M.Sc.
Solar Energy Engineering (SEE)

Module Handbook

Version 1.5
Last edit on 15.08.2026

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Preamble

An Overview of the Master's Program

The growth of solar energy technology has been tremendous in the last decades. Today, photovoltaics (PV) is the cheapest technology in electricity production. The International Energy Agency (IEA) *World Energy Outlook 2020* report declares that solar energy is "the new king" of electricity generation and renewables. Moreover, all energy scenarios predict solar energy to be an indispensable player in the energy transition and fight against climate change. Our planet urgently needs people who will take part in this endeavour.

However, we are still at the beginning of the transition towards renewable energy systems. New technologies and business models for integrating renewable energy into future energy systems, along with the Internet of Things (IoT), will create a multitude of new jobs and opportunities. Therefore, we offer this comprehensive master's program in solar energy engineering so that students and graduates of this program can be a vital part of the solar revolution!

The M.Sc. Solar Energy Engineering (SEE) program is designed to be studied simultaneously to a full-time job, in the student's desired location, anywhere in the world with sufficient internet connection. The program's duration is 3.5 years (full track) or 2.5 years (expert track), depending on the student's previous academic qualification. Study tracks are explained further below in detail. The design of these tracks is based on more than a decade of experience in online teaching and feedback from many previous students and alumni. The language of instruction is English. The final semester is dedicated to writing a scientific master's thesis. Once a year, we host a voluntary on-campus week in Freiburg, generally in mid-September. Students are invited to join us to meet instructors and fellow students and to get hands-on experience at our facilities. One time during the program, participation in the on-campus events is mandatory due to the laboratory workshops, as explained later.

Students will access the learning management system (ILIAS) of the University of Freiburg to follow the course content. The content is delivered online and consists of vivid online meetings and asynchronous parts, e.g., pre-recorded lectures, reading materials, project works, and simulation tasks. Engaging forum discussions provide the chance for the most direct feedback. A major part of the program can be studied in an individual rhythm. The regular live virtual meetings are done in small groups with the instructors and tutors for discussions and questions. These meetings usually take place in the evenings (Berlin time zone) and weekends and are recorded; participation is voluntary.

A unique aspect of this program is the chance of joining the high-end research laboratories in Freiburg during the final semester of the program depending on the open positions in cooperating institutions. Students have the option to conduct research and write their master's thesis on-site as full-time students. Of course, it is also possible to study the entire program remotely. The program offers the flexibility to fit prospective students' learning needs and make their Solar Energy Engineering education satisfying and successful.

Who Can Pursue M.Sc. in Solar Energy Engineering at the University of Freiburg?

The M.Sc. in Solar Energy Engineering is suitable for highly qualified students who already have an academic background in one of the STEM subjects such as physics, chemistry, electronics, mechanical engineering, electrical engineering, material sciences, computer engineering, etc. For prospective students who want to expand their knowledge and skills in the solar energy field, this program is the right choice. Specialists with a production or sales background in solar energy systems or even beginners in the solar energy field can gain in-depth knowledge from this program. This program is also suitable for teachers, researchers, and committed young scientists who want to further specialise in solar energy topics. **Prospective students are expected to have the necessary flexibility and self-discipline for studying in a distant and online higher education program.** They must also have at least one year of work experience and sufficient knowledge of English.

Why Study M.Sc. in Solar Energy Engineering with Us?

Solar energy has been declared the “king of energy” and has a promising future for various applications. We are at the beginning of a critical decade; the decade of the energy transition, which will play a crucial part in the future of our planet. By studying Solar Energy

Engineering with us, graduates can be a part of this transition and be at the heart of both academy and industry.

- This program is accredited according to the high standards of German public universities. The SEE master's degree will be acknowledged in Germany as well as internationally.
- Our scientific cooperation with the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE) presents students with the possibility of accessing the world's leading research facilities in solar energy for hands-on experience.
- During the program, students will be guided by renowned academic instructors. Our instructors are international experts and scientists who are dedicated to our students' development.
- The online learning environment gives the freedom to study wherever and whenever students want. Students will be able to study online, at their pace, without disrupting their professional and private life.
- Students will receive comprehensive, interdisciplinary, technical, and scientific training in the solar energy field. They will acquire subject-relevant skills, from developing and designing photovoltaic and solar thermal systems to the assembly of complex plants, power stations, and energy networks.
- Tutors will closely support students in small and individual groups throughout their studies.
- Students will become a part of our international solar community with students and alumni from all over the world.
- SEE students contribute to a faster transition to renewables for a better world. Our motto is to keep learning and be the change!

Why Study at the University of Freiburg?

Founded in 1457, the University of Freiburg is one of the oldest universities in Germany. The University of Freiburg is a prestigious institution where students can actively participate in the latest research and teaching activities with internationally renowned professors. Nationwide it ranks 5th among comprehensive universities, according to the 2020/21 Times Higher Education World University Ranking. See https://uni-freiburg.de/ for more information about the university rankings.

Image by Couleur from Pixabay

Prologue

Program Overview

Subject	Solar Energy Engineering
Degree	Master of Science (M.Sc.)
Duration of study	4-7 semesters depending on previous academic qualification and professional experience
Study format	Blended learning, part-time
Language	English
Type of course	Non-consecutive, Further Education Program (*Weiterbildung*)
University	University of Freiburg (Albert-Ludwigs-Universität)
Faculty	Faculty of Engineering
Institute	Department of Sustainable Systems Engineering - INATECH
Homepage	https://www.studysolar.uni-freiburg.de

A short profile of the degree

The Solar Energy Engineering program is a blended learning program designed to be studied next to a full-time job in any desired location in the world. It is suitable for graduates of physics, engineering, or similar fields with at least one year of work experience. The comprehensive curriculum trains highly qualified engineers with professional competence in theory, research, and applications. Full track and Expert track versions of the curriculum are designed to tailor this program for students' needs. The final semester is dedicated to the master's thesis. A unique option is the chance to spend the last semester in Freiburg and become part of the research environment in our cooperating institutes. Each module of the program has an exclusive character and is only available to the students of M.Sc. Solar Energy Engineering (PO 2021) program.

Admission requirements

- First academic degree in engineering or natural sciences (physics, chemistry, electronics, mechanical engineering, electrical engineering, material sciences, computer engineering, etc.).
- One year of work experience.
- Proof of English proficiency; minimum equal to B2 according to CEFR.

Note: Admission with an alternative bachelor's degree will be considered if the necessary mathematical and technical expertise is proved (e.g., relevant industrial experience).

Enrolment

Enrolment is possible for summer and winter semesters.

Note: In the German education system, the academic year is divided into the winter semester – from October to March and the summer semester – from April to September, with respective breaks between the semesters. Enrolment in the program is possible in both semesters, though it is recommended to start in the winter semester.

Program fees

Expert track: 18.000 €

Full track: 25.000 €

Note: There is an additional matriculation fee per semester. It is currently 190€ -status August 2026-, which is subject to change according to the State University Fees Act of Baden-Württemberg and the university's regulations.

Qualification goals and expertise to be achieved

The program provides subject-relevant skills ranging from

- understanding the **physical principles of solar cells, photovoltaic modules, solar radiation, and solar thermal applications**

to

- **developing, designing, analysing, and optimising photovoltaic systems and solar power plants**, while understanding their integration into energy networks and storage systems.

Students can specialise in one (or more) topics in solar energy, such as **solar cell technologies, photovoltaic systems and power plants, grid integration, energy storage, and emerging solar technologies**. After successful completion of the program, students can:

- Achieve a **qualitative and global understanding of today's and tomorrow's energy needs** and the role of solar energy in the energy transition.
- Understand the **physics of solar cells and photovoltaic energy conversion**, the integration of renewable energies into the power grid, and the fundamentals of energy storage applications.
- Understand the principles of **solar radiation, thermodynamics, heat transfer, solar thermal collectors, and solar thermal applications**.
- Develop and design **solar cells, photovoltaic modules, off-grid and grid-connected photovoltaic systems**, while applying knowledge of solar thermal technologies where relevant.
- Optimise and analyse **photovoltaic systems, components, and photovoltaic power plants**, taking innovation, efficiency, cost, reliability, and durability into account.
- Evaluate **new and emerging solar cell, photovoltaic, and solar energy technologies**.
- Apply the standards of **scientific writing, research, and presentation**.
- Conduct independent scientific research and create their scientific work in the form of a **Master's thesis**.
- Collaborate with **international students from all over the world**, working together effectively in digital teams and online learning environments.

Overview of All Modules and Sample Study Plan

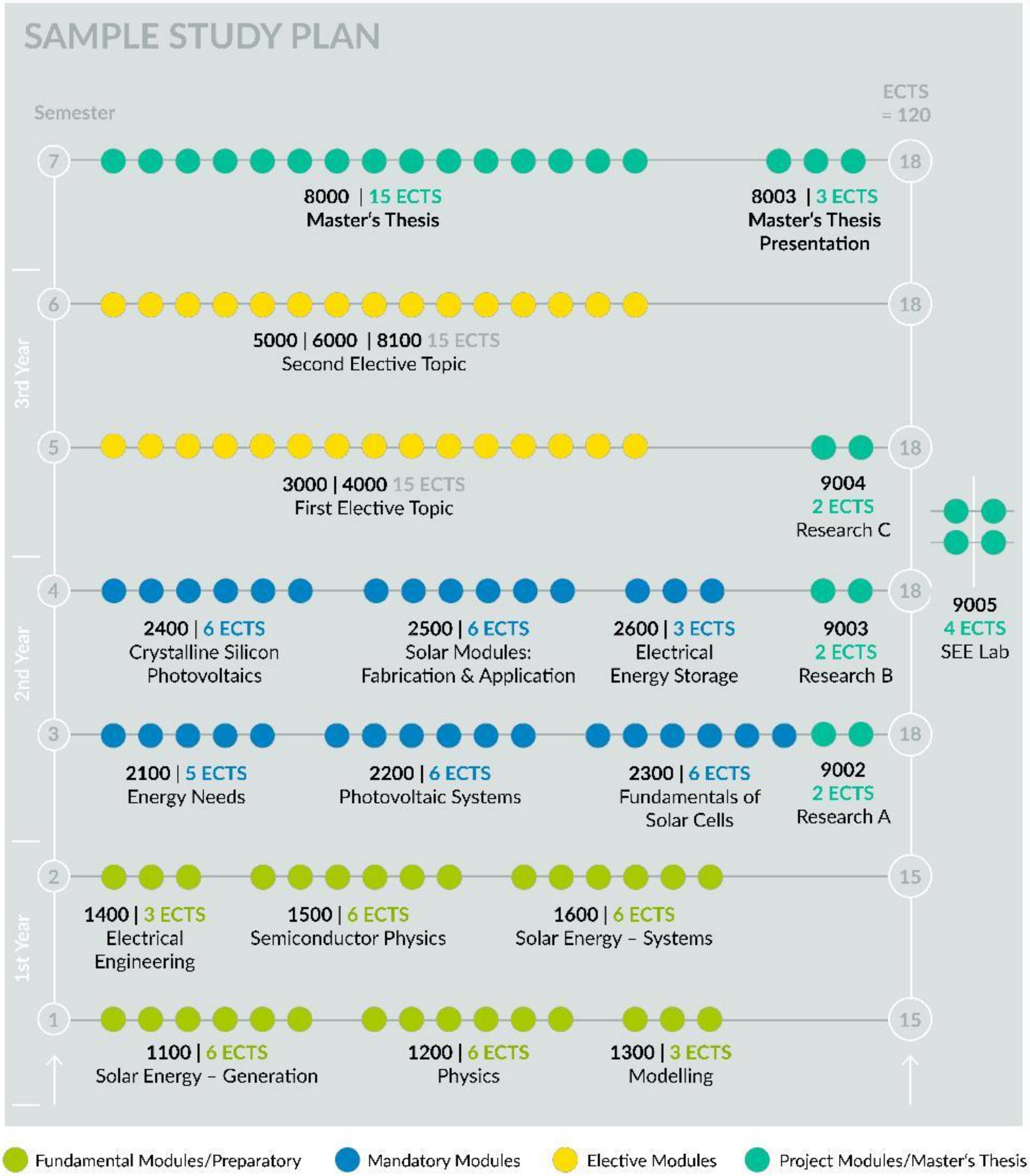


Figure 1: M.Sc. Solar Energy Engineering, an example overview of semesters distribution of modules throughout the years. Each module consists out of one or several different courses. The grading is done per module. So, these are the modules that will also occur on the final transcript. The graphic is designed from bottom to top, starting with the first semester. Each student has to pass two SEE-Labs. These short laboratory workshops can be done during the on-campus weeks in Freiburg during the semester breaks. The graphic shows the full track with an off-campus master's thesis option; different options are described in the following pages. The master's thesis is not necessarily connected to the semester rhythm. The thesis is individually supervised, and personal time plans will be applied.

Overview of All Courses

COURSE OVERVIEW

1000 | FUNDAMENTAL MODULES (FM) 30 ECTS

Recommended Semester: 1			
Module	**1100 | 6 ECTS** **Solar Energy – Generation** **PL (Assignment)**	**1200 | 6 ECTS** **Physics** **PL (Written exam)**	**1300 | 3 ECTS** **Modelling** **PL (Assignment)**
Course	1101 | 2 ECTS Solar Radiation and Solar Thermal Energy *Lecturer: S. Hess*	1201 | 6 ECTS Physics for Solar Engineers *Lecturer: M. Glatthaar*	1301 | 3 ECTS Parameter Estimation *Lecturer: M. Diehl*
Course	1102 | 2 ECTS Introduction to Solar Cells *Lecturer: R. Preu*		
Course	1103 | 2 ECTS Seminar on Technologies for Renewable Energy Conversion *Lecturer: T. Schlegl*		

Recommended Semester: 2			
Module	**1400 | 3 ECTS** **Electrical Engineering** **PL (Written exam)**	**1500 | 6 ECTS** **Semiconductor Physics** **PL (Written exam)**	**1600 | 6 ECTS** **Solar Energy – Systems** **PL (Assignment)**
Course	1401 | 3 ECTS Electrical Engineering for Solar Engineers *Lecturer: L. Reindl*	1501 | 4 ECTS Semiconductor Physics and Technology *Lecturer: M. Zacharias*	1601 | 4 ECTS Off-grid Solar Electricity *Lecturer: L. Probst*
Course		1502 | 2 ECTS Seminar: Selected Semiconductor Devices *Lecturer: O. Höhn*	1602 | 2 ECTS Introduction to Power Grids *Lecturer: V. Wachenfeld*

Figure 2: Overview of the fundamental modules. In the full track option, the Fundamental Modules are the content of the first year of studies. Each module consists out of one or several different courses. Grading is done per module.

COURSE OVERVIEW

2000 | MANDATORY MODULES (MM) 32 ECTS

Recommended Semester			
3			
Module	**2100 | 5 ECTS** **Energy Needs**	**2200 | 6 ECTS** **Photovoltaic Systems** **PL (Assignment)**	**2300 | 6 ECTS** **Fundamentals of Solar Cells** **PL (Written exam)**
Course	2101 | 5 ECTS The Global Energy Needs in a Nutshell *Lecturer: W. Hoffmann*	2201 | 6 ECTS Photovoltaic Systems – from Rooftop to Large Scale *Lecturer: R. Rüther*	2301 | 3 ECTS Physics of Solar Cells *Lecturer: U. Würfel*
4			
Module	**2400 | 6 ECTS** **Crystalline Silicon Photovoltaics** **PL (Written exam)**	**2500 | 6 ECTS** **Solar Modules: Fabrication & Application** **PL (Written exam)**	**2600 | 3 ECTS** **Electrical Energy Storage** **PL (Written exam)**
Course	2401 | 2 ECTS Feedstock and Crystallisation *Lecturer: M. Schubert*	2501 | 2 ECTS Silicon Module Technology and Reliability *Lecturer: H. Wirth*	2601 | 3 ECTS Electrical Energy Storage *Lecturer: A. Weidlich*
Course	2402 | 2 ECTS Silicon Solar Cells – Structure and Analysis *Lecturer: S. Glunz*	2502 | 2 ECTS Solar Modules: An Overview *Lecturer: H. Neuhaus*	
Course	2403 | 2 ECTS Solar Cell Production Technology *Lecturer: R. Preu*	2503 | 2 ECTS Agrivoltaics *Lecturer: M. Trommsdorff*	

Figure 3: Overview of the mandatory modules. Each student of the M.Sc. Solar Energy Engineering must complete these courses. They are the core curriculum of the degree. The Mandatory Modules are only offered in winter semesters. Each module consists out of one or several different courses. Grading is done per module.

Figure 4: Overview of the elective tracks. Each student must complete two of the elective tracks. Each track will take a complete semester. Some elective tracks are only offered in winter semesters and others only in summer semesters.

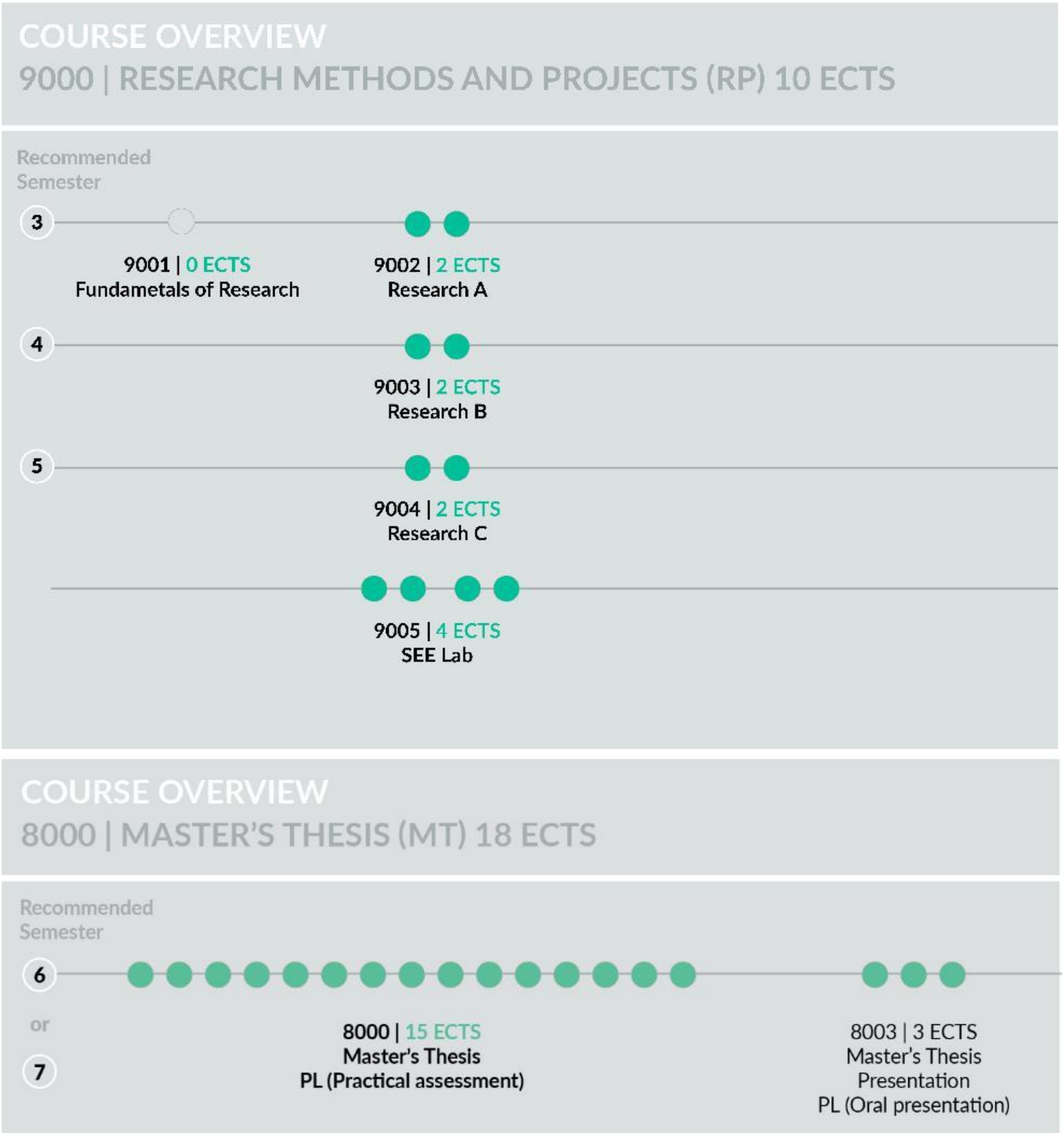


Figure 5: Overview of research projects, the SEE Lab and the master's thesis. Starting with a lecture about the fundamentals of research, students will conduct three research projects. By application, students will improve the writing and presentation skills needed to complete a well-written master's thesis. SEE Labs are offered by our partner – the Fraunhofer ISE in Freiburg. One time during their studies, students must join a three-day laboratory workshop in Freiburg. The SEE Labs are not connected to the semester rhythm. Students can freely choose in which semester they join these. In the final semester of the program, students conduct their master's thesis and present their results upon completion. The master's thesis is the crowning piece of the degree. Students will conduct their own research closely accompanied by our professors. There are options to do the master's thesis off-campus or on-campus. These are described in detail on the following pages.

