time-(in)variant (discrete-time) systems.
- Stability of linear and nonlinear systems, global and local stability criteria, observability, and controllability.
- Parametric, dynamic modeling of mechanical, thermodynamic, fluid dynamic, and electrical systems using state-of-the-art methods and novel approaches, as well as design and selection criteria for interdisciplinary system design.

- Empirical modeling methods (black-box models) and their application to concrete examples.
- Numerical solvers for differential equations and their application to concrete examples, analog computing methods, numerical stability, and numerical errors.
- Observation and estimation of states and parameters, Kalman filters.
- Analytical and empirical design of classical PID controllers and state controllers.
- Synthesis and analysis methods for advanced control problems and multivariable control, decoupling, Smith predictor.
- Practical testing of exemplary methods on real-world systems.

Educational form / Language

a) Tutorial (2 WLH) / Lecture (2 WLH) / German / English

Examination methods

• Written exam 'Modelling and Design of Dynamic Systems' (120 min., Part of modul grade 100,0 %)

Requirements for the award of credit points

Passed final module examination: Written exam

Module applicability

- MSc. Mechanical Engineering
- MSc. Sales Engineering and Product Management

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV

FAK: The weighting factors can be taken from the table of contents.

DIV: The values can be taken from the table of contents.

Further Information

Multiscale Mechanics of Materials

Multiscale Mechanics of Materials

Module number	Credits	Workload	Semester[s]	Duration	Group size
440620	5 CP	150 h	9. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Multiscale Mechanics of Materials	a) 4 WLH (60 h)	a) 90 h	a) each winter

Module coordinator and lecturer(s)
Prof. Dr. Alexander Hartmaier
a) Dr. Rebecca Janisch

Admission requirements
Recommended previous knowledge:
keine

Learning outcome, core skills
Students possess a fundamental understanding of the multiscale nature of the mechanical behaviour of materials and of the different approaches to take this into account in mechanical modelling of microstructures. They can identify the relevant length- and timescales of the microscopic processes that lead to meso-/macroscopic structure-property relationships. The students understand the principles of effective theory construction, coarse graining and homogenisation methods, and they can apply them to identify, analyse and model multiscale problems, such as plastic deformation, hardening behaviour, and fracture of microstructures. They are familiar with state of the art numerical and theoretical scale-bridging modelling methods. They can apply numerical tools on different length scales, and understand the underlying principles (atomistic modelling, discrete dislocation dynamics, crystal and continuum plasticity). Finally, students build up the skill to independently develop scale- bridging models that integrate all necessary scales and employ these models to describe and predict mechanical properties of materials under given conditions.

Contents
a)

- Introduction to problems in materials mechanics that involve multiple length and time scales
- Overview on concepts of concurrent and hierarchical multiscale modeling of materials
- Principles of effective theory construction and its realisability in numerical modeling (extracting and passing information in hierarchical models); coarse graining and homogenisation
- Bridging scales in plasticity
- Bridging scales in fracture
- Numerical models and technical aspects of hierarchical multiscale simulations (atomistic modeling, discrete dislocation dynamics, continuum and crystal plasticity)

Educational form / Language
a) Tutorial / Seminar / English / German

Examination methods
• Written exam 'Multiscale Mechanics of Materials' (120 min., Part of modul grade 100,0 %, oder mündliche Prüfung (30 Min., wird zu Beginn der Lehrveranstaltung festgelegt))

Requirements for the award of credit points
Bestandene Modulabschlussprüfung: Mündliche Prüfung oder Klausur

Module applicability • MSc. Maschinenbau • MSc. Sales Engineering and Product Management • MSc. Materials Science and Simulation
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Numerical Methods for Internal Aerodynamics

Numerical Methods for Internal Aerodynamics

Module number	Credits	Workload	Semester[s]	Duration	Group size
138270	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Numerical Methods for Internal Aerodynamics	a) 4 WLH (60 h)	a) 90 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr. Francesca di Mare

a) Prof. Dr. Francesca di Mare

Admission requirements

Prerequisites for a successful participation to the lectures: Gasdynamics Thermodynamics Numerical Mathematics Fluid Mechanics