Study Tracks and Important Components of the Degree Program

In this Module Handbook's context, a module refers to a self-contained unit about a scientific topic with specific learning objectives. Modules may consist of one or more courses. A course is the smallest unit described in this module handbook. Each course in the module should be passed to complete that module.

Full Track

Tracks refer to the study routes that students have to take to complete courses in the SEE curriculum. The full track of the SEE has a total workload of 120 ECTS. The first year of the full track covers the essential aspects of solar energy with the fundamental modules (30 ECTS), which consist of:

- Solar Energy Generation
- Physics
- Modelling
- Electrical Engineering
- Semiconductor Physics
- Solar Energy Systems

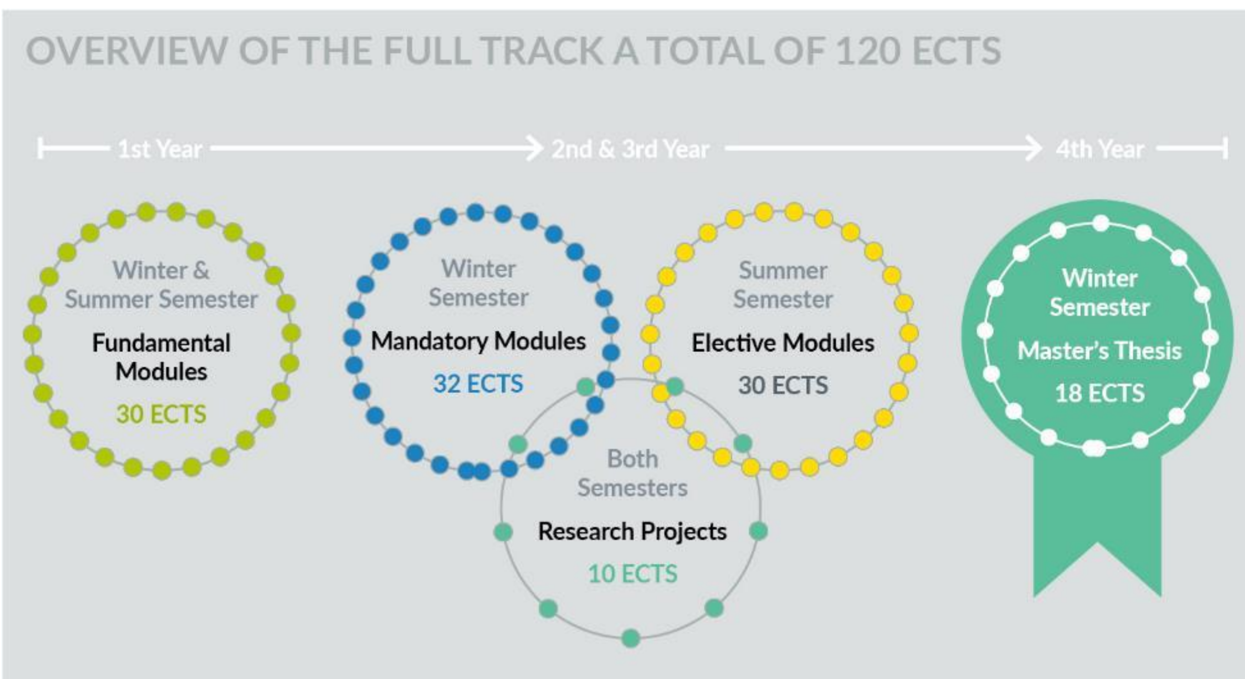


Figure 6: Overview of the full track. The full track has 120 ECTS. It is suitable for candidates who hold a previous 3–4-year bachelor's degree with a value of 180 – 239 ECTS in STEM subjects and at least one year of professional experience.

Thanks to the fundamental modules, students gain substantial knowledge in introductory subjects to solar energy, which prepares them for specialised courses in the mandatory modules (32 ECTS) that consist of:

- Energy Needs
- Photovoltaic Systems
- Fundamentals of Solar Cells
- Crystalline Silicon Photovoltaics
- Solar Modules: Fabrication & Application
- Electrical Energy Storage

Expert Track

The expert track of the SEE has a workload of 90 ECTS and is the right choice for students who have sound prior knowledge in the solar energy field and a B.Sc. /B.Eng. or M.Sc. degree that is equivalent to at least 240 ECTS (~5 years full-time study) in physics, electrical engineering, or similar fields with a solid background in the physics of semiconductors. Students who have sufficient experience and knowledge can skip the fundamental modules and directly start their first semester with the mandatory modules (32 ECTS), which is why this track is named expert track.

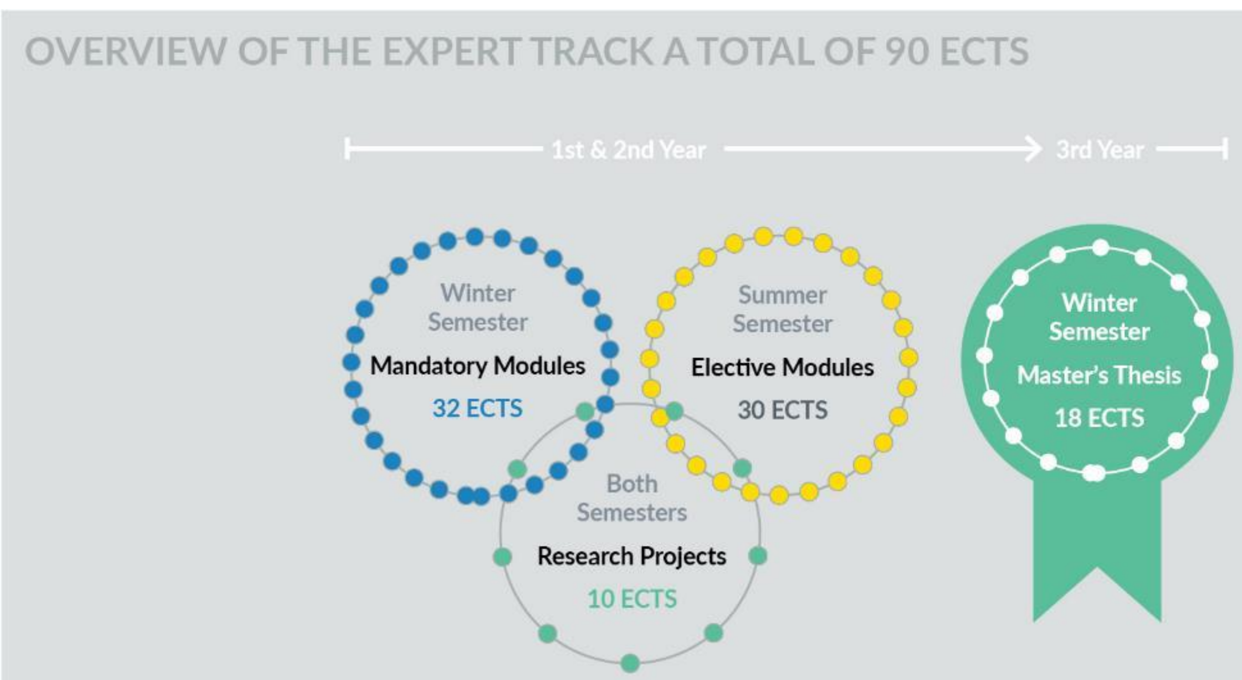


Figure 7: Overview of the expert track. The expert track is the 90 ECTS version of the program. Suitable for candidates who hold a previous master's or 5 years bachelor's degree in STEM subjects and professional experience in a closely related field.

Elective Modules

Elective module courses aim to train graduates who specialise in real-life applications of solar energy topics. Combining two elective modules provides in-depth knowledge and expertise in chosen topics while creating a clear path for possible research and future employment.

Each elective module is 15 ECTS. All students are required to choose two elective modules to earn 30 ECTS. Elective modules are:

- Solar Cell Technology (online)
- Solar Energy Integration into the Power Grid (online)
- Photovoltaic Power Plants (online)
- Smart and Integrated Photovoltaics: Design, Technologies, and Digitalization (online)
- Applied Research (on-campus)

The on-campus elective module, Applied Research, can only be taken in the last semester of studies. Students who choose the elective module Applied Research must combine their 3-month research duration with the master's thesis module and complete both in 6 months. Thus, the whole final semester is dedicated to research and thesis, and the master's thesis is conducted in Freiburg.

Research Projects

All students must complete three research projects (RP) in total. The RP offer training in scientific writing and presentation, which are crucial skills for successfully completing the master’s thesis. During the first semester, students join a Fundamentals of Research lecture, which introduces the principles and ethics of scientific and academic work in Germany.

Students conduct an individual research project each semester. Each project (named A, B, and C) lasts 1 semester. Highly qualified experts supervise and support students during their research. A written report and scientific presentation must be delivered at the end of each research; deadlines are specified throughout the semesters. Each project is concluded with a public presentation of the topic.

Master's Thesis

The culmination of the program is the master's thesis. There are two ways to conduct the thesis: students can either write an off-campus or an on-campus master's thesis.

- The off-campus master's thesis is written remotely.
- Students who want to write an on-campus master's thesis must join a research team in one of our cooperating institutes in Freiburg.
- Students who take the elective module Applied Research must conduct their master's thesis process in Freiburg.

Further details about the master's thesis are provided in the master's thesis course description section. A comprehensive guideline regarding the conduct of the whole master's thesis process will be provided. Students can access this guide via the online learning platform ILIAS once they are enrolled in the program.

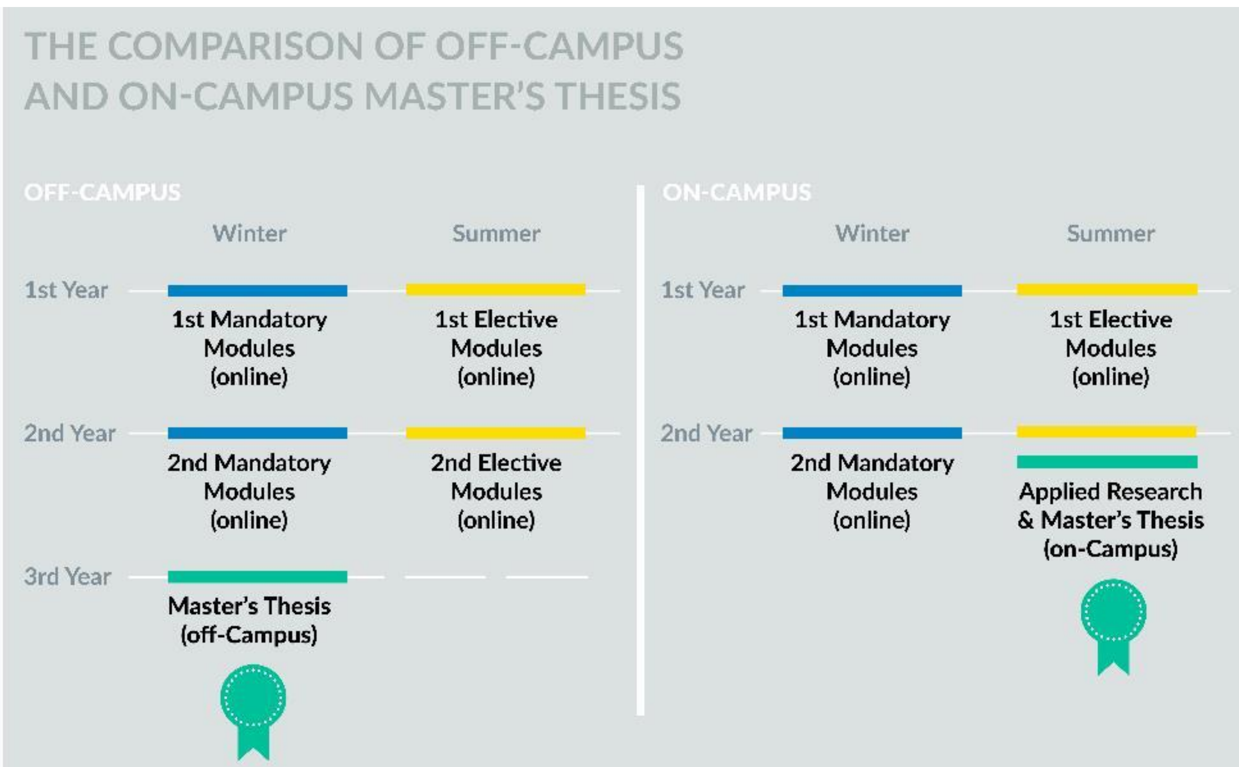


Figure 8: The comparison of off-campus and on-campus master's thesis. Overall study duration changes depending on the conduct of the master's thesis. The workload of the master's thesis is always 18 ECTS = 450 hours. The thesis can be either done full-time in Freiburg (3 months & on-campus); or next to one's job, part-time and remotely (6 months & off-campus). The Expert Track option is used for demonstration here; for a student in the Full Track, compare to ***Figure 6***.

Program Duration

Study duration ranges from 2 to 3.5 years (4 to 7 semesters) depending on students' previous education and preferred way to write their master's thesis.

Assessment Types

The courses are assessed either with a *Studienleistung* (SL), which refers to non-graded coursework, or a *Prüfungsleistung* (PL), which refers to assessed/graded coursework.

- A Studienleistung (SL) is a pass/fail assessment and must only be passed (min. 4.0 on a German grading scale). These assessments do not count into the final overall grade, even if they are graded. In other words, they can be graded but do not have to. A definition can be found in §13 of the General Examination Regulations. Studienleistungen are written, oral or practical assessments that students must complete in conjunction with the module/course.
- A Prüfungsleistung (PL) is a graded assessment. These assessments and their grades count into the final overall grade. A definition can be found in §14 of the General Examination Regulations. The types of PL are as follows; written Prüfungsleistungen are written supervised exams (Klausuren) and written reports (schriftliche Ausarbeitungen). Oral Prüfungsleistungen refer to oral exams (Prüfungsgespräche) and oral presentations. Practical Prüfungsleistungen consist of conducting experiments and the writing of a report. The duration of the written and oral assessments and the length of reports (e.g., number of pages) are usually defined in the module descriptions. Lecturers provide details in respective courses. Generally, written PL can have a duration of min. 60 minutes and max. 240 minutes. Oral PL can last min. 10 minutes and max. 30 minutes.

Explanation of the Grading and Examination System

Students need to achieve a grade of 4.0 (sufficient) in the German grading system to pass a course. For a more refined evaluation of assessed work, decimal grades may be given by raising or lowering the grade by 0.3. The grades 0.7, 4.3, 4.7, and 5.3 are barred. An overview of these grades is below.

Subject-related assessments must be conducted online and are supervised via webcam. If a student does not want to be supervised via camera, the assessment can be alternatively taken on-campus in Freiburg. The final grade is calculated with the arithmetic mean of the grades from each module. To be awarded credit points, students are required to:

- Actively take part in each course/seminar/hands-on of the module and its online meetings.
- Maintain a disciplined self-study routine and independently and adequately prepare for lectures and their reading materials.
- Pass the written and oral exams, perform oral presentations.
- Maintain academic honesty.

Exam, presentation, lab journal, or written report of each course/seminar/hands-on must be passed successfully to complete a given module.

EXPLANATION OF THE GRADING AND EXAMINATION SYSTEM

ECTS SYSTEM	GERMAN SYSTEM	EXPLANATION	DECIMAL GRADE	GRADE AWARDED
A	1	Excellent/ outstanding performance	1.0 to 1.5	Very good
B	2	Good performance that meets standards completely; above average	1.6 to 2.5	Good
C	3	Satisfactory/ average performance	2.6 to 3.5	Satisfactory
D	4	Sufficient/standard has been met but with several notable errors	3.6 to 4.0	Sufficient
F	5	Insufficient/failed	Higher than 4.0	Insufficient

Figure 9: The German grading system explained. The ECTS grading scale is a grading system defined in the European Credit Transfer and Accumulation System (ECTS) framework by the European Commission. On the left side of the graphic, the ECTS System is compared to the German numeric grading system. The decimal grades and their corresponding description are shown on the right side of the graphic. On the final transcript, an average grade for the whole program will be shown.

Failing and Repeating Assessments

Prüfungsleistungen (PL) that have been assessed with the grade “insufficient” (5.0) or are considered to fail can be repeated once. Before retaking an exam, the student can attend the class or classes relevant to the exam again. Also, a maximum of five failed examinations can be repeated a second time, with the provision that a maximum of two of these can be attributed to the fundamental modules and a maximum of four to the compulsory and elective areas. The second repeat exam will take place on the first possible regular exam date after the first repeat exam. Studienleistungen (SL) can be repeated as many times as needed until they are passed. SL can be graded but do not count towards the final grade.

Solar Energy Laboratory and On-campus Events

Each year, in mid-September, we offer one-week-long on-campus events in Freiburg. Students are required to join the on-campus week at least one time during their studies. Students can freely choose in which semester they will join. Two laboratory workshops that are offered each year are among the highlights of on-campus events. Each laboratory workshop is 2 ECTS. These lab internships can also be done in a laboratory in another country if the facility's infrastructure is compatible with Fraunhofer ISE (see Laboratory Course #9005: SEE Lab).

Additionally, throughout the week of on-campus events, students can deepen their understanding of solar energy topics thanks to invited speakers from the scientific field and industry. They also connect with the growing global community of solar energy, which creates a great networking opportunity. Besides, they have the chance to explore Europe's Solar City - Freiburg im Breisgau and to connect with fellow students.

Technical and Interdisciplinary Qualification Goals

Technical qualifications refer to specific abilities, such as knowledge of software, processes, machinery, and other work knowledge that applies to specific tasks. Interdisciplinary qualifications include but are not limited to what is referred to as soft skills such as communication, problem-solving, and teamwork.

Technical Qualification Goals

The program provides subject-relevant skills ranging from understanding the physical principles of solar cells, solar modules, and solar thermal collectors to developing and designing photovoltaic and solar thermal systems, assembling complex photovoltaic power plants, power stations, energy networks, and more. Students can specialise in one (or more) topics in solar energy, such as solar cell technologies, photovoltaic systems, solar thermal energy, grid integration, and electricity networks. After successful completion of the program, students can (depending on their specialisation):

- Implement scientific writing and presentation into the creation of their scientific work.
- Understand the physics of solar cells and evaluate innovative solar cell technologies.
- Construct a model of the integration of renewable energy into the power grid.
- Identify the fundamentals of storage applications and solar thermal systems.
- Develop and design solar cells, PV modules, off-grid and grid-connected PV systems, and solar thermal collectors.
- Optimise and analyse PV systems and photovoltaic power plants by considering innovation, efficiency, cost, and durability.
- Collaborate with international students in virtual teams.
- Achieve a strong understanding of current and future energy needs.

Finally, they can put the in-depth knowledge they gain in elective courses to use in several specialised areas of solar energy technologies.

Interdisciplinary Qualification Goals

Throughout the program, students will be involved in many discussions and assessments. They will get regular feedback from their instructors, tutors, and fellow students and become a part of a lively and engaging scientific culture. Students will achieve the competencies to:

- have originality in developing or applying their ideas, often in a research context. (e.g., students can conduct scientific research, write reports, give a lecture/presentation, or create a poster on solar energy-related topics.)
- show problem-solving abilities in new or unfamiliar environments within broader contexts. (e.g., students can use their expertise in various professional settings.)
- demonstrate their ability to integrate knowledge, handle complexity, and formulate judgments with incomplete data.
- convey their conclusions, knowledge, and rationale to specialist and non-specialist audiences.
- study in a largely self-directed or autonomous manner. (e.g., students can work on a given technical question largely independently.)