Learning outcome, core skills

After successfully completing the course the students master all theoretical and numerical tools to derive and analyse the mathematical model governing the flow of a compressible gas mixture. Furthermore, they understand how a flow solver for compressible fluids should be constructed. Particularly:

- The students understand the physical principles and can translate them in a mathematical model
- The students understand the the most relevant aspects of the flow of compressible fluids and are capable of making the correct assumption to simplify the corresponding mathematical models
- The students can translate mathematical models In a computed programme in a a structured and logical manner
- The students can assess the efficiency and accuracy of the programmed solver and the correctness of the results
- The students can design procedures to verify and validate the numerical results

Contents

a)

- Review of the fundamentals of Fluid Mechanics, Gasdynamics and Thermodynamics

- Derivation of the conservation equations (Mass, Momentum and Energy) in differential form
- Forms of the energy equation
- Non-dimensional form of the conservation equations
- Euler and Navier-Stokes Equations

- Classification of the conservation equations (elliptic, hyperbolic, parabolic)

- Definition of total quantities

- Thermal and caloric state equations and thermodynamic relations

- State variables

- Variable transformation and jacobian matrices

- Weak formulation of the conservation equations: discontinuities

- Example: advection equations

- Fundamentals of the spatial and temporal discretisation of hyperbolic problems

- Numerical treatment of dicsontinuities considering the example of the advection equation

  - Varisou schemes and formulations (Roe, Lax-Wendroff, etc.)

- Numerical treatment if the 1D Euler equations

  - Ideal gas model
  - Thermally perfect gas model

- Boundary conditions

- Theoretical formulation and implementation

- Stability and error analysis

Educational form / Language
a) Tutorial (1 WLH) / Lecture (3 WLH) / English

Examination methods
• Oral exam 'Numerical Methods for Internal Aerodynamics' (45 min., Part of modul grade 100,0 %, if the number of participants in the exam exceeds 5, the exam mode can be switched to a written examination (120 Min.))
• Examination form will be defined after the first lecture depending on the number of participants

Requirements for the award of credit points
Passed final module examination

Module applicability
no information

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information
The final mark consists exclusively of the examination mark. The lecture notes will be provided in English

Operations Research for Energy System Applications

Operations Research for Energy System Applications

Module number	**Credits**	**Workload**	**Semester[s]**	**Duration**	**Group size**
138120	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	**Contact hours**	**Self-study**	**Frequency**
a) Operations Research for Energy System Applications	a) 4 WLH (60 h)	a) 90 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr. rer. pol. Valentin Bertsch
a) Dr.-Ing. Jonas Finke

Admission requirements

Recommended prior knowledge: Basic knowledge of energy economics, such as that covered in the B.Sc. module Energy Economics is recommended. Any prior knowledge in operations research and programming with Python is advantageous but not necessary. Knowledge from the M.Sc. module Energy Systems Analysis can be helpful, but is also not necessary. Most exercises are organised as computer tutorials. If possible, these take place in the CIP pool(s) on campus. If students want to work on the exercises outside the CIP pool hours, they need a (mobile) computer on which they can install Python and a package for linear optimisation, both of which are open-source. This will also be advantageous for the case study.

Learning outcome, core skills

After successful completion of this module the students are able to

- Explain basic concepts of linear programming and solve linear optimisation problems manually and with Python
- Explain and interpret the structure and elements of linear energy system optimisation models by referring to concepts of linear programming and techno-economic characteristics of real energy systems
- Apply the concepts and methods learnt to a case study to answer a research question about the energy transition by developing, implementing and solving an energy system optimisation model using Python
- Analyse and interpret optimisation results and draw conclusions for the energy transition
- Work independently in project groups and present results of their group work in an understandable way, both in an oral and written form

Moreover, the students will have

- developed the ability to think in a networked and critical way and are able to select and apply established methods and procedures,
- acquired in-depth and interdisciplinary methodological competence and are able to apply it in a situationally appropriate manner.

The students practice scientific learning and thinking and can

- develop complex problems in technical systems in a structured way and solve them in an interdisciplinary way using suitable methods,
- transfer knowledge/skills to concrete systems engineering problems.

Contents

a)

- Linear programming

- Standard form and graphical solution
- Strong duality
- Karush-Kuhn Tucker conditions

- Energy system optimisation models

- Typical formulations and key components (Variables, parameters, constraints, objectives)
- Selected case studies

- Multi-criteria optimisation approaches

- Linear programming in Python with Linopy (taught in computer exercises)

- Formulating and solving basic linear problems
- Formulating and solving small and large energy system models
- Using multi-criteria optimisation methods

- Students work on a case study in small project groups

- Students develop an own energy system model to address a selected research question / problem
- Students evaluate the corresponding results and draw conclusions from it
- Students communicate their model and findings in a presentation and a short report

Educational form / Language

a) Tutorial (2 WLH) / Lecture (2 WLH) / English

Examination methods

• Project report 'Operations Research for Energy System Applications' (90 h., Part of modul grade 100,0 %, group work consisting of a written report, presentation and model code – details will be announced at the beginning of the semester)

Requirements for the award of credit points

Successful completion of project work (details will be announced at the beginning of the semester)

Module applicability

M.Sc. Mechanical Engineering

M.Sc. Sales Engineering and Product Management

M.Sc. Umweltingenieurwesen

Weight of the mark for the final score

Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.
DIV: The values can be taken from the table of contents.

Further Information

Process Design Process Design					
Module number 138250	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Process Design			**Contact hours** a) 2 WLH (30 h)	**Self-study** a) 110 h	**Frequency** a) each summer
Module coordinator and lecturer(s) Prof. Dr.-Ing. Marcus Grünewald a) Prof. Dr.-Ing. Marcus Grünewald, Dr. Helmut Mothes					
Admission requirements Recommended previous knowledge: none					
Learning outcome, core skills After successful completion of the module, students can use the latest methods and procedures of process design in engineering sciences / mechanical engineering and are familiar with application examples: • familiarize themselves with process design methods using industrially relevant examples, • identify these methods in current problems, considering the boundary conditions of process integration and intensification, • be able to recognize so-called "no regret solutions", i.e. process designs that are based on optimized performance instead of optimized equipment design, for various process examples, be able to transfer corresponding knowledge/skills to specific and new problems.					
Contents a) High-tech materials, agricultural chemicals and pharmaceuticals are essential to provide food, healthcare and consumer goods to a growing world population. It is the fundamental task of process design to design and layout chemical processes that convert raw materials into the above-mentioned products. The process design is used in later stages of development as the basis for the Detail Engineering and the construction of the chemical plant. In the past, detailed business plans could reliably predict the supply and demand side, raw material and energy supply and competitive situations over the entire lifecycle of a product. Today, in an increasingly complex world, the ability to adapt processes flexibly to changing conditions is becoming an important additional criterion. Changing boundary conditions include, for example, unexpected and sudden changes in the supply of raw materials or demand. The new, overarching goal of process design is therefore to develop so-called "no-regret solutions", i.e. process designs that focus on optimized performance in various future scenarios instead of an optimized equipment design. The course focuses on the key methodological aspects that lead to the development of robust, ecologically, and economically sustainable process designs. The approaches learnt are deepened through the detailed discussion of various examples of industrial relevance.					
Educational form / Language a) Lecture (2 WLH) / English					
Examination methods					

• for 3 credit points: Oral examination (30 min.), for 5 credit points: Oral examination (30 min.) AND Project work (90h)
Requirements for the award of credit points Passed final module exam: Oral examination and project work
Module applicability Msc. Mechanical Engineering MSc. Sales Engineering and Product Management
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Product Lifecycle Management (PLM)

Product Lifecycle Management

Module number	Credits	Workload	Semester[s]	Duration	Group size
138577	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Product Lifecycle Management (PLM)	a) 4 WLH (60 h)	a) 90 h	a) each summer