Institutes in Cooperation with the SEE Program

INATECH

The Department of Sustainable Systems Engineering – INATECH is the fruit of the partnership among the Albert Ludwigs University of Freiburg and five Freiburg Fraunhofer institutes. The focal research areas in INATECH are sustainable materials, energy systems, and resilience.

Sustainable energy systems research and photovoltaic technology teams at INATECH are led by our program coordinators Prof. Dr. Anke Weidlich and Prof. Dr. Stefan Glunz. See www.inatech.de/en/home

Fraunhofer Institute for Solar Energy Systems

The University of Freiburg has a longstanding scientific cooperation with the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE). Fraunhofer ISE was founded in 1981 in Freiburg. This institute is dedicated to promoting sustainable, economical, safe, and socially just energy systems worldwide. With an annual research budget of over 100 million Euros and over 1200 staff members, it is Europe's largest research institute in solar energy.

Through excellent research results, successful projects, industry partners, and global cooperation, Fraunhofer ISE plays a crucial role in shaping the worldwide energy system transformation. At Fraunhofer ISE, original ideas turn into innovations that benefit society and strengthen German and European economies. The specific areas that Fraunhofer ISE works in and students might conduct their research are:

I. Photovoltaics
II. Energy Efficient Buildings
III. Hydrogen Technologies and Electrical Energy Storage
IV. Solar Thermal Power Plants and Industrial Processes
V. Power Electronics, Grids, and Smart Systems

Many of our instructors are researchers and professors working at Fraunhofer ISE, which provides students with the opportunity of being close to the most recent research and innovation. A unique highlight of this program is the two hands-on workshops offered each September exclusively for the SEE students at the outstanding Fraunhofer ISE facilities.

Fraunhofer Academy

The SEE is a partner program of Fraunhofer Academy. Since 2006, the Fraunhofer Academy is the Fraunhofer-Gesellschaft's specialist provider in continuing education and part-time training for people in employment. Through diverse training programs, the Fraunhofer Academy passes the current knowledge and expertise of the Fraunhofer institutes onto private sector enterprises that seek to provide their employees with the best possible qualifications.

Forms of Teaching and Learning

We offer a flexible and online learning environment that gives students the freedom to study wherever and whenever they want next to their family and a full-time job. The teaching components of the SEE are:

- Regular online meetings and tutor-led live sessions
- Recorded video lectures
- Engagement in discussions in online forums
- Reading and exercise material specified for each course
- Exercise sheets and quizzes
- Scientific projects that are conducted with close supervision
- Student presentations
- Modelling and simulation tasks

Overall, in all courses, students are encouraged to participate actively and work in groups when necessary. Thus, fruitful discussions, engagement, and a productive learning environment are created. Students from all over the world can connect and network, thanks to this interactive and participation-oriented approach.

Program Fees and Funding Studies

The fees for the full track are 25.000 € (6-7 semesters). For the expert track, the fees are 18.000 € (4-5 semesters). Payments have to be done before each semester at rates of 4.000 € and 3.500 € for respective tracks. The master's thesis semester is 2.000 € for both tracks. An additional student activity and administrative fee (currently 180 € - status February 2024) applies for each semester; this fee is subject to change under §§ 1 to 3 of the Contribution Regulations of the "Studierendenwerk Freiburg" and the State University Fees Act of Baden-Württemberg (see the University webpage.)

Additional semesters after the official study time, a fee of 500€ per semester will be charged. Tuition fee payments must be made on time to maintain the student status. Applicants can check the following links for third party scholarship opportunities:

- www.daad.de
- www.mystipendium.de
- www.uni-freiburg.de

PROGRAM FEES

	FULL TRACK		EXPERT TRACK	
	August	February	August	February
1st Year	3 500 €	3 500 €	4 000 €	4 000 €
2nd Year	4 000 €	4 000 €	4 000 €	4 000 €
3rd Year	4 000 €	4 000 €	2 000 €	
4th Year	2 000 €			

+ Additional matriculation fee of ~161 € per semester

Figure 10: Overview of the semester fees for the M.Sc. Solar Energy Engineering: In each August and February, the fees for the next semester must be paid. Overall costs are, for the Full Track: 25.000 €, and for the Expert Track 18.000 €. Also, there is a student activity and administrative fee of 180€ (Status February 2024).

Further Career Opportunities and After Graduation

The solar PV industry retains the top spot, with 33% of the total renewable energy workforce (IRENA 2020, *Renewable Energy and Jobs*), and is estimated to grow more. A career in solar energy could take you to work outdoors on land or at sea, in an office or a laboratory. Besides, many roles provide travel opportunities and work in international environments.

As part of the clean energy economy, Solar Energy Engineers can design large-scale photovoltaic or solar thermal systems; after the design phase, they evaluate effectiveness, cost, reliability, and safety. They can work to integrate solar energy into the power grid safely, effectively, and efficiently. They can also provide technical direction or support to field teams during installation, start-up, testing, system commissioning. They can monitor performance and recommend necessary changes to achieve solar energy objectives.

So, what a solar engineer can do is versatile. In the rapidly developing solar industry, a little bit of imagination and passion are enough to play multi- and inter-disciplinary roles. For instance, software engineers can study this master's program and combine their solar knowledge with digital solutions in solar investment, simulations, operations, sales, customer service and more. Another possible path for graduates of this master's program is to engage in the research and development departments in the industry or the academics. The degree qualifies to enter a PhD program in Europe and beyond.

Many of our SEE students and alumni actively work as engineers and managers in the global solar energy industry. Graduates can start their own solar business or stay in academia to pursue a PhD. Whichever path they choose, they are sure to become essential agents in the ever-growing, international renewable energy arena. Some potential employers including, but not limited to, are equipment manufacturers, consulting companies, energy utility companies, government and non-government organisations, research and development departments.

Detailed Module and Course Descriptions

The master's program consists of fundamental modules, mandatory modules, elective modules, research projects, and the master's thesis.

#1000 Fundamental Modules: Overview

Fundamental Modules contain basic knowledge about solar energy (photovoltaic, thermal, and energy systems), physics, semiconductors, and electrical engineering fields. Fundamentals provide the knowledge needed to understand and apply solar energy engineering expertise and skills in practice. Fundamental Modules are recommended for students who do not have previous essential knowledge, experience, or training in the field of solar energy, as well as for those who would like to improve or brush up on their existing foundational understanding. Hence, #1000 modules are mandatory for the students of full track and suggested for the first year of study. In the table below, an overview of the six different fundamental modules is given.

Module	*Module Name*	*ECTS* (30)*	*Offered in***
1100	Solar Energy: Generation	6	Winter Semester
1200	Physics	6	Winter Semester
1300	Modelling	3	Winter Semester
1400	Electrical Engineering	3	Summer Semester
1500	Semiconductor Physics	6	Summer Semester
1600	Solar Energy: Systems	6	Summer Semester

**The European Credit Transfer and Accumulation System (ECTS) makes studies and courses more transparent.*
***Semester periods are Winter (October-March) and Summer (April-September).*

We observed that the knowledge of fundamentals is crucial for moving onto further modules. Since the SEE students come from diverse backgrounds and work experiences, the fundamental modules are beneficial for those who have been away from academia for a while or want to renew their confidence in these topics. Even though the courses in these modules are considered introductory, they are still comprehensive and subject-specific with respective learning objectives. After completing the fundamental modules, students can confidently take on the courses in mandatory modules and perhaps shape their specific interests in the solar energy field.

COURSE OVERVIEW

1000 | FUNDAMENTAL MODULES (FM) 30 ECTS

Recommended Semester			
1			
Module	**1100 | 6 ECTS** **Solar Energy – Generation** **PL (Assignment)**	**1200 | 6 ECTS** **Physics** **PL (Written exam)**	**1300 | 3 ECTS** **Modelling** **PL (Assignment)**
Course	1101 | 2 ECTS Solar Radiation and Solar Thermal Energy *Lecturer: S. Hess*	1201 | 6 ECTS Physics for Solar Engineers *Lecturer: M. Glatthaar*	1301 | 3 ECTS Parameter Estimation *Lecturer: M. Diehl*
Course	1102 | 2 ECTS Introduction to Solar Cells *Lecturer: R. Preu*		
Course	1103 | 2 ECTS Seminar on Technologies for Renewable Energy Conversion *Lecturer: T. Schlegl*		
2			
Module	**1400 | 3 ECTS** **Electrical Engineering** **PL (Written exam)**	**1500 | 6 ECTS** **Semiconductor Physics** **PL (Written exam)**	**1600 | 6 ECTS** **Solar Energy – Systems** **PL (Assignment)**
Course	1401 | 3 ECTS Electrical Engineering for Solar Engineers *Lecturer: L. Reindl*	1501 | 4 ECTS Semiconductor Physics and Technology *Lecturer: M. Zacharias*	1601 | 4 ECTS Off-grid Solar Electricity *Lecturer: L. Probst*
Course		1502 | 2 ECTS Seminar: Selected Semiconductor Devices *Lecturer: O. Höhn*	1602 | 2 ECTS Introduction to Power Grids *Lecturer: V. Wachenfeld*

Module #1100: Solar Energy: Generation

The solar energy generation module is designed to give fundamental knowledge about solar energy and its two significant applications: photovoltaics and thermal energy. The module consists of three courses: two courses are lecture-based, and one course is a seminar.

1. The first course "Solar Radiation and Solar Thermal Energy" gives an overview of solar geometry, solar radiation, basics of thermodynamics, fundamentals of solar thermal systems, different applications of solar thermal systems.
2. The second course "Introduction to Solar Cells" covers the basics of photovoltaic energy and solar cells, from the principles of photovoltaics to the energy yield of photovoltaic systems and the levelized cost of electricity.
3. The third "Seminar on Technologies for Renewable Energy Conversion" provides an overview of different renewable energy technologies, their characteristics, behaviour in the energy systems, economic and environmental specifications, advantages & disadvantages as well as the market situation. The idea behind this seminar is for you to become an "expert" on one of the topics covered.

In the following table, an overview of the module is given.

<table>
<tr><th>Total ECTS</th><th>Recommended Semester</th><th>Duration</th><th>Offer Frequency</th></tr>
<tr><td>6</td><td>1st</td><td>12 Weeks</td><td>Each winter semester</td></tr>
<tr><td colspan="2">Teaching Methods</td><td colspan="2">• Recorded lectures (asynchronous)
• Live-virtual meetings (synchronous)
• Exercises
• Essay presentation
• Literature review
• Simulation and modelling with POLYSUN</td></tr>
<tr><td colspan="2">Responsible Instructor</td><td colspan="2">Dr. Stefan Hess</td></tr>
<tr><td colspan="2">Grading</td><td colspan="2">Graded</td></tr>
<tr><td colspan="2">Assessment</td><td colspan="2">Written assignment applying Polysun software</td></tr>
<tr><td colspan="2">Courses</td><td colspan="2">1101: Solar Radiation and Solar Thermal Energy
1102: Introduction to Solar Cells
1103: Seminar on Technologies for Renewable Energy Conversion</td></tr>
<tr><td colspan="2">Usability of the Module</td><td colspan="2">Part of fundamental modules, mandatory for the full track students of the study program M.Sc. Solar Energy Engineering (PO 2021)</td></tr>
</table>

Course #1101 Solar Radiation and Solar Thermal Energy

ECTS	Lecturer	Tutor
2	Dr. Stefan Hess	Dr. Rebekka Eberle

Course Content

This course covers the following topics:

Course Content:

- Introduction to Solar Energy
- Solar Geometry
- Open and Closed Systems
- Laws of Thermodynamics
- Heat Transfer Mechanisms
- Solar Thermal Collectors and Systems
- Applications of Solar Thermal Energy

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending online meetings regularly and actively participating in the forum discussions
- Solving exercises with Polysun software

Approximate Workload (Total 50 h):

- 4 h live-online meetings
- 4 h recorded lectures
- 8 h exercises
- 14 h work with Polysun and preparing the assignment
- 20 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Have a general understanding of solar energy - from the sun to earth.
- ✓ Discuss and explain solar geometry, distribution of solar radiation over time and space.
- ✓ Have a broad understanding of work and heat and laws of thermodynamic.
- ✓ Explain different heat transfer forms and calculate heat transfer in simple applications (for example, solar thermal collectors, walls, windows, etc.)
- ✓ Explain the working principle of solar thermal collectors and systems.
- ✓ Discuss various fields of solar thermal applications.

Assessment

- Written assignment applying Polysun software
- Graded (PL), the grade obtained in this course applies to the whole module 1100

Software and Literature

Software:

- Polysun

Literature:

- S.-N. Boemi, O. Irulegi and M. Santamouris, Energy Performance of Buildings -Energy Efficiency and Built Environment in Temperate Climates, Springer International Publishing, 2016.
- U. Eicker, Solar Technologies for Buildings, Wiley, 2003.
- J. Duffie, W. Beckman and N. Blair, Solar Engineering of Thermal Processes, Photovoltaics and Wind, Wiley, 2020.

Course #1102: Introduction to Solar Cells

ECTS	Lecturer	Tutor
2	Dr. Ralf Preu	Dr. Rebekka Eberle

Course Content

Understanding the physics behind the photovoltaic energy conversions and solar cells' basics is an essential step for studying solar energy – particularly photovoltaics.

Course Content:

- Basics of Solar Cell Principles
- Characterisation of Silicon Photovoltaic Value Chain: Cell Technology
- Overview of Other Photovoltaic Technologies
- The Simple Design of Photovoltaic Systems and Energy Gain

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 50 h):

- 4 h recorded lectures
- 4 h live-online meetings
- 12 h exercises
- 30 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the working principle of photovoltaics.
- ✓ Describe the primary mechanism of photon absorption and carrier generation.
- ✓ Explain the dependency of solar cell performance on characteristic voltage and current.
- ✓ Understand the different optical and electrical loss mechanisms.
- ✓ Give a rough overview of the different technologies used for manufacturing photovoltaic modules.
- ✓ Identify important characterisation methods.
- ✓ Make simple energy yield calculations for PV systems.
- ✓ Recognise the cost issues and different scenarios for the photovoltaic technology.

Assessment

- Submission of 8 fully fullfilled exercises within the deadline
- Non-graded - Pass/Fail (SL)

Software and Literature

Literature:

- A. Smets, Solar Energy: The Physics and Engineering of Photovoltaic Conversion, Technologies and Systems, UIT Cambridge LTD, 2016.
- K. Mertens, Photovoltaics: Fundamentals, Technology, and Practice, 2nd ed., Wiley, 2018.
- P. Würfel and U. Würfel, Physics of Solar Cells – From Basic Principles to Advanced Concepts, Berlin: Wiley-VCH, 2016.
- M. Green, Solar Cells: Operating Principles, Technology and System Applications, UNSW Press, 1986.
- S. M. Sze and M.-K. Lee, Semiconductor Devices: Physics and Technology, Wiley, 2012.

Course #1103: Seminar on Technologies for Renewable Energy Conversion		
ECTS	**Lecturer**	**Tutor**
2	Dr. Andreas Velte-Schäfer	-

Course Content

This course is structured to get all the students on board for the conversion technologies for renewable resources.

Course Content:

- Wind Energy (onshore, offshore)
- Concentrated Solar Power (CSP, only thermal)
- Solar Poly Generation (Cooling, Process heat, Electricity)
- Combined Heat and Power
- Heat Pumps
- Bioenergy
- Energy Storage Technologies (electrical, thermal, chemical)
- Power to Gas
- Power to Liquid
- Fuel Cells
- Waste to Energy
- Small Hydro

Learning Method and Workload

Learning Method:

- Literature study on a selected topic
- Preparing a presentation with a scientific approach
- Writing a paper with a scientific approach

Approximate Workload (Total 50 h):

- 8 h live-online meetings
- 22 h self-study
- 20 h presentation and report preparation

Learning Objectives

After finishing this course, students should be able to

- ✓ Gain a basic but general understanding of the chosen topic.
- ✓ Assess the principles and technological characteristics, behaviour in the energy systems, economic and environmental aspects, advantages and disadvantages, market situation, etc., about the selected topic.
- ✓ Teach other participants about the technology.
- ✓ Demonstrate the ability for critical assessment and condense the literature on a selected topic.
- ✓ Get an overview of energy technology that contribute to a sustainable energy system.

Assessment

- Presentation (15 minutes) and written report about a chosen topic (1-3 pages)
- Non-graded - Pass/Fail (SL)

Software and Literature

Literature:

- D. Rekioua, Hybrid Renewable Energy Systems -Optimisation and Power Management Control, 1st ed., Springer International Publishing, 2020.
- V. Quaschning, Understanding Renewable Energy Systems, Routledge, 2016.
- M. Kaltschmitt, N. J. Themelis, L. Y. Bronicki, L. Söder and L. A. Vega, Renewable Energy Systems, Springer-Verlag New York, 2013.
- M. Kanoglu, Y. Cengel and J. Cimbala, Fundamentals and Applications of Renewable Energy, McGraw Hill Book co, 2019.
- M. Kaltschmitt, W. Streicher and A. Wiese, Eds., Renewable Energy -Technology, Economics and Environment, 1st ed., Springer-Verlag Berlin Heidelberg, 2007.

Module #1200: Physics

This module provides the fundamental knowledge of physics that is necessary to become a solar energy engineer. The module has one course worth 6 ECTS. It is a crash course that covers all introductory topics, i.e., mechanics, electrodynamics, optics, thermodynamics, and quantum mechanics. The course has a strong emphasis on essential topics for solar energy engineering to fit into one semester. Many topics that are irrelevant for solar energy engineering are left out. Still, when necessary, the course also goes beyond what is typically treated in introductory courses to provide students with the required knowledge for future classes of this master’s program.

<table>
<tr><th>Total ECTS</th><th>Recommended Semester</th><th>Duration</th><th>Offer Frequency</th></tr>
<tr><td>6</td><td>1st</td><td>12 Weeks</td><td>Each winter semester</td></tr>
<tr><td colspan="2">Teaching Methods</td><td colspan="2">• Self-study of manuscripts
• Recorded lectures (asynchronous)
• Live-virtual meetings (synchronous)
• Exercises</td></tr>
<tr><td colspan="2">Responsible Instructor</td><td colspan="2">Dr. Markus Glatthaar</td></tr>
<tr><td colspan="2">Grading</td><td colspan="2">Graded</td></tr>
<tr><td colspan="2">Assessment</td><td colspan="2">Online written exam with video supervision (duration: 75 minutes)</td></tr>
<tr><td colspan="2">Courses</td><td colspan="2">1201: Physics for Solar Engineers</td></tr>
<tr><td colspan="2">Usability of the Module</td><td colspan="2">Part of fundamental modules, mandatory for the full track students of the study program M.Sc. Solar Energy Engineering (PO 2021)</td></tr>
</table>

Course #1201: Physics for Solar Engineers		
ECTS	**Lecturer**	**Tutor**
6	Dr. Patrick Schygulla	-

Course Content

This course covers the following topics:

- Energy and Mechanics
- Electrodynamics
- Optics
- Quantum Mechanics
- Thermodynamics

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework
- Self-study of manuscripts

Approximate Workload (Total 150 h):

- 12 h live-online meetings
- 6 h recorded lectures
- 52 h exercises
- 80 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Have a general understanding of energy, work, and power.
- ✓ Explain the basics of electricity and conduct calculations with essential circuit components.
- ✓ Express (understand) Snell's law, reflection, diffraction, polarisation, and understand the application of Fresnel's formulas.
- ✓ Interpret De Broglie wavelength, calculate the photon's energy, explain the wave function of a particle, and clarify the energy levels in a bound state.
- ✓ Understand the basics of thermodynamic.

Assessment

- Online written exam with video supervision (duration: 75 minutes) - Graded (PL)
- Submission of fully fullfilled exercises within the deadline - Non-graded, Pass/Fail (SL)

Software and Literature

Literature:

- R. P. Feynman, R. B. Leighton and M. Sands, The Feynman Lectures on Physics, Addison–Wesley, 2005.