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Detlef Gerhard

a) Prof. Dr.-Ing. Detlef Gerhard

Admission requirements

Recommended previous knowledge:

none

Learning outcome, core skills

After successful completion of the module

- students have a broad, integrated knowledge of the challenges of holistic information management in the product life cycle and the resulting requirements for software systems to support PLM.
- Students know and understand the sub-processes of the product lifecycle, the methods of Product Lifecycle Management (PLM) and the scientific principles of the underlying IT systems. By working on practical examples and tasks with appropriate application software, they can transfer the skills they have learned in dealing with PLM software to concrete and practice-oriented PLM problems.
- have a comprehensive understanding of the interaction of PLM software systems and can critically differentiate and assess the suitability of methods for object management, product structure and configuration management as well as project and process management.
- can approach PLM tasks in a process-oriented manner, reflect on and evaluate them and pursue them in a self-directed manner.
- can work cooperatively on PLM tasks in heterogeneous groups, justify processes and results and communicate comprehensively about issues.

Contents

a)

The module teaches methods and tools for product lifecycle management (PLM), in particular the basic knowledge required for this and the relevant methodological aspects of product innovation processes.

The focus is on the various PLM functions of corresponding software systems (e.g. parts, document and product structure management, classification, configuration management, project and process management)

Furthermore, general methods for the organization and handling of product data and user information as well as methods of collaborative engineering and the procedure for PLM implementation are taught.

Educational form / Language

a) Tutorial (2 WLH) / Lecture (2 WLH) / German / English

Examination methods

• Written exam 'Final module examination: Product Lifecycle Management' (90 min., Part of modul grade 100,0 %)

• Course-related tasks: Term papers (if the term papers are completed before the final module examination, optional bonus points for the written examination are possible) (scope and submission deadlines will be announced at the beginning of the semester)
Requirements for the award of credit points • Passed final module examination: Written exam • Completed course-related assignments: Term papers (scope and deadlines will be announced at the beginning of the semester")
Module applicability • MSc. Mechanical Engineering • MSc. Sales Engineering and Product Management
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information The course "Product Lifecycle Management" covers identical skills and content in German.

<table>
<tr><td colspan="6">Process Control and Optimal Control
Prozessführung und Optimalsteuerung</td></tr>
<tr><td>Module number
137270</td><td>Credits
5 CP</td><td>Workload
150 h</td><td>Semester[s]
9. Sem.</td><td>Duration
1 Semester[s]</td><td>Group size
no limitation</td></tr>
<tr><td colspan="3">Courses
a) Process Control and Optimal Control</td><td>Contact hours
a) 4 WLH (60 h)</td><td>Self-study
a) 90 h</td><td>Frequency
a) each winter</td></tr>
<tr><td colspan="6">Module coordinator and lecturer(s)
Prof. Dr.-Ing. Martin Mönnigmann
a) Prof. Dr.-Ing. Martin Mönnigmann</td></tr>
<tr><td colspan="6">Admission requirements
Recommended previous knowledge:
Undergraduate course on frequency space control, undergraduate or graduate course on state-space control methods</td></tr>
<tr><td colspan="6">Learning outcome, core skills
After successfully completing the module
Students understand and can use the fundamentals of optimal control, are able to distinguish between different task classes (e.g., time-optimal tasks, tasks with and without constraints), and recognize tasks that are solved by piecewise extremal solutions (bang-bang solutions).
Students know how to develop and design model predictive control systems, evaluate their recursive feasibility and stability, and design optimal controllers using linear dynamics and quadratic costs.
Students can develop explicit model predictive controllers.
Students can analyze flatness properties and design flatness-based feedforward controllers.
Students can assess the importance of new scientific results in the fields of process and optimal control.
Students are capable of life-long learning in the fields of process and optimal control.</td></tr>
<tr><td colspan="6">Contents
a)
Introduction to optimal control, task classes (including time-optimal tasks, tasks with and without constraints), tasks with piecewise extremal solutions (bang-bang solutions)
Classes and properties of optimization problems and corresponding solution methods (linear, quadratic, and nonlinear programs with and without constraints, optimality conditions, convexity, local and global optima)
Model predictive control, stability, linear-quadratic problems
Explicit model predictive control, connection to the Riccati controller
Methods for analyzing nonlinear dynamic systems (phase portraits, nullclines, topological equivalence and Hartman-Grobman theorem, bifurcations, Lyapunov stability, direct and indirect Lyapunov methods)
Exact linearization, Lie derivatives, systems with and without internal dynamics, connection to the controllability of linear systems
Flatness, flatness-based feedforward, two-degree-of-freedom structure</td></tr>
<tr><td colspan="6">Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / German / English</td></tr>
</table>

Examination methods • Written exam 'Process Control and Optimal Control' (120 min., Part of modul grade 100,0 %)
Requirements for the award of credit points Passed final module exam: written exam
Module applicability • MSc. Mechanical Engineering • MSc. Sales Engineering and Product Management
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information This module is equivalent to the module Prozessführung und Optimalsteuerung in the German course catalogue.

Process Simulation of Energy Plants Prozesssimulation energietechnischer Anlagen					
Module number 139920	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9. Sem.	**Duration** 1 Semester[s]	**Group size** 45
Courses a) Process Simulation of Energy Plants			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Dr.-Ing. Roland Span
a) Prof. Dr.-Ing. Roland Span

Admission requirements
Knowledge with regard to the thermodynamic analysis of processes and plants in energy technologies, which can typically be taken for granted after completion of a Bachelor course with an appropriate extent of content relevant for energy technologies. No specific preconditions for participation.

Learning outcome, core skills
After successful completion of the module

- Building on fundamental knowledge regarding processes in energy technologies, students are able to model existing and new (discussed in the scientific literature) processes using modern simulation tools,
- Students can assess power and efficiency of plants and processes in energy technologies and can identify influential parameters,
- Students can analyse and assess the operating behaviour of real and hypothetical processes and plants in energy technologies,
- Students can explain and assess the relevance of specific parameters of a process on a high level of abstraction based on parameter studies,
- Students know the mathematical and thermodynamic foundations of process-simulation software,
- Students can use advanced simulation tools to solve complex tasks,
- Students can assess the performance and limits of simulation tools and can critically evaluate their performance (advantages and disadvantages).

Contents
a)
Starting from the manual evaluation of processes in energy technology, which has been dealt with in different modules in pertinent Bachelor courses, the essential requirements for software for the simulation of processes in energy technologies are derived. The four main elements of such programs (graphical user interface, nonlinear equation solver, models for specific components, property package) are exemplarily introduced. Advantages and disadvantages of different solutions are discussed. The students set up models for simple processes (gas turbine and steam power-plants, ORC process, heat pump, solar power plant). The influence of the most important operating parameters is explained using the self-developed models as examples. Options for a systematic variation of operating parameters are introduced. As special case the application of process-simulation tools for an assessment of completely new processes (scientific application) and for the validation of measured process parameters (process control in operating plants) is discussed.

Educational form / Language
a) Lecture with tutorial / German / English

Examination methods • Written exam 'Process Simulation of Energy Plants' (120 min., Part of modul grade 100,0 %, In case less than 10 students are enrolled, the written exam can be replaced by an oral exam (30 minutes) with 60 minutes preparation of the questions at a computer (60 minutes))
Requirements for the award of credit points Passed module examination: written or oral exam, see above
Module applicability no information
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information Lecture and tutorials integrated (4 SWS); the module is offered in a bilingual mode. Supervision of the enrolled students can be offered in German and English in parallel.

Service Engineering Service Engineering					
Module number 138230	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Service Engineering			**Contact hours** a) 3 WLH (45 h)	**Self-study** a) 105 h	**Frequency** a) each summer

Module coordinator and lecturer(s)
Prof. Dr. Jens Pöppelbuß
a) Prof. Dr. Jens Pöppelbuß

Admission requirements
Recommended previous knowledge:
none

Learning outcome, core skills
After successful completion of the module,

- Students will be able to explain the opportunities and challenges of servitization in manufacturing, i.e., the transformation of manufacturing companies towards a growing service business.
- Students will be able to explain and differentiate between different types of industrial services and product-service systems.
- Students will be able to apply established frameworks and methods to analyze business models of firms and to develop exemplary approaches for innovative business models.
- Students will be able to apply customer-oriented methods to develop innovative service offerings.
- Students will be able to explain the importance of service quality and service excellence for business success.
- Students will be able to engage with current research results from the field of service engineering, communicate them to others and relate them to the state of the art of service research.