Module #1300: Modelling

Modelling is an essential part of all engineering fields. This module introduces methods to estimate parameters of discrete-time nonlinear models from measured data. The methods are applied in practical exercises and implemented using Matlab. Throughout this module, basic modelling tasks will be completed in exercises. In many practices, a solar module's modelling will be explored. At the end of this course, participants will be equipped to understand the scopes and limitations of modelling results.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
3	1st	12 Weeks	Each winter semester
Teaching Methods		• Recorded lectures (asynchronous) • Live-virtual meetings (synchronous) • Exercises • Project work	
Responsible Instructor		Prof. Dr. Moritz Diehl	
Grading		Graded	
Assessment		Project work applying MATLAB	
Courses		1301: Parameter Estimation	
Usability of the Module		Part of fundamental modules, mandatory for the full track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #1301: Parameter Estimation		
ECTS	**Lecturer**	**Tutor**
3	TBC	TBC

Course Content

This course covers the following topics:

- Introduction
- Statistical Estimators and Optimisation
- Linear Least Squares Estimation
- Weighted Least Squares Estimation
- Maximum Likelihood Estimation
- Nonlinear Least Squares Estimation

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving the assignment with MATLAB

Approximate Workload (Total 75 h):

- 10 h live-online meetings
- 10 h recorded lectures
- 20 h working on exercises
- 25 h Project work (MATLAB)
- 10 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the methods of parameter estimation and their mathematical derivation.
- ✓ Apply the learned methods to a given model and data.
- ✓ Assess the accuracy of the resulting estimate.

Assessment

- Project work: Simulation with MATLAB – Graded (PL)
- Submission of fully fullfilled exercises within the deadline - Non-graded, Pass/Fail (SL)

Software and Literature

Software:

- MATLAB

Literature:

- M. Diehl, Lecture Notes on Modelling and System Identification, 2020. [Online]. Available: https://www.syscop.de/files/2020ws/MSI/msi.pdf.
- J. Schoukens, System Identification, 2013. [Online]. Available: https://www.syscop.de/files/2015ws/msi/Schoukens_sysid_2013.pdf.
- L. Ljung, System Identification: Theory for the User, Prentice Hall, 1998.

Module #1400: Electrical Engineering

This module is designed to provide basic knowledge about electrical engineering, which is essential for students in the solar energy field and this master's program. This module has one course worth 3 ECTS. The course consists of fundamentals of mathematics and electrical engineering models, which are required to understand the operation of PV systems (DC), electricity grids (AC), and power electronics converters. It gives a basic introduction into electrical engineering in order to prepare the students for the contents of the mandatory modules. Topologies such as the buck-converter, boost-converter, single phase and three-phase inverter will be explained in detail.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
3	2^{nd}	6 Weeks	Each summer semester
Teaching Methods		• Recorded lectures (asynchronous) • Live-virtual meetings (synchronous) • Exercises • Tutorials	
Responsible Instructor		Prof. Dr. Leonhard Reindl	
Grading		Graded	
Assessment		Online written exam with video supervision (duration: 45 minutes)	
Courses		1401: Electrical Engineering for Solar Engineers	
Usability of the Module		Part of fundamental modules, mandatory for the full track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #1401: Electrical Engineering for Solar Engineers		
ECTS	**Lecturer**	**Tutor**
3	Prof. Dr. Leonhard Reindl	Akshay Mahajan

Course Content

This course covers the following topics:

- Basics of Electrical Energy Systems
- Power Semiconductors
- Buck and Boost Converters
- Single and Three-Phase Transformers
- Single and Three-Phase PV Inverters
- On-grid PV Inverters

Leaning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving the assignments

Approximate Workload (Total 75 h):

- 6 h live-online meetings
- 6 h recorded lectures
- 18 h exercises
- 45 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand and describe the electrical DC and AC processes in electrical power systems and converters mathematically.
- ✓ Explain the operating principles of basic power converter topologies.
- ✓ Model basic power converter topologies and describe the functions of active and passive components.

Assessment

- Online written exam with video supervision (duration: 45 minutes)
- Graded (PL)

Software and Literature

Literature:

- S. Makarov, R. Ludwig and S. J. Bitar, Practical Electrical Engineering, 1st ed., Springer International Publishing, 2016.

Module #1500: Semiconductor Physics

This module dives into details of what happens in a semiconductor at the molecular level. It also explains how it is produced. The module is divided into two parts: a lecture in the first part and a seminar in the second part.

1. In course "Semiconductor Physics and Technology", students learn how silicon semiconductors are constructed for solar cells and electrical circuits. Each step of their fabrication, starting with sand, is discussed. Also, the fundamental physics behind semiconductor devices is explained.
2. In the seminar "Selected Semiconductor Devices", each student must choose a semiconductor device, conduct a literature review, and give a presentation on that device. The devices introduced in this seminar are not only used in photovoltaics but usually have applications in nearly all fields of electronics. Additionally, devices complementary to solar cells, such as light emitting diodes are covered.

<table>
<tr><th>Total ECTS</th><th>Recommended Semester</th><th>Duration</th><th>Offer Frequency</th></tr>
<tr><td>6</td><td>2nd</td><td>12 Weeks</td><td>Each summer semester</td></tr>
<tr><td colspan="2">Teaching Methods</td><td colspan="2">• Recorded lectures (asynchronous)
• Live-virtual meetings (synchronous)
• Exercises
• Tutorials
• Literature review
• Preparing a presentation with a scientific approach
• Writing a paper with a scientific approach</td></tr>
<tr><td colspan="2">Responsible Instructor</td><td colspan="2">Prof. Dr. Oana Cojocaru-Mirédin</td></tr>
<tr><td colspan="2">Grading</td><td colspan="2">Graded</td></tr>
<tr><td colspan="2">Assessment</td><td colspan="2">Online written exam with video supervision (duration: 60 minutes)</td></tr>
<tr><td colspan="2">Courses</td><td colspan="2">1501: Semiconductor Physics and Technology
1502: Seminar: Selected Semiconductor Devices</td></tr>
<tr><td colspan="2">Usability of the Module</td><td colspan="2">Part of fundamental modules, mandatory for the full track students of the study program M.Sc. Solar Energy Engineering (PO 2021)</td></tr>
</table>

Course #1501: Semiconductor Physics and Technology

ECTS	Lecturer	Tutor
4	Prof. Dr. Oana Cojocaru-Mirédin	Vijay Vinod Karekar

Course Content

This course covers the following topics:

- Silicon Crystal Growth and Oxidation
- Lithography, Etching, and Doping
- Surface Coating, Metallization, and Cleaning
- CMOS Processing and Packaging
- Introduction to Semiconductor Devices
- Crystal Structure
- Energy Bands and Conductivity
- P-n Junction
- Solar Cells

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and active participation in the forum discussions
- Solving the given exercises

Approximate Workload (Total 100 h):

- 8 h live-online meetings
- 16 h recorded lectures
- 24 h exercises
- 52 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand how integrated circuits are built up and what equipment is needed for silicon-based technology.
- ✓ Assess the critical elements involved in each step of the production of silicon.
- ✓ Explain the crystal structure and imperfections.
- ✓ Describe the electronic band structure in metal, insulators, and semiconductors.
- ✓ Discuss the optical properties of semiconductors, doping, and carrier concentration at equilibrium.
- ✓ Illustrate p-n junction and IV characteristics.
- ✓ Understand the quantum charge transport mechanisms through insulators.
- ✓ Explain the basics of solar cells and energy conversion in solar cells.

Assessment

- Online written exam with video supervision (duration: 60 minutes)
- Graded (PL)- The grade obtained in this course applies to the whole module 1500

Software and Literature

Literature:

- K. Seeger, Semiconductor Physics -An Introduction, 9th ed., Springer-Verlag Berlin Heidelberg, 2004.
- J. C. Philips and G. Lucovsky, Bonds and Bands in Semiconductors, 2nd ed., Momentum Press, 2009.
- S. M. Sze and M.-K. Lee, Semiconductor Devices: Physics and Technology, John Wiley & Sons Ltd, 2008.
- M. J. Madou, Fundamentals of Microfabrication: The Science of Miniaturization, CRC Press, 2018.
- U. Hilleringmann, Silizium-Halbleitertechnologie, Springer, 2019.

Course #1502: Seminar: Selected Semiconductor Devices		
ECTS	**Lecturer**	**Tutor**
2	Dr. Oliver Höhn	-

Course Content

This course covers the following topics on Semiconductor Devices:

- PN Diode
- Esaki Diode/Tunnel Diode
- Schottky Diode
- Zener Diode
- Light-Emitting Diode
- Laser Diode
- Photodiode
- Bipolar Transistor
- Phototransistor
- Thyristor
- Field-effect Transistors

Learning Method and Workload

Learning Method:

- Literature study on a selected topic
- Preparing a presentation with a scientific approach
- Writing a paper with a scientific approach

Approximate Workload (Total 50 h):

- 8 h live-online meetings
- 30 h self-study
- 12 h presentation and report preparation

Learning Objectives

After finishing this course, students should be able to

- ✓ Describe existing semiconductor devices that are used in the context of PV energy conversion.
- ✓ Explain the working principles of semiconductor devices.
- ✓ Perform oral and written work on a scientific topic.
- ✓ Conduct independent research via literature and gain the potential for collaborative research.

Assessment

- Presentation (15 minutes) and written assignment (4-5 pages).
- Non-graded - Pass/Fail ((SL)

Software and Literature

Literature:

- S. M. Sze and M.-K. Lee, Semiconductor Devices: Physics and Technology, John Wiley & Sons Ltd, 2008.

Module #1600: Solar Energy Systems

An intelligent and robust system to distribute and store energy is a critical milestone to increase the share of renewable energy in the electricity grid. Renewable energy, especially, solar energy is subjected to intermittency. For example, during the night, there is no solar electricity, and during cloudy days the electricity supply is limited. Also, in remote places where there is no power supply facility yet, off-grid systems become essential. This unit covers the basics of an off-grid system and introduces the students to the power grid. The module contains two courses.

1. "Off-grid Solar Electricity" course is designed to give an overview of off-grid electricity, focusing on solar energy. The course covers the topics: Energy poverty & electricity access, Photovoltaic modules for off-grid applications, Batteries for off-grid applications, Charge controllers & maximum power point tracking, Micro-grids & conversion technology integration, Electrical loads: lighting, water pumping, cooling, & cooking, System design with software tools, Mounting/Installation of PV components and Operation & Maintenance.
2. The other course in this module "Introduction to Power Grids" introduces power grids and their operation. It covers generation stations, electrical substations, high voltage transmission lines, distribution stations, and distribution lines and gives an overview to the topic of electricity supply, concept of AC power supply and three-phase electric circuits. Mini and microgrids, grid elements are also discussed in this course. At the end of the course, renewable energy intergration and how to control the grid when the intermittent renewable energy is connected to the grid topics, will be explained.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
6	2nd	12 Weeks	Each summer semester
Teaching Methods		• Recorded lectures (asynchronous) • Live-virtual meetings (synchronous) • Exercises • Tutorials	
Responsible Instructor		Prof. Dipl. -Ing. Volker Wachenfeld	
Grading		Graded	
Assessment		Written scientific paper (contributes to 50% of the course grade) and presentation about a chosen topic (contributes to 50% of the course grade)	
Courses		1601: Off-grid Solar Electricity 1602: Introduction to Power Grids	
Usability of the Module		Part of fundamental modules, mandatory for the full track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #1601: Off-grid Solar Electricity

ECTS	Lecturer	Tutor
4	Leonhard Gandhi	-

Course Content

This course covers the following topics:

- Energy Poverty and Electricity Access
- Photovoltaic Modules for Off-grid Applications
- Batteries for Off-grid Applications
- Charge Controllers and Maximum Power Point Tracking
- Electrical Loads: Lighting, Water Pumping, Cooling, and Cooking
- System Design with Software Tools
- Mounting / Installation of PV components
- Operation & Maintenance

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Design-based learning
- Documentation of design, development, testing, and results

Approximate Workload (Total 100 h):

- 8 h live-online meetings
- 8 h recorded lectures
- 40 h modelling and testing of the off-grid electricity system
- 34 h self-study
- 10 h documentation of the testing of the off-grid electricity system

Learning Objectives

After finishing this course, students should be able to

- ✓ Design and build their solar off-grid system.
- ✓ Program their charge controller and control a solar mini-grid.
- ✓ Understand grid loads of an off-grid system and their effects on the system.
- ✓ Work out an operation and maintenance plan for an off-grid system.
- ✓ Assess the technical and economic aspects of solar off-grid systems.

Assessment

- Project work: Modelling and testing of an off-grid electrical system
- Non graded – Pass/Fail (SL)

Software and Literature

Literature:

- P. Mohanty, T. Muneer and M. L. Kolhe, Solar Photovoltaic System Applications -A Guidebook for Off-Grid Electrification, Springer International Publishing, 2016.
- H. Louie, Off-Grid Electrical Systems in Developing Countries, Springer International Publishing, 2018.

Course #1602: Introduction to Power Grids

ECTS	Lecturer	Tutor
2	Prof. Dr. Volker Wachenfeld	-

Course Content

This course covers the following topics:

- Concept of AC power supply
- Three-phase electric circuits
- mini-grids and microgrids Structure and elements of power grids
- Grid operation and ancillary services
- Renewable energy integration to the power grid
  - Frequency control
  - Voltage control

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving the assignments

Approximate Workload (Total 50 h):

- 4 h live-online meetings
- 8 h recorded lecture
- 6 h exercises
- 30 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the fundamentals of AC power supply
- ✓ Distinguish between mini-grid and microgrid structures.
- ✓ Describe the components and structure of an electrical power systems.
- ✓ Explain the principles of frequency control in an mini-grid and the utility grid
- ✓ Formulate the power flow problem for small grid structures.
- ✓ Understand voltage control for simple examples.
- ✓ Describe the challenges of renewable energy integration for the power grid.

Assessment

- Written scientific paper (contributes to 50% of the course grade) and presentation about a chosen topic (contributes to 50% of the course grade).
- Graded (PL) - The grade obtained in this course applies to the whole module 1600

Software and Literature

Literature:

- Glover, J. D., M. S. Sarma, T. J. Overbye: Power System Analysis & Design, 6th edition, Cengage Learning, 2017.
- [in German] Heuck, K., K.-D. Dettmann, D. Schulz: Erzeugung, Übertragung und Verteilung elektrischer Energie für Studium und Praxis, 9th edition, Springer Vieweg, 2013.
- Freris, L., D. Infield: Renewable Energy in Power Systems, Wiley, 2008.
- Wood, A. J., B. F. Wollenberg; G. B. Sheblé: Power Generation, Operation and Control, 3rd edition, Wiley, 2013.

#2000 Mandatory Modules: Overview

Mandatory modules contain advanced knowledge in solar energy (photovoltaics and energy systems), physics, semiconductors, and electrical engineering fields. The courses in these modules are designed to teach in-depth knowledge and specialised applications of solar energy engineering. From cell to the module level, from storage to energy needs, these modules are the backbone of solar energy engineering and this master's program. The courses in module #2000 are compulsory for both full and expert tracks. Students of full track should first cover the materials of #1000 modules to acquire the knowledge necessary for in-depth understanding of the #2000 modules.

Module	*Module Name*	*ECTS* (32)*	*Offered in***
2100	Energy Needs	5	Winter Semester
2200	Photovoltaic Systems	6	Winter Semester
2300	Fundamentals of Solar Cells	6	Winter Semester
2400	Crystalline Silicon Photovoltaics	6	Summer Semester
2500	Solar Modules: Fabrication & Application	6	Summer Semester
2600	Electrical Energy Storage	3	Summer Semester

**The European Credit Transfer and Accumulation System (ECTS) makes studies and courses more transparent.*
***Semester periods are Winter (October-March) and Summer (April-September).*

Beginning with a global look at the energy needs and energy's future, focusing on solar energy, students move onto the design, installation, and optimisation of PV systems from rooftop to large scale. Going back to the cell level in the Fundamentals of Solar Cells module, the physics, efficiency, and limitations of solar cells are explored. As can be seen from the table below, the ECTS per course is higher in mandatory modules compared to the fundamental modules, which means mandatory module courses are more demanding. Yet, they also provide the necessary theoretical and technical tools for becoming a full-equipped solar energy engineer.

In the module Crystalline Silicon PV, each course focuses on a different aspect of crystalline silicon solar cells. After finishing this module, students have a command on silicon PV from quartz level to the finished solar module. For students interested in the PV at the module level, Solar Modules: Fabrication & Application module presents an excellent opportunity to explore the practical aspects of solar modules from silicon module technology, reliability, and their various applications. The storage module wraps up the mandatory module courses by providing an insight into the electrical energy storage options for solar energy conversion and its integration into the grid. The mandatory modules are necessary to master crucial aspects of the solar energy field.

COURSE OVERVIEW
2000 | MANDATORY MODULES (MM) 32 ECTS

Recommended Semester			
3			
Module	**2100 | 5 ECTS** **Energy Needs**	**2200 | 6 ECTS** **Photovoltaic Systems** **PL (Assignment)**	**2300 | 6 ECTS** **Fundamentals of Solar Cells** **PL (Written exam)**
Course	2101 | 5 ECTS The Global Energy Needs in a Nutshell *Lecturer: W. Hoffmann*	2201 | 6 ECTS Photovoltaic Systems – from Rooftop to Large Scale *Lecturer: R. Rüther*	2301 | 3 ECTS Physics of Solar Cells *Lecturer: U. Würfel*
4			
Module	**2400 | 6 ECTS** **Crystalline Silicon Photovoltaics** **PL (Written exam)**	**2500 | 6 ECTS** **Solar Modules: Fabrication & Application** **PL (Written exam)**	**2600 | 3 ECTS** **Electrical Energy Storage** **PL (Written exam)**
Course	2401 | 2 ECTS Feedstock and Crystallisation *Lecturer: M. Schubert*	2501 | 2 ECTS Silicon Module Technology and Reliability *Lecturer: H. Wirth*	2601 | 3 ECTS Electrical Energy Storage *Lecturer: A. Weidlich*
Course	2402 | 2 ECTS Silicon Solar Cells – Structure and Analysis *Lecturer: S. Glunz*	2502 | 2 ECTS Solar Modules: An Overview *Lecturer: H. Neuhaus*	
Course	2403 | 2 ECTS Solar Cell Production Technology *Lecturer: R. Preu*	2503 | 2 ECTS Agrivoltaics *Lecturer: M. Trommsdorff*	

Module #2100: Energy Needs

This module provides comprehensive knowledge about global energy needs in the future. In this module, all renewable energy systems are introduced and discussed, with a particular focus on photovoltaic systems. The module consists of only one course, emphasising the importance of achieving 100% renewable energy goals with more pragmatic and industrial aspects.

In the course “The Global Energy Needs in a Nutshell” you will experience a journey starting from the early days of solar energy and wind towards 100% renewable energies for all secondary energy needs. The course starts with an analysis about the global energy needs as of today, the whole portfolio of renewable energy types and the general demand. Having these numbers in mind we then will have a look on the different renewable energy types, how they work and compare them to the conventional energy sources. Onwards the global energy market is analyzed and the role of the photovoltaic segment is highlighted. As it is important to understand the PV value chain in order to get a feeling why prices drop, the photovoltaic basics in physics and technology are given. We move on to a very clever instrument - the Price Experience Curve. For mass produced products it is possible by analyzing the past price development to predict the future price development with an astonishing accuracy. The course is then concluded with a look on storage systems and integration into the grid systems as well as some future scenarios that are most likely to happen based on recent market numbers.