Contents
a)
- Servitization of Manufacturing
- Industrial services, customer solutions and product-service systems
- Digital services and smart services
- Business models
- Frameworks and methods for analyzing, developing and communicating business models (Business Model Canvas, St. Gallen Business Model Navigator).
- Service engineering/design/innovation methods (e.g., personas, customer journey mapping, service blueprinting)
- Service quality
- Procedure models for service engineering

Educational form / Language
a) Tutorial (1 WLH) / Lecture (2 WLH) / English

Examination methods

• Written exam 'Service Engineering' (120 min., Part of modul grade 100,0 %, or oral exam (20 min., share of module grade 100%); type of exam will be announced at the beginning of the semester.) • Assignments during the course: Presentation of an academic article or a case study from the field of service research (group performance, presentation duration 15 minutes, workload per group member: 10 hours; possible dates will be announced at the beginning of the semester).
Requirements for the award of credit points • Passed final module examination: written or oral examination • Passed study-related tasks: Presentation
Module applicability MSc. Sales Engineering and Product Management MSc. Mechanical Engineering
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Subsurface Energy and Gas Storage Subsurface Energy and Gas Storage					
Module number 138220	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 8. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Subsurface Energy and Gas Storage			**Contact hours** a) 3 WLH (45 h)	**Self-study** a) 105 h	**Frequency** a) each summer

Module coordinator and lecturer(s)
Prof. Dr. rer. nat. Rolf Bracke
a) Dr. sc. ETH Zürich Katharina Alms

Admission requirements
Recommended previous knowledge:
English language skills.

Learning outcome, core skills
This course is an introduction to underground energy and gas storage technologies, focusing on the geological subsurface and its potential for the storage of heat and/or natural gas, hydrogen and CO2 in the context of energy transition and security. Students will be able to differentiate between different storage options and technologies, learn to calculate resource capacities, describe the components and functions of an underground gas storage facility and give an outlook on future developments. The lecture is accompanied by an exercise with practical examples and excursions.

Contents
a)

- Introduction to the energy market, security of supply and energy transition; historical background and state of the art of storage technologies focusing on storage processes, capacities and constraints
- Seasonal heat storage in aquifers and mines and its integration into the energy infrastructure (with field visit to a storage site)
- Natural gas storage in salt caverns, depleted hydrocarbon fields and saline aquifers; Geological requirements and technological components
- Carbon capture and storage (with lab visit): CO2 capture technologies from point sources and direct air capture technologies; CO2 transport and geological requirements for underground gas storage and mineralization; Example projects
- Underground hydrogen storage: Challenges and opportunities in a future energy market; Example projects

Educational form / Language
a) Tutorial (1 WLH) / Lecture (2 WLH) / English

Examination methods
• Written exam 'Subsurface Energy and Gas Storage' (90 min., Part of modul grade 100,0 %, If the number of participants is smaller than 14 the examination mode can be changed to a presentation.)
• Semester-accompanying exercises

Requirements for the award of credit points
Passed final module examination: Written exam

Passed semester accompanying exercises

Module applicability
M.Sc. Mechanical Engineering M.Sc. Sales Engineering and Product Management M.Sc. Geosciences
Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Thermodynamics of Mixtures

Thermodynamics of Mixtures

Module number	Credits	Workload	Semester[s]	Duration	Group size
138040	5 CP	150 h	8. Sem.	1 Semester[s]	no limitation

Courses	Contact hours	Self-study	Frequency
a) Thermodynamics of Mixtures - Lecture b) Thermodynamics of Mixtures - Group Tutorials	a) 3 WLH (45 h) b) 1 WLH (15 h)	a) 30 h b) 60 h	a) each summer b) each summer

Module coordinator and lecturer(s)

Prof. Dr.-Ing. Roland Span
a) Prof. Dr.-Ing. Roland Span
b) Prof. Dr.-Ing. Roland Span

Admission requirements

Recommended previous knowledge:
Basics of thermodynamics, as they are commonly taught in Bachelor courses in Mechanical Engineering or equivalent subjects. No specific preconditions.

Learning outcome, core skills

After successful completion of the module

- Students can explain the specifics of thermodynamic properties of mixtures on a high level of abstraction,
- Students can challenge and assess new findings in the area of thermodynamic properties of mixtures,
- Students can utilize their knowledge on thermodynamic properties of mixtures to solve complex problems in energy and process engineering,
- Students can identify missing information in the field of thermodynamic properties, can access available information, and can assess found data critically,
- Students can assess the relevance of new research results in the field of thermodynamic properties of mixtures.

Contents

a)

- Calculation of thermodynamic properties for processes in energy technologies (equation of state models, properties of water and steam as special case, ideal mixture of real gases)
- Thermodynamic properties of mixtures, representation as excess properties and as partial molar properties
- Foundation of mixture effects on a molecular basis
- Models for the excess Gibbs-enegry and for the activity coefficient
- Phase equilibria with liquids, solids and gases
- Modern equations of state for mixtures

b)

Educational form / Language

a) Lecture (3 WLH) / English
b) Tutorial (1 WLH) / English

Examination methods • Written exam 'Thermodynamics of Mixtures' (150 min., Part of modul grade 100,0 %)
Requirements for the award of credit points Passed final module examination: Written exam
Module applicability no information
Weight of the mark for the final score Percentage of total grade [%] = 5,00 * 100 * FAK / DIV FAK: The weighting factors can be taken from the table of contents. DIV: The values can be taken from the table of contents.
Further Information

Turbulence Modelling Turbulence Modelling					
Module number 137365	**Credits** 5 CP	**Workload** 150 h	**Semester[s]** 9. Sem.	**Duration** 1 Semester[s]	**Group size** no limitation
Courses a) Turbulence Modelling			**Contact hours** a) 4 WLH (60 h)	**Self-study** a) 90 h	**Frequency** a) each winter

Module coordinator and lecturer(s)
Prof. Romuald Skoda
a) Prof. Romuald Skoda

Admission requirements
Recommended previous knowledge:
Fundamental of Fluid Mechanics (Grundlagen der Strömungsmechanik), ideally also Advanced Fluid Mechanics (Fortgeschrittene Strömungsmechanik), Numerical Methods for internal aerodynamics

Learning outcome, core skills
After attendance, the students understand recent turbulence models, which are implemented in common CFD software. They have expanded their competences of networked and critical thinking and are able to assess established methods with regard to accuracy, stability and effort. The students have achieved detailed, also interdisciplinary methodological competences and based on these, they can elaborate solutions of new problems.

Contents
a)

- Review of fluid dynamical and numerical fundamentals
- Overview over turbulence theory
- Introduction to Direct and Large Eddy Simulation
- Detailed presentation of statistical turbulence models (Eddy Viscosity and Reynolds Stress models)
- Hybrid models: Scale Adaptive (SAS) und Detached Eddy (DES) Simulation
- Wall treatment
- Laminar turbulent transition
- Model additives for stagnation flow, rotation and compressibility

Educational form / Language
a) Tutorial (2 WLH) / Lecture (2 WLH) / English

Examination methods
• Oral exam 'Turbulence Modelling' (45 min., Part of modul grade 100,0 %, Oral exam in English or optionally in German)

Requirements for the award of credit points
Passed module exam: Oral exam

Module applicability
M.Sc. Mechanical Engineering

Weight of the mark for the final score
Percentage of total grade [%] = 5,00 * 100 * FAK / DIV
FAK: The weighting factors can be taken from the table of contents.

DIV: The values can be taken from the table of contents.
Further Information Manuscripts for lecture and exercise are available in both English and German. Also, the entire module will be made available in German as a video stream via Moodle. Further literature will be recommended during the lecture.