<table>
<tr><th>Total ECTS</th><th>Recommended Semester</th><th>Duration</th><th>Offer Frequency</th></tr>
<tr><td>5</td><td>3rd</td><td>10 Weeks</td><td>Each winter semester</td></tr>
<tr><td colspan="2">Teaching Methods</td><td colspan="2">• Recorded lectures (asynchronous)
• Live-virtual meetings (synchronous)
• Exercises</td></tr>
<tr><td colspan="2">Grading</td><td colspan="2">Non-graded - Pass/Fail (SL)</td></tr>
<tr><td colspan="2">Responsible Instructor</td><td colspan="2">Dr. Winfried Hoffmann</td></tr>
<tr><td colspan="2">Courses</td><td colspan="2">2101: The Global Energy Needs in a Nutshell</td></tr>
<tr><td colspan="2">Usability of the Module</td><td colspan="2">Part of mandatory modules, compulsory for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)</td></tr>
</table>

Course #2101: The Global Energy Needs in a Nutshell

ECTS	Lecturer	Tutor
5	Dr. Winfried Hoffmann	Sebastian Illner

Course Content

This course covers the following topics:

- Today's Energy Picture and Future Energy Needs
- The Astonishing Predictive Power of Price-Experience-Curves
- Renewable Energies – Technology, Market and Applications
- Photovoltaics in Detail
- Electricity Storage
- Integration of Renewable Technologies into the Energy System
- Future Outlook towards 100% Renewables

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 125 h):

- 20 h recorded lectures
- 10 h live-online meetings
- 30 h exercises
- 65 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Achieve a qualitative and global understanding of today and tomorrow's energy needs.
- ✓ Explain the importance of energy efficiency.
- ✓ Construct and use Price Experience Curves to predict the future price trend of mass-produced and globally traded products (like PV modules and batteries).
- ✓ Understand the portfolio of all renewable technologies and their role in power the global needs by 100% renewables.
- ✓ Explain that PV and wind, together with storage, is key to 100% renewable energies.
- ✓ Assess why renewable energy is the best choice to fight climate change.
- ✓ Understand the future renewable energy scenarios published by various organizations (e.g., IEA, BP, and others) and compare these critically with our 100% scenario.

Assessment

- Handing over assignments on time
- Non graded – Pass/Fail (SL)

Software and Literature

Literature:

- W. Hoffmann, The Economic Competitiveness of Renewable Energies: Pathways to 100% Global Coverage, John Wiley & Sons Incorporated, 2014.
- World Energy Outlook, International Energy Agency (IEA).
- Global Market Outlook, SolarPower Europe.
- Energy Outlook, BP, 2020 Edition.
- Renewables: 2020 Global Status Report www.ren21.net.

Module #2200: Photovoltaic Systems

This module dives into various topics related to the design, installation, and optimisation of photovoltaic (PV) systems in the field. The knowledge provided in this module helps students to understand the interaction among several system components, as well as their influence on PV energy production.

The module consists of one course “Photovoltaic Systems – From Rooftop to Large Scale”. In this course, students design their own project using the software PVSyst and get customized feedback from their lecturers.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
6	3rd	12 Weeks	Each winter semester
Teaching Methods		• Recorded lectures (asynchronous) • Live-virtual meetings (synchronous) • Exercises • Assignments	
Grading		Graded	
Assessment		Project work by PVSyst	
Responsible Instructor		Prof. Dr. Ricardo Rüther	
Courses		2201: Photovoltaic Systems – From Rooftop to Large Scale	
Usability of the Module		Part of mandatory modules, compulsory for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #2201: Photovoltaic Systems – From Rooftop to Large Scale

ECTS	Lecturer	Tutor
6	Prof. Dr. Ricardo Rüther	Marília Braga

Course Content

This course covers the following topics:

- Fossil Fuels and Solar Irradiance
- Electrical Modelling of PV Cells
- Electrical Modelling of PV Systems
- Basics of On-grid PV Systems: Components
- Basics of On-Grid PV Systems: An Introduction to PVsyst® Software Tool
- Solar Concentration and Tracking
- Quality, Optimisation, and Performance Control
- Basics of Off-Grid and Min-Grid PV Systems
- Components of Off-Grid PV Systems

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Writing critical essays about current publications
- Preparing a project with PVSyst software tool

Approximate Workload (Total 150 h):

- 20 h recorded lectures
- 10 h live-online meetings
- 60 h project work with PVSyst software
- 20 h writing critical essays
- 40 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand and explain why solar photovoltaic systems are essential for our energy mix.
- ✓ Describe solar irradiance and its measurement.
- ✓ Understand what the optimal orientation and tilt angle are of a solar array.
- ✓ Interpret electrical modelling of PV Cells: Ideal PV Cell, 1-diode model, 2-diode model and consequences of irradiance and temperature fluctuation on a PV cell.
- ✓ Outline the electrical modelling of PV modules: Series, parallel connection of PV cell, and reverse current and voltage.
- ✓ Investigate the sources of shadings and their influence on the IV curve of a solar module.
- ✓ Describe the impact of module cooling and soiling on a solar module's performance.
- ✓ Explain the components of on-grid PV systems.
- ✓ Classify and explain different PV inverters and PV mounting systems.
- ✓ Size and simulate an on-grid PV system using a software tool.
- ✓ Understand solar concentration and tracking.
- ✓ Perform quality check, optimisation, and quality control.
- ✓ Explain the basics of off-grid and mini-grid PV systems.
- ✓ Describe the components for off-grid PV systems.

Assessment

- Writing critical essays (12 essays, ca. 1 page each) - Non graded (SL)
- Preparing a project work by PVSyst – Graded (PL)

Software and Literature

Software:

- PVsyst

Module #2300: Fundamentals of Solar Cells

This module teaches the physics behind the solar cell and the various aspects of solar cell functionality. Also, improving and increasing the efficiency of solar cells and their limits are described. This module consists of one course, which builds the base for all solar cell-related modules in the rest of this program. Thus, this course is a prerequisite for all scientific and technological activities in the photovoltaics field.

<table>
<tr><th>Total ECTS</th><th>Recommended Semester</th><th>Duration</th><th>Offer Frequency</th></tr>
<tr><td>6</td><td>3rd</td><td>12 Weeks</td><td>Each winter semester</td></tr>
<tr><td colspan="2">Teaching Methods</td><td colspan="2">• Recorded lectures (asynchronous)
• Live-virtual meetings (synchronous)
• Exercises
• Assignments</td></tr>
<tr><td colspan="2">Grading</td><td colspan="2">Graded</td></tr>
<tr><td colspan="2">Assessment</td><td colspan="2">Online written exam with video supervision (duration: 75 minutes)</td></tr>
<tr><td colspan="2">Responsible Instructor</td><td colspan="2">Dr. Uli Würfel</td></tr>
<tr><td colspan="2">Courses</td><td colspan="2">2301: Physics of Solar Cells</td></tr>
<tr><td colspan="2">Usability of the Module</td><td colspan="2">Part of mandatory modules, compulsory for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)</td></tr>
</table>

Course #2301: Physics of Solar Cells

ECTS	Lecturer	Tutor
6	Dr. Uli Würfel	Mohamed Mahmoud

Course Content

This course covers the following topics:

- Introduction
- Principle Structure
- Conversion Efficiency and Solar Spectrum
- Limitations of Solar Cell Performance: Spectral and Current Losses
- Limitation of Solar Cell Performance: Voltage Limitation
- Limitation of Solar Cell Performance: Fill Factor Losses

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 150 h):

- 10 h recorded lectures
- 10 h live-online meetings
- 30 h exercises
- 100 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the fundamental physical processes of photovoltaic energy conversion.
- ✓ Describe the operating principles of photovoltaic devices.
- ✓ Apply the knowledge of photovoltaic energy conversion and operating principles of photovoltaic devices to any kind of solar cell.

Assessment

- Online written exam with video supervision (duration: 75 minutes)
- Graded (PL)

Software and Literature

Literature:

- P. Würfel and U. Würfel, Physics of Solar Cells -From Basic Principles to Advanced Concepts, Berlin: Wiley-VCH, 2016.

Module #2400: Crystalline Silicon Photovoltaics

In this module, students get an overview and basic understanding of the value chain of silicon solar cells. The course ranges from the production of silicon feedstock from quartz sand to the finished solar cell.

This module includes contributions by experts in the field who discuss aspects of their work in scientific research and development. The module covers three main topics:

1. The first topic, Silicon: Feedstock, Crystallisation and Wafering, introduces the students to the main industrial production methods to create silicon wafers for solar cell fabrication. It also discusses alternative production routes and their advantages and disadvantages. The main topics discussed include the Siemens purification process, the Czochralski crystallisation method and wafering. Alternative pathways discussed include directional solidification, direct wafer fabrication and alternative feedstock sources.
2. The second topic, Silicon Solar Cells: Structure and Production, covers how the most common solar cell structures were derived and discusses the central production steps. The topics discussed include the PERC and TOPCon solar cell concepts and important aspects of industrial solar cell production.
3. The third topic, Improvement of Solar Cells, gives insights into the development of solar cells by discussing how numeric simulation and characterization of limitations factor into development cycles. The topic also includes a discussion of more advanced solar cell concepts and a perspective on the advent of industrial terrestrial silicon-based tandem solar cells.

<table>
<tr><th>Total ECTS</th><th>Recommended Semester</th><th>Duration</th><th>Offer Frequency</th></tr>
<tr><td>6</td><td>3rd or 4th</td><td>12 Weeks</td><td>Each summer semester</td></tr>
<tr><td colspan="2">Teaching Methods</td><td colspan="2">• Recorded lectures (asynchronous)
• Live-virtual meetings (synchronous)
• Exercises
• Group Assignment</td></tr>
<tr><td colspan="2">Grading</td><td colspan="2">Graded</td></tr>
<tr><td colspan="2">Assessment</td><td colspan="2">Online written exam with video supervision (duration: 90 minutes). The exam questions cover all 3 courses in the module (1/3rd of questions from each course)</td></tr>
<tr><td colspan="2">Responsible Instructor</td><td colspan="2">Dr. Tim Niewelt</td></tr>
<tr><td colspan="2">Courses</td><td colspan="2">2401: Crystalline Silicon Photovoltaics</td></tr>
<tr><td colspan="2">Usability of the Module</td><td colspan="2">Part of mandatory modules, compulsory for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)</td></tr>
</table>

Course #2401: Crystalline Silicon Photovoltaics

ECTS	Lecturer	Tutor
6	Dr. Tim Niewelt, Dr. Martin Schubert, Prof. Dr. Stefan Glunz, Dr. Ralf Preu	Dr. Tim Niewelt

Course Content

This course covers the following topics:

- Reduction of Quartz to Silicon and Purification
- Czochralski Crystallisation Technique and Wafering
- Alternative Silicon Wafer Fabrication Approaches
- Relevant Solar Cell Concepts for Industrial Solar Cell Fabrication
- Developments from Al-BSF to PERC and to modern Solar Cells
- Passivating Contacts Technology
- Production Steps of Industrial Solar Cell Fabrication
- Fundamentals of Characterisation and Simulation for Solar Cell Development

Learning Method and Workload

Learning Method:

- Working through interactive course pages
- Studying recorded lectures
- Solving exercises and simulation tasks
- Attending online meetings
- Participating in discussions on the course forum

Approximate Workload (Total 50 h):

- ca. 10 hours of recorded lectures and materials
- ca. 7 hours of live online meetings
- ca. 20 hours of exercises and a group task+report
- ca 113 hours of self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the conventional fabrication route for solar cell wafers from quartz sand.
- ✓ Differentiate central aspects of silicon wafers depending on how they were produced
- ✓ Explain the main properties of silicon wafers that affect the efficiency of fabricated solar cells
- ✓ Assess trends in wafer fabrication and possible alternatives
- ✓ Describe the Al-BSF and the PERC solar cell concepts and their core differences
- ✓ Name and discuss the important production steps of silicon solar cell fabrication
- ✓ Discuss solar cell improvement based on iterative and disruptive improvements
- ✓ Recognise the benefit of characterisation and simulation of solar cell limitations
- ✓ Perform basic simulation tasks in Quokka3
- ✓ Explain core aspects of improved solar cell concepts

Assessment

- Online written exam with video supervision (graded, PL)
- Written report on group project work (not graded, SL)

Software and Literature

Required software and literature for additional reading are provided within the course

Module #2500: Solar Modules – Fabrication & Application

This module focuses on the practical aspects of solar modules. It is divided into three parts: the first part is about silicon module technology and reliability; the second course is an overview of different types of solar modules. The final course is about the applications in building-integrated photovoltaics (BIPV).

1. "Silicon Module – Technology and Reliability" course focuses on interconnection and safe packaging of solar cells into modules to generate electricity reliably. The associated module technology must provide a product that can operate for 20–25 years.
2. "Solar Modules: An Overview" course gives an overview of different module technologies. It starts with a historic overview of the evolution of PV modules looking into different PV technologies and changes that took place over the years. The current product landscape is discussed comparing thin-film modules and latest developments in crystalline silicon photovoltaics. We will benchmark different technologies considering module efficiencies, cost, lifetime energy yield, levelized cost of electricity & sustainability aspects. Finally, a technology outlook is given considering cost, resources & environmental limitations.
3. The last course "Agrivoltaics" dives into the world of agrivoltaics. You learn about a technology that allows to combine food and energy production at the same time on the same place. By installing PV modules over or in between agricultural fields, not only solar energy is genereted but the modules are shadowing the plants which makes them more resilient to events like heavy rain, hail or droughts.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
6	4th	12 Weeks	Each summer semester
Teaching Methods		• Recorded lectures (asynchronous) • Live-virtual meetings (synchronous) • Exercises • Assignments	
Grading		Graded	
Assessment		Online written exam with video supervision (duration: 90 minutes). The exam questions covers all 3 courses in the module (1/3rd of questions from each course)	
Responsible Instructor		Dr. Holger Neuhaus	
Courses		2501: Silicon Module – Technology and Reliability 2502: Solar Modules: An Overview 2503: Agrivoltaics	
Usability of the Module		Part of mandatory modules, compulsory for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #2501: Silicon Module: Technology and Reliability

ECTS	Lecturer	Tutor
2	Dr. Holger Neuhaus	Dr. Paul Gebhardt

Course Content

This course covers the following topics:

- Cell Interconnection
- Encapsulation and Cover Material
- Production and Characterisation
- Nominal Power and Efficiency
- Performance
- Reliability
- Sustainability
- Customised Designs

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 50 h):

- 5 h recorded lectures
- 3 h live-online meetings
- 12 h exercises
- 30 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Explain cell interconnection, encapsulation, and cover materials.
- ✓ Discuss the production and characterisation of solar modules and quality control.
- ✓ Interpret Solar Module Electrical Properties.
- ✓ Examine Cell to Module Power and Efficiency.
- ✓ Assess the Cell to Module (CTM) factors and their effects on module performance.
- ✓ Characterise the energy yield and discuss the effect of incident angle modifier (IAM), bifaciality.
- ✓ Assess LCOE, discuss service life and degradation.
- ✓ Explain stress factors and failure modes.
- ✓ Explain basic module testing procedures and degradation indicators.
- ✓ Discuss energy payback time, energy return on investment, and sustainability of PV modules.
- ✓ Introduce customized solar module design.

Assessment

- Online written exam with video supervision (Contributes to 1/3 of the questions in the module exam)
- Graded (PL)

Software and Literature

Literature:

- H. Wirth, Photovoltaic Module Technology, 2nd ed., De Gruyter, 2021.

Course #2502: Solar Modules: An Overview

ECTS	Lecturer	Tutor
2	Dr. Holger Neuhaus	Pamela Molina, Alexander Protti

Course Content

This course covers the following topics:

1. **Historical Evolution of PV Modules**
- Hope and Fall of a-Si
- Unbeatable Low Cost of CdTe
- The Effort to Reduce Silicon Consumption (EFG, …)
- Cz Finally Prevails over mc
- PERC Displaces BSF
- Wafer Size Evolution
- From Flat to Round Wire Interconnection

2. **State-of-the-art Module Technology and Product Landscape**
- CIS, CdTe
- PERC, HJT, TOPCon
- Wire Interconnection and Shingling
- Si/Perovskite Tandem

3. **Manufacturing Landscape**
- Production Flows and Complexity
- Fab Evolution and Throughput
- The Main Driver of Cost Reduction

4. **Benchmark of the Product Landscape**
- Lifetime Energy Yield
- Levelized Cost of Electricity
- LCA and Recycling

5. Technology and Product Trends
- What is Coming Next?
- Which Cost Can be Reached?
- Environmental Impact and Resource Use

Learning Method and Workload

Learning Method:
- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework using SmartCalc software

Approximate Workload (Total 50 h):
- 6 h recorded lectures
- 5 h live-online meetings
- 14 h exercises
- 25 h self-study

Learning Objectives

After finishing this course, students should be able to
- ✓ Discuss the basics of solar modules.
- ✓ Distinguish and compare different types of solar modules.
- ✓ Outline the fabrication steps of solar modules.
- ✓ Discuss the various factors that need to be taken care of during the fabrication process to improve a module's performance.

Assessment
- Online written exam with video supervision (Contributes to 1/3 of the questions in the module exam)
- Handing over assignments on time
- Graded (PL)

Software and Literature

Software:
- SmartCalc software

Course #2503: Agrivoltaics		
ECTS	**Lecturer**	**Tutor**
2	Dr. Max Trommsdorff	-

Course Content

This course covers the following topics:

- Relevance, history and market development of agrivoltaics
- Classification and standards of agrivoltaics
- Basics of agriculture, value creation and environmental influences
- Relevance of PV and functionality of PV components
- Market development, cost trends of PV worldwide
- System design, crop suitability, and water management
- Socio-economic aspects of agrivoltaics

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 50 h):

- 5 h recorded lectures
- 6 h live-online meetings
- 14 h exercises
- 25 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the relevance of agrivoltaics.
- ✓ Give an overview about history and market development of agrivoltaics.
- ✓ Understand the technical functioning of a PV system.
- ✓ Understand the mechanism in the agricultural sector.
- ✓ Discuss the relevance of agriculture, most important crops and machinery used.
- ✓ Distinguish the most relevant technical aspects of agrivoltaics including system design.
- ✓ Explain the socio-economic aspects of agrivoltaics

Assessment

- Online written exam with video supervision (Contributes to 1/3 of the questions in the module exam)
- Graded (PL)

Software and Literature

-

Module #2600: Energy Storage

Energy storage plays a vital role on the road for achieving 100% renewable energy in the energy share. The essential forms of renewable energy such as solar and wind are intermittent; so, uninterrupted energy storages are necessary. This module focuses on various forms of energy storage with electrical energy storage. This module consists of one course which focuses on electrical energy storage options for solar energy generation and its integration into the grid. Techno-economic aspects of various forms of electricity storage are also discussed.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
3	4^{th}	6 Weeks	Each summer semester
Teaching Methods		• Recorded lectures (asynchronous) • Live-virtual meetings (synchronous) • Exercise • Assignments	
Grading		Graded	
Assessment		Online written exam with video supervision (duration: 45 minutes)	
Responsible Instructor		Dr. Peter Schossig	
Courses		2601: Energy Storage	
Usability of the Module		Part of mandatory modules, compulsory for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #2601: Energy Storage		
ECTS	**Lecturer**	**Tutor**
3	Dr. Sebastian Gamisch, Dr. Tom Smolinka, Dr. Andreas Georg, Dr. Robert Kohrs	-

Course Content

This course covers the following topics:

- Mechanical Energy Storage
- Electric and Electrochemical Energy Storage
- Battery Storage Systems incl. Lithium-ion and non-lithium based Batteries (Modules, System Design, Management, System Integration, Auxiliary Components)
- Applications of Battery Systems
- Techno-economic Assessment of Batteries
- Hydrogen, Fuel Cells and Electrolysis
- Technical Applications and Power-to-X
- Thermal Energy Storage

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 75 h):

- 10 h recorded lectures
- 10 h live-online meetings
- 20 h exercises
- 35 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Argue why storage is necessary for the renewable energy transition.
- ✓ Describe electrochemical energy storage.
- ✓ Understand mechanical and electromagnetic energy storage.
- ✓ Classify battery storage technologies.
- ✓ Explain hydrogen storage and the principle behind it.
- ✓ Perform the techno-economic evaluation of electrical energy storage technologies.
- ✓ Introduce other energy storage technologies: Thermal storage and pumped hydro storage.

Assessment

- Online written exam with video supervision (duration: 45 minutes)
- Graded (PL)

Software and Literature

Literature:

- T. Letcher, Ed., Storing Energy, 1st ed., Elsevier, 2016.
- G. Pistoia, Ed., Lithium-Ion Batteries Advances and Applications, Elsevier, 2014.
- P. T. Moseley and J. Garche, Eds., Electrochemical Energy Storage for Renewable Sources and Grid Balancing, 1st ed., Elsevier, 2014.

Elective Modules: Overview

Elective Modules contain advanced and specialized knowledge in solar cells, photovoltaics systems, solar energy integration and thermal energy systems. Students of full and expert track must first cover the material of mandatory #2000 modules to acquire in-depth knowledge of solar cells and modules, solar energy, physics, semiconductors, and electrical engineering fields, based on which they can further select their specialization track. There are five elective tracks, as shown below. Students must choose two tracks out of five to complete the elective module.

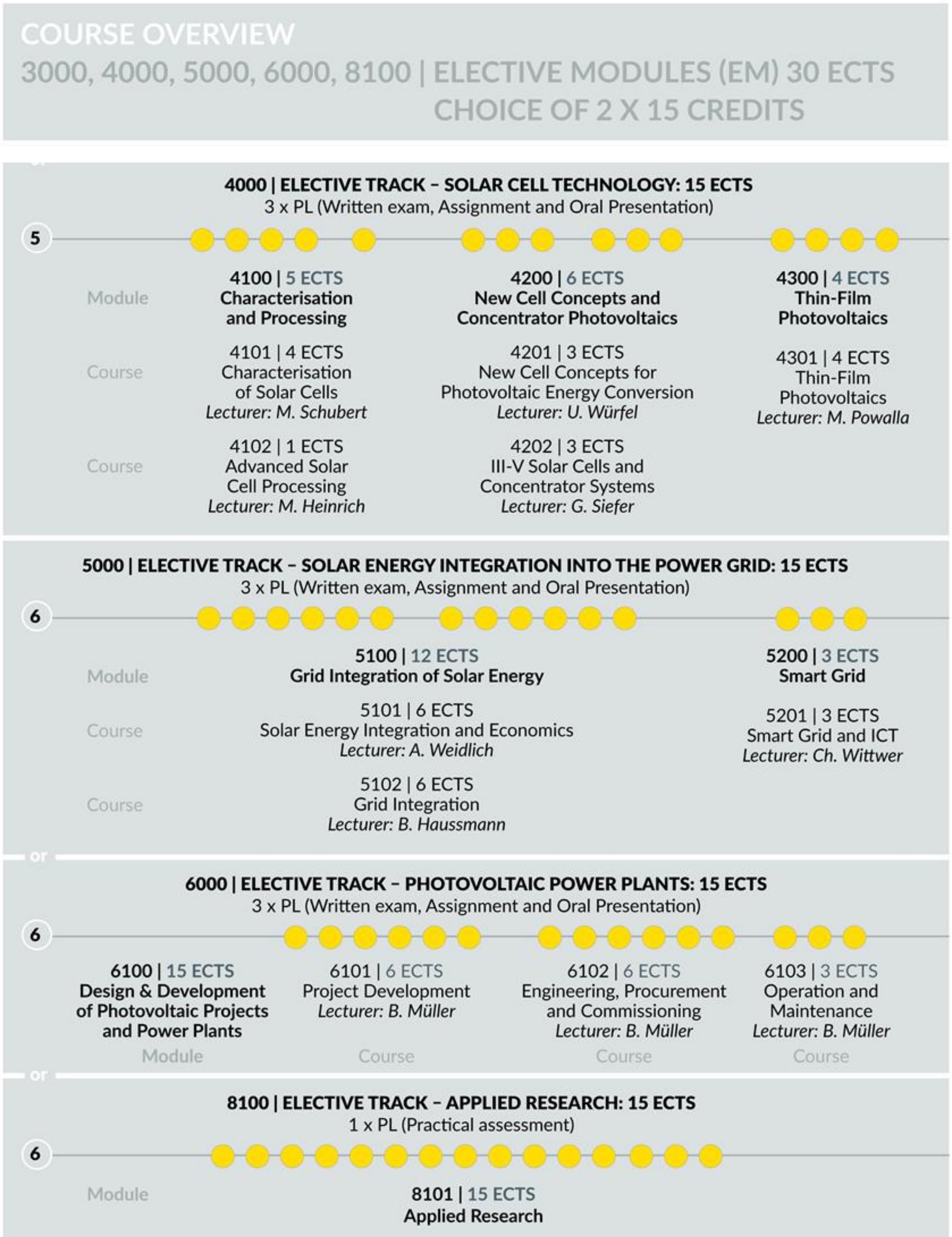
Module	***Module Name***	***ECTS* (30)***	***Offer Semester***
4000	Solar Cell Technology	15	5th semester
5000	Solar Energy Integration into the Power Grid	15	6th semester
6000	Photovoltaic Power Plants	15	6th semester
7000	Smart and Integrated Photovoltaics: Design, Technologies, and Digitalization	15	6th semester
8100	Applied Research	15	6th semester

**The European Credit Transfer and Accumulation System (ECTS) makes studies and courses more transparent.*

Elective module courses are created as diverse as possible to train graduates who specialise in real-life applications of solar energy topics. Combining two elective modules provides in-depth inspection and expertise in chosen topics while creating a clear path for possible research and future employment. Elective modules are supposed to allow students to explore their specific interests in solar energy engineering. The precise and advanced content of these courses, most of the time, lead to a master's thesis research.

The solar thermal energy module is divided into three courses, where students learn about solar thermal systems, system engineering & hybrid solar systems. If you want to become an expert on solar cells, the solar cell technology module focuses on solar cell characterisation, thin-film & concentrator PV, advanced processing, and new cell concepts. Another exciting and relevant topic is renewable energy integration into the grid and its economics, which is explored in the solar energy integration into the power grid module in three parts. From project development to operation & maintenance, everything about PV power plants is explored in module 6000.

The on-campus elective module, Applied Research, can only be taken in the last semester of studies. Students who choose this module must combine their 3-month research duration with the master's thesis module and complete both in 6 months. Thus, the whole final semester is dedicated to research and thesis, and the master's thesis is conducted in Freiburg. Details about this module and its conduct can be discussed six months before students intend to begin this work.



Elective Module #4000: Solar Cell Technology

This elective track provides comprehensive knowledge on solar cell characterisation, thin-film and concentrator photovoltaics, advanced processing, and new solar cell concepts. This module is for students who want to become experts in solar cell technologies. It is divided into three main parts: characterisation and processing, new cell concepts and concentrator photovoltaics, thin-film photovoltaics. The first two have two courses each, and the later part one course.

1. The first course "Characterisation of Solar Cells" provides an overview over the most important characterization tools used in material and solar cell characterization. Students gain the knowledge required for correct selection and use of the methods and get an understanding of the limits of different methods.
2. In the second seminar "Advanced Solar Cell Processing" new techniques in solar cell production, which originate from the related fields of microsystems engineering and nanoscience will be introduced. The processes introduced in this course are likely to concern the PV engineer in an upcoming 10 year period.
3. In the course "New Cell Concepts for Photovoltaic Energy Conversion" the students will get a recapitulation of the fundamental processes in the photovoltaic energy conversion. We will then have a close look on different kinds of new types of solar cells and see in how far they differ from conventional solar cells made from inorganic semiconductors. The advantages and the weak points in these emerging technologies will be analyzed.
4. The course "III-V Solar Cells and Concentrator Systems" gives an overview on the field of high concentration photovoltaics. This involves the approach of multi-junction solar cells and issues related to the operation of solar cells under concentrated light. The knowledge gained in this lecture will enable the students to assess present and future novel photovoltaic concepts.
5. The final course "Thin-Film Photovoltaics" gives a deep insight into the world of thin-film PV. A thin-film solar cell is a second generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si).

As Solar Cell Technology module consists of five different courses, three separate types of assessments (written exam, oral presentation and written report) are implemented to comprehensively examine the competencies of students.

Total ECTS	Recommended Semester	Duration	Offer Frequency
15	5th	18 Weeks	Each winter semester
Teaching Methods		• Recorded lectures (asynchronous) • Live-virtual meetings (synchronous) • Exercises, essay • Presentation • Literature review	
Responsible Instructor		Dr. Martin Schubert	
Grading		Graded (PL)	
Assessment		Written assignment, oral presentation, two online written exams with video supervision (duration of each exam: 45 minutes)	
Courses		4100: Characterisation & Processing: • 4101: Characterisation of Solar Cells • 4102: Advanced Solar Cell Processing 4200: New Cell Concepts and Concentrator Photovoltaics • 4201: New Cell Concepts for Photovoltaic Energy Conversion • 4202: III-V Solar Cells and Concentrator Systems 4300: Thin-Film Photovoltaics • 4301: Thin-Film Photovoltaics	
Usability of the Module		Part of elective modules, mandatory elective for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #4101: Characterisation of Solar Cells		
ECTS	**Lecturer**	**Tutor**
4	Dr. Martin Schubert	Dr. Tim Niewelt

Course Content

This course covers the following topics:

- Purity of silicon
- Characterisation of silicon feedstock (NAA, ICPMS, FTIR, DLTS and SIMS)
- Characterisation of silicon wafers (EPD, EBSD, EDX/XRF, QSSPC, MW-PCD, PLI-lifetime and Fe-Imaging)
- Reflectivity and optical losses
- IV-curve, resistivity and electrical losses
- Characterisation of silicon solar cells (SunsVoc, QE, SRLBIC, TLM, Rs-Imaging, LIT and Local IV)
- Inline characterisation in prodcution

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 100 h):

- 8 h recorded lectures
- 6 h live-online meetings
- 26 h exercises
- 60 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the different material and device analysis techniques used in solar cell characterisation.
- ✓ Select appropriate measurement techniques/methods for the investigation of specific properties and problems of devices.
- ✓ Use the most fundamental measurement techniques for solar cell characterisation.
- ✓ Interpret measurement results and explain the underlying processes and properties of solar cells and materials.

Assessment

- Written assignment (project work)
- Graded (PL)

Software and Literature

Literature:

- D. Schröder, Semiconductor Material and Device Characterization, John Wiley & Sons, 2015.
- P. Würfel and U. Würfel, Physics of Solar Cells -From Basic Principles to Advanced Concepts, Berlin: Wiley-VCH, 2016.

Course #4102: Advanced Solar Cell Processing		
ECTS	**Lecturer**	**Tutor**
1	Dr. Martin Heinrich	-

Course Content

This course covers the following topics:

- Atomic Layer Deposition
- Graphene for Solar Cell Application
- High-Performance Multi Crystalline Silicon
- Ion Implantation
- Kerfless Wafer Manufacturing
- Light-Induced Plating
- Passivated Contacts
- Perovskite for Solar Cell Applications
- Roll-to-Roll Printing
- Shingled Cell Interconnections
- Tandem Solar Cells
- Transparent Conductive Oxides
- Vehicle-Integrated Photovoltaics
- Wired Busbar Interconnection

Learning Method and Workload

Learning Method:

- Literature study on a selected topic
- Preparing a scientific presentation
- Writing a scientific paper

Approximate Workload (Total 25 h):

- 8 h live-online meetings
- 10 h self-study
- 7 h presentation and report preparation

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the different techniques of solar cell processing.
- ✓ Conduct a detailed literature review on the selected topics.
- ✓ Prepare and present the selected topic in front of the audience.
- ✓ Follow up and understand the topic presented by fellow students.

Assessment

- Oral presentation (20 minutes)
- non-graded (SL)

Software and Literature

-

Course #4201: New Concepts for Photovoltaic Energy Conversion		
ECTS	**Lecturer**	**Tutor**
3	Dr. Uli Würfel	Kristina Winkler

Course Content

This course covers the following topics:

- Dye and Organic Solar Cells
- Hybrid, Quantum Dot, and Perovskite Solar Cells
- Shockley Queisser limit
- Beyond Shockley Queisser: 3rd generation photovoltaics
- Tandem/ multijunction cells
- Hot carrier cell
- Impurity photovoltaic effect
- Manipulating the spectrum: up- and down-conversion

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 75 h):

- 6 h recorded lectures
- 4 h live-online meetings
- 5 h exercises
- 60 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Explain dye and organic solar cells.
- ✓ Describe hybrid, quantum dot, and perovskite solar cells.
- ✓ Explain the physical principle behind perovskite solar cells.
- ✓ Assess the possibilities beyond the Shockley Queisser limit.

Assessment

- Online written exam with video supervision (duration: 45 minutes)
- Graded (PL)

Software and Literature

Literature:

- P. Würfel and U. Würfel, Physics of Solar Cells -From Basic Principles to Advanced Concepts, Berlin: Wiley-VCH, 2016.

Course #4202: III-V Solar Cells and Concentrator Systems		
ECTS	**Lecturer**	**Tutor**
3	Dr. Gerald Siefer	-

Course Content

This course covers the following topics:

- Introduction to Multijunction Solar Cells
- Tunnel Diodes
- Solar Cells Under Concentration
- Alternative Cell Concepts
- Optimisation of Design of Concentrator Cells
- Temperature Dependence and Cooling of Concentrator Cells
- Solar Resources and Tracking
- Optics for Solar Concentration
- Module Assembly- System
- Characterisation of Multijunction Concentrator Cells and Modules

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 75 h):

- 5 h recorded lectures
- 10 h live-online meetings
- 25 h exercises
- 35 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Give an overview of multijunction solar cells.
- ✓ Explain the working principle of tunnel diodes and their characterization.
- ✓ Describe concentrator solar cells and their general characteristics.
- ✓ Outline alternative cell concepts and explain the physical concepts behind them.
- ✓ Explain the temperature and irradiance dependence of solar cell performance.
- ✓ Describe the optics for CPV: Fresnel lenses, silicone on glass, temperature dependencies, secondary optics.
- ✓ Explain CPV module manufacturing, advantages of series and parallel connection.
- ✓ Describe the specific characterization methods for multijunction concentrator cells and modules.

Assessment

- Online written exam with video supervision (duration: 45 minutes)
- Graded (PL)

Software and Literature

Literature:

- C. Algora and I. Rey –Stolle, Eds., Handbook of Concentrator Photovoltaic Technology, John Wiley & Sons Ltd, 2016.

Course #4301: Inorganic Thin Film Solar Cells		
ECTS	**Lecturer**	**Tutor**
4	Prof. Dr. Michael Powalla	Dr. Friedrich Kessler

Course Content

This course covers the following topics:

- General Overview of Inorganic Thin Film Solar Cells
- Characteristics, Physics and Production
- Technologies: a-Si, CIGS, and CdTe
- Modules, New Materials, and Advanced Characterisation

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Student presentations about the topics
- Solving exercises and homework

Approximate Workload (Total 100 h):

- 15 h recorded lectures
- 10 h live-online meetings
- 10 h exercises
- 15 h preparation of a presentation
- 50 h self-study

Learning Objectives

After finishing this course, students should be able to

✓ Describe the general aspects and historical development of thin-film solar cells.
✓ Explain different applications of thin-film solar cells and the PV market.
✓ Describe the characteristics of thin films in general.
✓ Understand the fundamental physics within the thin-film solar cell.
✓ Define essential properties for the contacts used in thin-film solar technology and explain the monolithic integration of cells to the module.
✓ Assess three leading thin-film technologies, a-Si, CIGS, and CdTe.
✓ Analyse a module according to test standards.
✓ Explain flexible cells and modules discuss new materials for thin-film PV.
✓ Give an overview of advanced characterization methods.

Assessment

- Oral presentation (duration: ca. 20 minutes, contributes to 50% of the course grade) and online exam (contributes to 50% of the course grade).
- Graded (PL)

Software and Literature

Literature:

- D. Abou-Ras, T. Kirchartz and U. Rau, Advanced Characterization Techniques for Thin Film Solar Cells, Wiley, 2016.
- K. Ellmer, A. Klein and B. Rech, Eds., Transparent Conductive Zinc Oxide: Basics and Applications in Thin Film Solar Cells, Springer-Verlag Berlin Heidelberg, 2008.
- H. Frey and H. R. Khan, Eds., Handbook of Thin Film Technology, Springer-Verlag Berlin Heidelberg, 2015.
- R. Scheer and H.-W. Schock, Chalcogenide Photovoltaics: Physics, Technologies, and Thin Film Devices, Wiley, 2011.
- A. V. Shah, Thin-Film Silicon Solar Cells, EPFL Press, 2010.

Elective Module #5000: Solar Energy Integration into the Power Grid

This elective track is designed for students who want to gain professional knowledge in renewable energy integration into the grid and economics of renewable energy. This elective track consists of three parts that cover all the crucial aspects of grid integration and economics.

1. The first course of this elective "Solar Energy Integration and Economics" is structured to train students for solar energy integration, particularly in Solar PV and economics. Solar energy is expected to become the world's primary energy resource in the upcoming decades. One of the most relevant problems is integrating photovoltaic (PV) power into the electric grid system. Information and education on technologies, control strategies, economic aspects, and stakeholder relationships that enable the adaptation of PV systems into existing grid infrastructure are in high demand by current and future energy professionals. The course will facilitate comprehension of the implications, challenges, and possible solutions for a predominantly renewable energy system, specifically focusing on the role of solar PV power.
2. The second course "Grid Integration and Control" will give comprehensive knowledge about grid integration and control, including computer-based simulations distinguished by different voltage levels. The course starts with an overview of the different targets of power system control followed by a section on modelling connections and transformers. The next part deals with the global frequency control of power systems and explains inherent frequency control with synchronous machines. In the last part, voltage and current control in distribution grids will be explained. To deepen the understanding of the content, the lectures are combined with hands-on computer-based simulations. Students are also requested to choose a topic. They will write a scientific article about that topic and present the main findings to the other students.
3. The third course "Smart Grid and ICT" is about smart grids and Information and Communication Technologies (ICTs). Smart grid deployment will play a vital role in the efficient management of the grid and transition to renewable energy. ICTs are also becoming an integral part of smart grid management since they increase the grid's efficiency and control. The knowledge provided in this course will be a valuable assistance to the students in order to understand the interaction of several system components as well as their dynamic system behaviour.

As Solar Energy Integration into the Power Grid module consists of three broad courses, three separate types of assessments (written exam, oral presentation and written report) are implemented to comprehensively examine the competencies of students.

<table>
<tr><th>Total ECTS</th><th>Recommended Semester</th><th>Duration</th><th>Offer Frequency</th></tr>
<tr><td>15</td><td>6th</td><td>18 Weeks</td><td>Each summer semester</td></tr>
<tr><td colspan="2">Teaching Methods</td><td colspan="2">• Recorded lectures (asynchronous),
• Live-virtual meetings (synchronous),
• Exercises
• Grid optimization with Typhoon HIL.</td></tr>
<tr><td colspan="2">Responsible Instructor</td><td colspan="2">Prof. Dr. Anke Weidlich</td></tr>
<tr><td colspan="2">Grading</td><td colspan="2">Graded (PL)</td></tr>
<tr><td colspan="2">Assessment</td><td colspan="2">Online written exam (duration: 75 minutes), written assignment and oral presentation</td></tr>
<tr><td colspan="2">Courses</td><td colspan="2">5100: Grid Integration of Solar Energy
• 5101: Solar Energy Integration and Economics
• 5102: Grid Integration and Control

5200: Smart Grid
• 5201: Smart Grid and ICT</td></tr>
<tr><td colspan="2">Usability of the Module</td><td colspan="2">Part of elective modules, mandatory elective for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)</td></tr>
</table>

Course #5101: Solar Energy Integration and Economics

ECTS	Lecturer	Tutor
6	Prof. Dr. Anke Weidlich	Nick Harder

Course Content

This course covers the following topics:

- Characteristics of Solar Energy in Power Systems (generation patterns and forecasts, demand and supply matching, netload, grid parity, impact on electricity prices, the role of solar in highly renewable energy scenarios)
- Grid Integration Challenges (frequency control and possible contributions of solar PV, power quality in the distribution grid, inverter control strategies, storage)
- Economic Assessment (investment appraisal, levelized cost of electricity, learning curves, the value of solar generation/intermittency, market integration, optimal system sizing, and design decisions, economic comparison of different PV technologies, thermal vs electric usage of solar energy, support schemes)
- Business Models and Applications of Solar PV Systems (self-consumption, communities, off-grid solutions, microgrids)

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 150 h):

- 12 h recorded lectures
- 12 h live-online meetings
- 50 h exercises
- 76 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the technical challenges of integrating solar power into the electricity grid.
- ✓ Evaluate economic strategies to increase renewable energies' share (particularly solar energy) in the energy mix.
- ✓ Analyse the possible contribution of PV plants, inverter technologies, and control strategies from a cost-benefit viewpoint.
- ✓ Compare the latest models for utilizing PV power: Community PV and Microgrid solutions.

Assessment

- Online written exam (duration: 75 minutes)
- Graded (PL)

Software and Literature

Literature:

- Infield, D. and Freris, L.: Renewable Energy in Power Systems, 2nd edition, Wiley 2020.
- Glover, J. D., M. S. Sarma, T. J. Overbye: Power System Analysis & Design, 6th edition, Cengage Learning, 2017.
- Wood, A. J., B. F. Wollenberg; G. B. Sheblé: Power Generation, Operation and Control, 3rd edition, Wiley, 2013.

Course #5102: Grid Integration and Control		
ECTS	**Lecturer**	**Tutor**
6	Dr. Bernhard Wille-Haussmann	Jakob Ungerland

Course Content

This course covers the following topics:

- Introduction into targets of power system control
- Modelling of Power Systems
- Transmission Grid - Frequency Control
- Flexible AC Transmission Systems (FACTS)
- Distribution Grid - Voltage Control

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 150 h):

- 12 h recorded lectures
- 12 h live-online meetings
- 50 h exercises with Typhoon HIL
- 76 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the control hierarchy of power systems.
- ✓ Understand the planning criteria depending on the voltage level.
- ✓ Perform power system simulations.
- ✓ Develop grid integration strategies.
- ✓ Evaluate grid integration measures for distributed generators.

Assessment

- Written assignment (project work, contributes to 60% of the course grade) and online exam (contributes to 40% of the course grade).
- Graded (PL)

Software and Literature

Software:

- Typhoon HIL

Literature:

- J. Randolph and G. M. Masters, Energy for Sustainability: Foundations for Technology, Planning, and Policy, Island Press, 2018.
- J. D. Glover, T. Overbye and M. Sarma, Power System Analysis and Design, 6th ed., Cengage Learning, 2017.
- A. E. Fitzgerald, C. Kingsley and S. D. Umans, Electric Machinery, McGraw Hill, 2003.
- S. N. Vukosavic, Electrical Machines, Springer-Verlag New York, 2013.
- G. Andersson, Script: Power System Analysis, ETH Zürich, 2019.

Course #5201: Smart Grid & Information and Communication Technologies (ICTs)

ECTS	Lecturer	Tutor
3	Prof. Dr. Christof Wittwer	Anas Abuzayed

Course Content

This course covers the following topics:

- Overview of the Electrical Energy System
- Duration Curve and Grid Structure
- Active and Reactive Power
- On Load Tap Changer (OLTC), its Use, Design and Operation
- Smart Grids (concept, motivation and components)
- Information and Communication Technology (ICT)
- Smart Meters
- European Energy Market (history and design) & Network Liberzation Concept

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending regular online meetings and actively participating in the forum discussions
- Solving exercises and homework

Approximate Workload (Total 75 h):

- 6 h recorded lectures
- 6 h live-online meetings
- 13 h exercises
- 50 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand and optimize the grid-connected energy systems.
- ✓ Illustrate energy flow in distribution grids with decentralized generation.
- ✓ Describe and design energy management systems for optimized energy production and storage.

Assessment

- Oral presentation (duration: ca. 20 minutes)
- Graded (PL)

Software and Literature

-

Elective Module #6000: Photovoltaic Power Plants

The elective track on Photovoltaic Power Plants is designed for students who want to gain expertise on photovoltaic power plant projects. This elective track covers all the topics related to photovoltaic power plants ranging from project development to operation and maintenance. Students are required to design their own large PV plant of at least 30 MW, starting from technical and economic feasibility in course one, moving to the engineering, design, simulation and comissioning of the project in course two, and finally designing the monitoring system and creating the operation and maintenance plan in course three.

There are three courses in this elective module.

1. The first one "Project Development" provides students with a comprehensive understanding of assessing, analyzing, and evaluating the feasibility of photovoltaic power plant projects. Through this course, students will gain the knowledge and skills needed to conduct solar resource assessments, site analysis, and environmental impact assessments. They will learn to perform comprehensive project feasibility studies considering technical, financial, and regulatory aspects. The course also covers system sizing calculations, risk assessments, financial analysis, and understanding regulatory and permitting considerations. By the end of the course, students will be equipped to make informed decisions during the project development phase, considering factors such as project profitability, risks, and environmental impact. The course includes theoretical lectures, practical exercises, and case studies to enhance learning and enable students to contribute effectively to the implementation of sustainable and efficient PV projects.
2. The second course "Engineering Procurement and Commissioning" is designed to equip students with the basic knowledge necessary to effectively design and execute large-scale solar energy projects. The course focuses on the key principles and practices involved in the engineering, procurement, and construction phases of solar energy systems, covering topics such as project optimization, power plant simulation, equipment selection, and quality assurance. Through a combination of theoretical instruction and practical case studies, students will develop a understanding of the entire project lifecycle and gain the expertise required to successfully lead and oversee solar energy projects from inception to completion.
3. The third course "Operation and Maintenance" provides students with a comprehensive understanding of the challenges and activities related to this phase of a PV system's life cycle. Through this course, students will gain the knowledge and skills needed to assess the

impact of issues to the performance of a PV system and formulate maintenance strategy plans. They will learn to analyze monitoring data and extract useful information for the operation of a PV system. By the end of the course, students will be equipped to make informed decisions during the O&M phase, considering factors such as typical issues and available resources for inspection and online monitoring. The course includes theoretical lectures, practical exercises, and case studies to enhance learning and enable students to contribute effectively to the implementation of sustainable and efficient O&M practices.

As Photovoltaic Power Plants module consists of three broad courses, three separate types of assessments (project work, oral presentation and written report) are implemented to comprehensively examine the competencies of students.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
15	6^{th}	18 Weeks	Each winter semester
Teaching Methods		• Recorded lectures (asynchronous), • Live-virtual meetings (synchronous), • Exercises • Project planning • Group work and oral presentation	
Responsible Instructor		Prof.Dr.-Ing. Mohammadreza Aghaei	
Grading		Graded (PL)	
Assessment		Project work, oral presentation and written assignment	
Courses		6101: Project Development 6102: Engineering, Procurement, and Commissioning 6103: Operation and Maintenance	
Usability of the Module		Part of elective modules, mandatory elective for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #6101: Project Development

ECTS	Lecturer
6	Prof.Dr.-Ing. Mohammadreza Aghaei & Prof. Killian Lobato

Course Content

This course covers the following topics:

- Solar Resource Assessment and Analysis
- Site Analysis and Environmental Impact Assessment
- Project Feasibility Study
- Financial Modeling and Cash Flow Analysis
- Grid Connection and Interconnection Requirements
- Environmental and Social Responsibility in Project Development

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending online meetings regularly and actively participating in the forum discussions
- Solving the exercises
- Project work: technical and economic feasibility analysis a PV plant of at least 30 MW

Approximate Workload (Total 150 h):

- 10 h live-online meetings
- 12 h recorded lectures
- 18 h exercises and discussions
- 74 h project work and reporting
- 36 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Conduct thorough solar resource assessments to determine the energy potential of a site.
- ✓ Perform site analysis and environmental impact assessments to evaluate the suitability of a location for a PV power plant.
- ✓ Conduct project feasibility studies, considering technical, financial, & regulatory aspects.
- ✓ Understand key factors influencing the feasibility of a PV power plant, such as solar resource, site characteristics, grid connection requirements & environmental impact.
- ✓ Apply appropriate methodologies and tools for evaluating the technical feasibility and profitability of a project, including system sizing calculations and risk assessments.
- ✓ Understand regulatory & permitting considerations in the project development phase.
- ✓ Evaluate the financial viability of a project through financial analysis, including indicators such as return on investment (ROI) and levelized cost of electricity (LCOE).

Assessment

- Oral presentation (contributes to 50% of the course grade) and project report (contributes to 50% of the course grade).
- Graded (PL)

Software and Literature

Software:

- PVSyst, SAM, PVGIS, SolarGIS, RETScreen, HOMER Pro

Course #6102: Engineering, Procurement, and Commissioning (EPC)

ECTS	Lecturer
6	Dr. Marília Braga

Course Content

This course covers the following topics:

- Fundamentals of Engineering, Procurement and Construction in PV projects
- Electrical design and equipment selection for PV power plants
- Optimization and simulation of PV power plants
- Quality assurance for PV projects: design and execution
- Quality assurance for PV projects: commissioning tests
- Quality assurance for PV projects: performance metrics
- Real EPC: evaluation of case studies

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending online meetings regularly and actively participating in the forum discussions
- Solving the exercises
- Project work: design, project and simulation of a PV plant of at least 30 MW

Approximate Workload (Total 150 h):

- 7 h live-online meetings
- 10 h recorded lectures
- 76 h project work and reporting
- 21 h exercises and discussions
- 36 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the fundamental principles of engineering, procurement, and construction specific to solar energy projects.
- ✓ Develop skills in electrical design and equipment selection for efficient solar energy systems.
- ✓ Learn techniques for the optimization and simulation of solar energy power plants.
- ✓ Gain proficiency in quality assurance topics specific to photovoltaics to ensure successful implementation of solar energy projects.
- ✓ Apply theoretical knowledge and problem-solving skills through a practical case study to simulate real-world scenarios in solar energy engineering projects.

Assessment

- Oral presentation (contributes to 50% of the course grade) and project report (contributes to 50% of the course grade).
- Graded (PL)

Software and Literature

-

Course #6103: Operation and Maintenance	
ECTS	**Lecturer**
3	Prof. Dr.-Ing. Mohammadreza Aghaei and Dr. Eduardo Sarquis

Course Content

This course covers the following topics:

- Introduction to PV systems O&M
- Analysis of Failure
- Maintenance paradigms: principles (Preventive, Corrective, Predictive) & application
- Online monitoring of Power Plant: data collection & main analysis (soiling, shading, fault detection)
- Optimisation and Performance Improvement

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending online meetings regularly and actively participating in the forum discussions
- Project work: designing of a monitoring system (including monitoring data analysis) and O&M plan for a PV plant of at least 30 MW

Approximate Workload (Total 75 h):

- 5 h live-online meetings
- 6 h recorded lectures
- 35 h project work
- 14 h exercises and discussions
- 15 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Describe the monitoring of system components and power plants.
- ✓ Execute failure analysis and report the failure.
- ✓ Understand the challenges and the main activities related to the O&M of PV systems.
- ✓ Build a maintenance strategy considering the guidelines, resources and characteristics of the system.
- ✓ Analyze and interpret data collected from a system in order to extract useful information for the O&M management.

Assessment

- Oral presentation (contributes to 50% of the course grade) and project report (contributes to 50% of the course grade).
- Graded (PL)

Software and Literature

Software:

- PVSyst

Elective Module #7000: Smart and Integrated Photovoltaics: Design, Technologies, and Digitalization

This elective track provides comprehensive and forward-looking knowledge in the fields of smart photovoltaics, integrated PV systems, and design-driven PV innovation. The module bridges engineering, digitalization, and design thinking to equip students with advanced competencies across the PV value chain, from solar cell and module design to large-scale smart power plant operation.
The module consists of three courses covering distinct yet complementary dimensions of modern photovoltaics:

- Course 7101 explores photovoltaics as a design-driven technology, combining engineering with creativity and sustainability-oriented product development.
- Course 7102 addresses integrated PV applications — including BIPV, agrivoltaics, floating PV, and vehicle-integrated PV, with a focus on system design, energy yield analysis, and real-world deployment.
- Course 7103 covers the application of emerging digital technologies (AI, IoT, Digital Twins, UAVs, satellite remote sensing) for the design, monitoring, and optimization of PV systems and power plants.

There are three courses in this elective module.

1. The first course *"Designing and Engineering with Photovoltaics: Innovation, Aesthetics, and Sustainable Product Development"* introduces photovoltaics as a design material. Students explore emerging PV technologies such as luminescent solar concentrators (LSC-PV), transparent and flexible PV, and color-customizable modules. Using design thinking frameworks, students develop innovative, user-centered, and sustainability-oriented PV concepts for products, buildings, and environments. The course addresses circular design, lifecycle thinking, and social acceptance.
2. The second course *"Integrated Photovoltaics: Technologies, Systems, and Applications for Sustainable Infrastructure"* provides an engineering-oriented exploration of integrated PV systems. Topics include Building-Integrated PV (BIPV), agrivoltaics, floating PV, urban PV, vehicle-integrated PV (VIPV), green-roof PV, and road-integrated PV. Students perform solar resource assessments, system design, techno-economic analyses, and learn to use tools such as PVsyst, SAM, PVLib, and BIMSolar.
3. The third course *"Smart Photovoltaics: Emerging Technologies for Design, Monitoring, and Optimization"* covers the application of AI, Machine Learning, Deep Learning, Digital Twins, IoT, UAVs (drones), and big data analytics in PV systems. Students learn to design intelligent monitoring architectures, apply predictive maintenance, perform fault detection, and work with satellite-based remote sensing for large-scale PV assessment. The course also addresses smart PV modules with embedded sensing and module-level power electronics (MLPE).
As the Smart and Integrated Photovoltaics module consists of three broad courses, three separate oral exams and course projects are implemented to comprehensively examine the competencies of students.

Total ECTS	Recommended Semester	Duration	Offer Frequency
15	6th Semester	18 Weeks	Each summer semester
Teaching Methods		• Recorded lectures (asynchronous), • Live-virtual meetings (synchronous), • Exercises • Project work • Group work and oral presentation	
Responsible Instructor		Prof.Dr.-Ing. Mohammadreza Aghaei	
Grading		Graded (PL)	
Assessment		Oral exam and course project	
Courses		7101: Designing and Engineering with Photovoltaics: Innovation, Aesthetics, and Sustainable Product Development 7102: Integrated Photovoltaics: Technologies, Systems, and Applications for Sustainable Infrastructure 7103: Smart Photovoltaics: Emerging Technologies for Design, Monitoring, and Optimization	
Usability of the Module		Part of elective modules, mandatory elective for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

Course #7101: Designing and Engineering with Photovoltaics: Innovation, Aesthetics, and Sustainable Product Development

ECTS	Lecturer
6	Prof.Dr.-Ing. Mohammadreza Aghaei & Prof. Killian Lobato

Course Content

This course covers the following topics:

- Photovoltaics as a Design Material: Capabilities and Limitations
- Emerging PV Technologies: LSC-PV, Transparent, Flexible, Organic, and Color-Customizable PV
- Design Thinking Methodology for PV Applications
- Ideation and Prototyping of User-Centered PV Concepts
- Aesthetic Integration of PV in Products, Buildings, and Environments
- Sustainability, Circular Design, and Lifecycle Thinking for PV
- Social Acceptance and Environmental Responsibility
- Communicating PV Design Concepts: Sketches, Models, and Visualizations

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending online meetings regularly and actively participating in forum discussions
- Solving exercises
- Course project: Develop a new concept by designing with photovoltaics for any desirable application

Approximate Workload (Total 150 h):

- 15 h compact lectures (asynchronous)
- 10 h live online meetings (synchronous)
- 10 h forum discussions
- 40 h self-study
- 10 h bilateral interactions with tutor
- 15 h oral exam preparation
- 35 h project work
- 15 h reporting and final presentation

Learning Objectives

After finishing this course, students should be able to

- ✓ Explain photovoltaics as a design material, including its technological capabilities and limitations in creative applications.
- ✓ Understand and evaluate emerging PV technologies (e.g., LSC-PV, transparent, flexible, and colored PV) and their potential for innovative design solutions.
- ✓ Apply design thinking methodologies to develop user-centered and sustainability-oriented PV concepts.
- ✓ Generate and develop innovative PV-based design solutions for products, buildings, or environments.
- ✓ Translate technical constraints into design opportunities, balancing efficiency, aesthetics, usability, and cost.
- ✓ Integrate PV into aesthetic and functional designs, considering form, materials, visual impact, and user interaction.
- ✓ Assess environmental and sustainability aspects of PV-based designs, including lifecycle thinking and circular design principles.
- ✓ Develop and communicate design concepts using sketches, models, and visualizations, supported by technical justification.
- ✓ Critically evaluate the feasibility, innovation potential, and societal impact of PV-based design solutions.

Assessment

- Oral exam (contributes to 50% of the course grade) and course project report (contributes to 50% of the course grade).
- Graded (PL)

Course #7102: Integrated Photovoltaics: Technologies, Systems, and Applications for Sustainable Infrastructure

ECTS	Lecturer
6	TBC

Course Content

This course covers the following topics:

- Building-Integrated PV (BIPV): Technologies and Design
- Agrivoltaics: Co-location of Agriculture and PV
- Floating PV Systems: Design and Performance
- Urban PV, Green-Roof PV, and Road-Integrated PV
- Vehicle-Integrated PV (VIPV)
- Solar Resource Assessment and Energy Yield Analysis for Integrated PV

- System Design and Sizing of Integrated PV Applications
- Techno-Economic Analysis and Lifecycle Assessment
- Digitalization: IoT Monitoring, AI Optimization, and Digital Twins for Integrated PV
- Policy Frameworks and Standards for Integrated PV

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending online meetings regularly and actively participating in forum discussions
- Solving exercises
- Course project: Techno-economic assessment of an integrated PV system (BIPV, floating PV, agrivoltaics, etc.)

Approximate Workload (Total 150 h):

- 15 h compact lectures (asynchronous)
- 10 h live online meetings (synchronous)
- 10 h forum discussions
- 40 h self-study
- 10 h bilateral interactions with tutor
- 15 h oral exam preparation
- 35 h project work
- 15 h reporting and final presentation

Learning Objectives

After finishing this course, students should be able to

- ✓ Explain and differentiate integrated PV applications, including BIPV, agrivoltaics, floating PV, urban PV, VIPV, and infrastructure-integrated PV.
- ✓ Understand PV system architectures and integration strategies across buildings, infrastructures, and natural environments.
- ✓ Design and size integrated PV systems for diverse real-world applications.
- ✓ Perform solar resource assessment and energy yield analysis using appropriate data and tools.
- ✓ Evaluate system performance, losses, degradation, and reliability of integrated PV systems.
- ✓ Apply engineering tools and simulation methods (e.g., PVsyst, PVLib, SAM, BIMSolar) for system design and analysis.
- ✓ Analyze trade-offs between energy production, land use, cost, and environmental impact in integrated PV solutions.
- ✓ Integrate PV systems with storage, grid infrastructure, and digital technologies.
- ✓ Develop and communicate technically sound PV integration solutions, considering economic feasibility, sustainability, and real-world constraints.

Assessment

- Oral exam (contributes to 50% of the course grade) and course project report (contributes to 50% of the course grade).
- Graded (PL)

Software and Literature

- PVsyst, PVLib, SAM, BIMSolar

Course #7103: Smart Photovoltaics: Emerging Technologies for Design, Monitoring, and Optimization	
ECTS	**Lecturer**
3	TBC

Course Content

This course covers the following topics:

- Emerging PV Technologies: Perovskite, OPV, and Tandem Solar Cells
- AI, Machine Learning, and Deep Learning for PV Applications
- Data-Driven Modeling and Forecasting of PV Systems
- Smart PV Modules: Embedded Sensing, MLPE, and Module-Level Intelligence
- IoT-Based Monitoring Architectures for PV Systems and Power Plants
- Digital Twins for PV Simulation, Predictive Maintenance, and Optimization
- Satellite and UAV-Based Remote Sensing for Solar Resource Assessment and Inspection
- Fault Detection, Hotspot Analysis, and Degradation Monitoring
- Self-Monitoring and Self-Diagnostic PV Systems
- Big Data Analytics for PV Performance and Reliability

Learning Method and Workload

Learning Method:

- Studying recorded lectures
- Attending online meetings regularly and actively participating in forum discussions
- Solving exercises
- Course project

Approximate Workload (Total 150 h):

- 15 h compact lectures (asynchronous)
- 10 h live online meetings (synchronous)
- 10 h forum discussions
- 40 h self-study
- 10 h bilateral interactions with tutor
- 15 h oral exam preparation
- 35 h project work
- 15 h reporting and final presentation

Learning Objectives

After finishing this course, students should be able to

- ✓ Explain the role of emerging technologies (AI, IoT, Digital Twins, satellite data, UAVs) across the PV value chain.
- ✓ Understand advanced PV technologies and datasets, including perovskite, OPV, tandem cells, and experimental/field data.
- ✓ Apply AI/ML/DL techniques for PV applications such as forecasting, fault detection, and performance optimization.
- ✓ Develop data-driven models for PV system analysis using real or synthetic datasets.
- ✓ Describe and evaluate smart PV module concepts, including module-level intelligence, embedded sensing, and power electronics (e.g., MLPE).
- ✓ Analyze and design self-monitoring and self-diagnostic PV systems, capable of detecting faults such as hotspots, shading, and degradation in real time.
- ✓ Design IoT-based monitoring architectures for PV modules, systems, and power plants.

✓ Utilize Digital Twin concepts for simulation, predictive maintenance, and system optimization. ✓ Apply satellite and UAV-based remote sensing techniques for solar resource assessment, inspection, and large-scale monitoring. ✓ Evaluate PV system performance, reliability, and degradation using data analytics and intelligent methods. ✓ Design integrated intelligent PV solutions combining AI, IoT, Digital Twins, and sensing technologies for real-world applications.
Assessment
• Oral exam (contributes to 50% of the course grade) and course project report (contributes to 50% of the course grade). • Graded (PL))

Elective Module #8100: Applied Research

The on-campus elective module, Applied Research, is a 3-month laboratory course. A solid basis for independent scientific working is created, preparing the students for the upcoming research training laboratory and the master's thesis.

The elective module "Applied Research" can only be taken in the last semester of studies. Students who choose the elective module Applied Research must combine their 3-month research duration with the master's thesis module and complete both in 6 months. Thus, the final semester is dedicated to research and thesis, and the master's thesis is conducted in Freiburg.

Total ECTS	**Recommended Semester**	**Duration**	**Offer Frequency**
15	6th	12 Weeks	Any time after student collects 20 ECTS from Mandatory Modules.
Teaching Methods		• Practical laboratory research • Applications of scientific methods	
Module Responsible		Prof. Dr. Stefan Glunz	
Grading		Graded (PL)	
Courses		8101: Applied Research	

Course #8101: Applied Research

Course Content

This course covers the following topics:

- Complex facts and issues are imparted based on the knowledge obtained in the previous courses.
- The students are introduced to sophisticated applications of scientific methods, which are adapted to state-of-the-art research.
- Preparation for the master's thesis.

Learning Method and Workload

Learning Method:

- Hands-on laboratory experience in a research-oriented environment in Freiburg.

Approximate Workload (Total 375 h):

- Mostly autonomous and independent work, so the distribution of hours is among the laboratory or researching, reading and writing about solar energy topics and more.

Learning Objectives

After finishing this course, students should be able to

- ✓ Have a solid basis for independently working on scientific research topics.
- ✓ Prepare for possible laboratory and research positions in academia or industry.
- ✓ Use scientific methods to obtain information that is relevant for research.
- ✓ Learn how to read, question, understand and write scientific articles.
- ✓ Apply their expert knowledge in a new, unfamiliar, and multidisciplinary context.

Assessment

- Practical assessment - Graded (PL)

Module #9000: Research Methods and Projects

In this module, students work on three research projects (RP), distributed as one for each semester. During this process, students develop their scientific writing and presentation skills and familiarise themselves with the standards and methods of scientific work. Each semester, students conduct one RP about possible implementations of the concepts that are presented in 9001 Fundamentals of Research. For each project, a scientific report must be written, and each student must give an oral presentation of their RP at the end of the semester. Students are given the opportunity to improve and enhance their skills as they build up experience through the feedback they receive after each project.

The first course of this module is a lecture that introduces principles and techniques of scientific research. The second and third RPs train students to improve their specific skills in the scientific field. During these projects, students learn how to write reports, format papers, and approach a task methodologically. The fourth RP is focused on energy data analysis. Students use available online data and analyse it to solve different problems in the renewable energy field.

Total ECTS	Recommended Semester	Duration	Offer Frequency
10	4th, 5th and 6th	12 Weeks*	One RP for each semester
Teaching Methods		• Recorded lectures (asynchronous), • Live-virtual meetings (synchronous), • Literature survey, • Self-study	
Responsible Instructor		Prof. Dr. Thomas Hanemann	
Grading		Non-graded (SL)	
Assessment		Specified on the course level	
Courses		9001: Fundamentals of Research 9002: Research Project A 9003: Research Project B 9004: Research Project C 9005: SEE Lab	
Usability of the Module		Research Methods and Projects module is compulsory for the full and expert track students of the study program M.Sc. Solar Energy Engineering (PO 2021)	

COURSE OVERVIEW

9000 | RESEARCH METHODS AND PROJECTS (RP) 10 ECTS

Recommended Semester	Course
3	9001 | 0 ECTS Fundametals of Research
4	9002 | 2 ECTS Research A
5	9003 | 2 ECTS Research B
6	9004 | 2 ECTS Research C
	9005 | 4 ECTS SEE Lab

Course #9001: Fundamentals of Research

ECTS	Lecturer
0	Prof. Dr. Thomas Hanemann

Course Content

This course covers the following topics:

- Fraud in Science
- Safeguarding and Good Scientific Practice
- Presentation Skills
- Lab Journal and Report Writing
- Master's Thesis and PhD. Thesis
- General Layout Rules
- Toolbox for Scientific Writing
- Writing a Scientific Paper

Learning Method and Workload

Learning Method:

- ✓ Studying recorded lectures

Approximate Workload (Total 25 h):

- ✓ 15 h recorded lectures
- ✓ 10 h self-study

Learning Objectives

After finishing this course, students should be able to

- ✓ Understand the basics of scientific writing.
- ✓ Define presentation skills in scientific research.
- ✓ Explain general layout rules for lab journal and report writing.
- ✓ Use toolbox for scientific working.
- ✓ Recognize the crucial parts in writing a scientific paper.

Assessment

-

Software and Literature

-

Course #9002: Project Research: A

ECTS	Lecturer	Responsible
2	Dr. Martin Heinrich	Prof. Dr. Thomas Hanemann

Course Content

The main task within this module is the writing of a scientific report covering an elaboration of a renewable energy topic. The topic can be selected from the following list:

- Building Energy Technology,
- Bioenergy,
- Electromobility,
- Energy Efficiency,
- Energy Resources,
- Energy Storage,
- Energy System Integration,
- Grid Stability,
- Hydrogen Technology,
- Hydropower,
- Photovoltaics,
- Renewable Energy (in general),
- Solar Thermal Energy,
- Wind Power.

Learning Method and Workload

Learning Method:

- ✓ Preparing a scientific report
- ✓ Presenting the result in front of an audience

Approximate Workload (Total 50 h):

- ✓ 20 h self-study
- ✓ 20 h preparation
- ✓ 10 h presentations

Learning Objectives

After finishing this course, students should be able to

- ✓ Approach a topic with the scientific method.
- ✓ Apply essential tools of scientific working like literature research.
- ✓ Write a well-structured scientific report.
- ✓ Perform a scientific oral presentation to an audience.

Assessment

- A detailed report on a topic selected by the student from a list of topics from the course content section (length: min. 6 pages).
- Presentation of the topic (duration: 20 min.)
- Non graded, Pass/Fail (SL)

Software and Literature

-

Course #9003: Project Research: B

ECTS	Lecturer	Responsible
2	Dr. Mirko Schäfer	Prof. Dr. Thomas Hanemann

Course Content

This course covers the following topics in renewable energy:

- Bioenergy,
- Building Energy Technology,
- Electromobility,
- Energy Efficiency,
- Energy Resources,
- Energy Storage,
- Energy System Integration,
- Grid Stability,
- Hydrogen Technology,
- Hydropower,
- Photovoltaics,
- Renewable Energy (in general),
- Solar Thermal Energy,
- Wind Power.

Learning Method and Workload

Learning Method:

- ✓ Preparing a scientific report
- ✓ Presenting the result in front of an audience

Approximate Workload (Total 50 h):

- ✓ 20 h self-study
- ✓ 20 h preparation
- ✓ 10 h presentations

Learning Objectives

After finishing this course, students should be able to

- ✓ Approach a topic with the scientific method.
- ✓ Apply essential tools of scientific working like literature research.
- ✓ Write a well-structured scientific report (length: min. 6 pages).
- ✓ Perform a scientific oral presentation to an audience (duration: 20 min).

Assessment

- Presentation on a selected topic (duration: 20 min)
- Non graded, Pass/Fail (SL)

Software and Literature

-

Course #9004: Project Research: C

ECTS	Lecturer	Responsible
2	Leonhard Gandhi	Prof. Dr. Thomas Hanemann

Course Content

This course covers the following topics related to different coding skills CS (the exact topics differ from semester to semester):

- CS A: Beginner - Algorithm to generate correction factors for live energy data, CO2eq factors for renewable energy power generations, transformation paths towards a climate-neutral energy system.
- CS B: Intermediate - Analysis of irradiation data for east-west installations linked with market prices, emissions of power plants in Germany, market values of different renewable energy sources, Wind / PV ratio for an efficient energy system.
- CS C: Advanced - Develop "Energy Charts" for your country of origin, sorted global warming potential curve of the German electricity mix.

Learning Method and Workload

Learning Method:

- ✓ Preparing a scientific report including coding skills
- ✓ Presenting the result in front of an audience

Approximate Workload (Total 50 h):

- ✓ 20 h self-study
- ✓ 20 h preparation
- ✓ 10 h presentations

Learning Objectives

After finishing this course, students should be able to

- ✓ Perform data processing of energy and laboratory data.
- ✓ Solve questions related to renewable energies and prove statements with data-based arguments.
- ✓ Visualize results of energy data processing.
- ✓ Write scientific reports (length: min. 6 pages).
- ✓ Present their results in the form of a scientific poster.

Assessment

- Presentation on a selected topic (duration: 20 min)
- Non graded, Pass/Fail (SL)

Software and Literature

-

Laboratory Course #9005: SEE Lab

During their studies, students come to Freiburg for lab workshops one time. Two lab workshops take place during the Campus Phase in September. Students can choose when they want to join the lab workshops; there is no designated semester. Each workshop is worth 2 ECTS. There are currently two workshops on Solar Cell Processing and Measurement Instrumentation. Both workshops are prepared and led by Fraunhofer ISE, and the university will credit them after completion and submission of the workshop report. In exceptional cases, it is also possible to do the workshops in other institutions. However, this needs to be approved by our examination committee, and the alternative institution should have a comparable infrastructure to Fraunhofer ISE.

Course #9005: SEE Lab		
ECTS	**Responsible**	**Lecturers**
2 x 2	Prof. Dr. Stefan Glunz	Dr. Jan Nekarda & Dr. Sebastian Mack & Dr. Holger Neuhaus

Course Content

Each September, our partner Fraunhofer ISE offers laboratory workshops exclusive to SEE students. Students have to participate in two workshops that take place during Campus Week in September in Freiburg.

Course Content:

- Hands-on Solar Cell Processing
- Hands-on Measurement Instrumentation

In terms of content, the participants get to know typical process problems in the production of solar cells and the application of current measurement technology for quality control of solar cells. The combination of the experiments and the accompanying teaching material sharpens the understanding of physical processes in solar cells. As a major solar cell technology, the crystalline silicon solar cell will initially be in the foreground.

Learning Method and Workload

Learning Method:

Fraunhofer ISE relies on a tried and tested combination of online distance learning and classroom teaching in the laboratory, which leads to a blended learning model. The division between face-to-face teaching and distance learning is around 50:50 for this course.

- ✓ Conducting individual experiments that the students work through with special sample sets (in groups of 2-3 students).
- ✓ Conducting a group experiment called “Task Forces”, where a certain process problem is to be examined and identified jointly with all available measurement methods (in groups of 5-8). The task forces are each assigned a sample set with a specific process problem. The task is to identify the process error by combining all measurement methods.
- ✓ In a final meeting, all task forces present their measurement results.
- ✓ In a joint discussion, groups work out solutions to eliminate the problems in the manufacturing process.

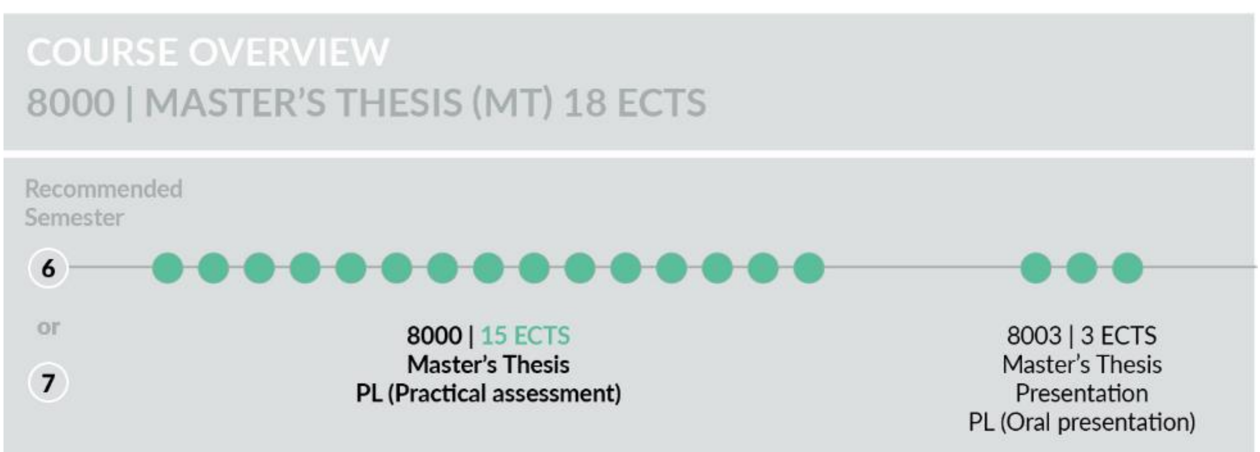
The results and suggested solutions must be recorded by each participant in the internship report as per the workshop protocol. **Approximate Workload (Total 2 x 50 h):** ✓ 12 h workshop in Freiburg (or external) ✓ 10 h preparation of the experiments ✓ 28 h writing of a lab report
Learning Objectives
After finishing this course, students should be able to ✓ Understand the practical aspects of solar cell production and characterisation. ✓ Describe the real-world situation in the industries. ✓ Discuss the current trends with industrial experts. ✓ Create a laboratory report. ✓ Develop collaborative problem-solving skills.
Assessment
• Report submission (1-2 pages) • Non graded, Pass/Fail (SL)
Software and Literature
-

Module #8000: Master's Thesis

The culmination of the program is the master's thesis. The importance of thesis work is reflected by the prominent role it takes within the whole M.Sc. program. After successful completion of compulsory and elective modules, the master's thesis offers the challenge to set up and to carry out a scientific research project with a high degree of autonomy and responsibility.

Total ECTS	Recommended Semester	Duration	Offer Frequency
18	Last semester of studies	Six months	Every semester/ Any time after the student collects 20 ECTS from Mandatory Modules.
Grading		Graded master's thesis (PL) and graded oral presentation (PL)	
Courses		8000: Master's Thesis (15 ECTS) 8003: Master's Thesis: Presentation (3 ECTS)	
Responsible Professor for the Module		Prof.Dr.-Ing. Mohammadreza Aghaei	

In SEE, there are two ways to conduct the thesis: students can either write an off-campus or an on-campus master's thesis. The off-campus master's thesis is written remotely. In comparison, students who want to write an on-campus master's thesis must join a research team in one of our cooperating institutes (Fraunhofer ISE, INATECH) in Freiburg. As much as the SEE supports students to find a position in a research team, we cannot guarantee a spot; it is mainly the student's responsibility to find one. The SEE provides a detailed guideline to support students and answer any possible questions about the master's thesis before beginning to work on the thesis. Project supervisors will fix individual requirements and standards for master's thesis projects



within the framework provided by the official examination regulations.

For the successful completion of a master's thesis, certain knowledge levels, as well as certain skills, are essential requirements. Sound knowledge of methods will be assumed as a basis at the beginning of the thesis work and will not be touched upon during the supervision. Furthermore, proper skills in using modern text, database, spreadsheet, drawing, modelling, and reference management software are expected from the beginning. It is the student's responsibility to acquire the necessary knowledge and skills before starting the master's thesis. If these skills must be developed during the thesis work, students should plan accordingly and expect an extended study time.

Appendix

We have thought very hard about how to name this handbook; it could have been a guidebook, catalogue, manual and more. We decided on the Module Handbook, hoping to answer any questions that may arise and become a source for current students and prospective students. We hope this Module Handbook shows you our enthusiasm about solar energy and our commitment to raising students who can be the change! If you still have questions, you can always contact us or check out the FAQ section on our website – you are very likely to find your answers.

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We thank all the professors, tutors, and Solar Energy Engineering team members for reading and giving their feedback to us in this long process of creating the MHB. We are also thankful to Fraunhofer Academy for funding support in visual communication.

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Admission and Examination Board

The admission and examination board of SEE consists of three professors as prominent members and one professor in a deputy's function. The board is elected for three years. From 2020 to 2023, the members are:

- Prof. Dr. Anke Weidlich, INATECH
- Prof. Dr. Stefan Glunz, INATECH
- Dr. Mirko Schäfer, INATECH

Acting as the deputy:

- Prof. Dr. Moritz Diehl, IMTEK

Related Departments within the University of Freiburg

Freiburg Academy for University Continuing Education (FRAUW)[1]

FRAUW is a transfer-oriented competence centre for education, training, and continuing education managed as a central operating institution of the university under the responsibility of the Vice-President for Academic Affairs. It consists of three departments: The Department of Academic Continuing Education, which is responsible for the master's program presented here, the Training Department (for the university employees), and the Center for Key Competencies.

FRAUW's task is the professional and interdisciplinary qualification of external persons, employees, and students at the university. Scientific continuing education is seen as a core task of the university. It supports reciprocal transfer with business and society and the numerous positive interactions with undergraduate university teaching, consecutive master's programs, and research. Continuing education and training are part of science communication in the sense of scientific outreach. Impulses from professionals participating in continuing education impact research questions, and the continuing education programs respond to society's needs and perceptions on different levels. ("reciprocal transfer understanding").

The faculties, institutes, and centres are responsible for the content of the academic continuing education programs. FRAUW serves as a central coordination and service platform, bringing support where needed and expanding the University's Lifelong Learning Programs. It also regulates the exchange of services with internal and external continuing education providers based on cooperation agreements. Together with the e-learning department, the University of Freiburg has become a leading university in online master's degree programs addressing professionals worldwide. FRAUW supports its providers in marketing and external representation and is responsible for administrative issues and central networking.

[1] see https://www.wb.uni-freiburg.de/ and https://www.wb.uni-freiburg.de/wb/continuing

The University of Freiburg's part-time continuing education programs, created in 2007, includes seven online and two face-to-face master's degree programs in medicine, health, technology, law, and taxation. Besides, there are numerous modular study programs and continuing education courses. The continuing education programs are realised in defined quality-assured formats.

The University of Freiburg is the first and, so far only, German university to cooperate with Swissuni, the Swiss Universities Association for Continuing Education. Its quality assurance and formats are based on this model.

E-Learning Department (AEL)[2]

The Department of E-Learning (AEL), located in the University Computer Center, is the central department at the University of Freiburg for digital learning and teaching. It provides a comprehensive IT infrastructure to support innovative teaching scenarios. In cooperation with the Department of University Didactics, the AEL is the central point of contact for all university members concerning consulting, qualification, and support for the use of e-learning and web technologies in teaching. Since 2009, the AEL has provided central support for the university's online continuing education offerings in the following areas:

- Development IT infrastructure for Learning and Teaching
- Didactic-technical consulting and support in the areas of e-learning, media use, and development of online teaching materials
- Qualification and Training

As an interface between technology and its application, the E-Learning Department supports all university members for meaningful integration and the use of digital media and educational technologies in teaching and continuing education programs. Based on service agreements, the e-learning department also provides further support services for continuing education courses, such as content production.

[2] https://www.rz.uni-freiburg.de/go/elearning

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