DENSYS

MASTER ERASMUS MUNDUS DECENTRALISED SMART ENERGY SYSTEMS

Detailed program booklet

2020/2022

With the support of the Erasmus+ Programme of the European Union

TWO YEARS ERASMUS MUNDUS JOINT MASTER DEGREE IN 4 LEADING EUROPEAN UNIVERSITIES

FOREWORD

Climate change is probably the most challenging situation the humanity has ever faced. Beyond the increase of greenhouse gases concentration in the atmosphere, massive loss of biodiversity and deforestation are threats that worsen the climate crisis.

To fight this global warming, a transition towards a low carbon energy is required: renewable energy sources integration along with decarbonized energy carriers production, decarbonization of the final uses of the energy in the housing, transportation and industrial sectors are required to achieve the ambitious objective of a carbon neutral world by 2050.

Decentralized smart energy systems play an increasing role in the perspective of renewable energy sources integration. This is the spirit of DENSYS. The overall goals of the DENSYS are:

- to educate with Multiphysics approaches (electrical, mechanical, chemical engineering) top skilled engineers, who will be able to design, size, optimize and operate decentralized smart energy systems while keeping a holistic vision to understand citizens' needs and to dialog with different stakeholders,
- to train future scientists, since decentralized energy systems still require R&D.

DENSYS is an European Union funded program, coordinated by University of Lorraine (UL, France), jointly built with the Royal Institute of Technology (KTH in Stockholm Sweden), the Polytechnic Institute of Torino (PoliTo, Italy) and the Universitat Politècnica de Catalunya (UPC in Barcelona, Spain).

DENSYS implements the "T-shaped" education profile, the vertical bar of the T being the core competences in engineering (namely mechanical, electrical and chemical engineering) and the horizontal bar complementary competences that are required to have a holistic vision and to engage the dialog with different specialists.

DENSYS will provide you a solid training in engineering and also competences in economics and humanities. These last are of primary importance since the energy transition is mainly a human and societal concern, especially in the case of decentralized energy systems, which are closed to the territories and citizens.

DENSYS is also an intercultural experience, which will enable us to share local contexts which are so important to develop relevant and efficient energy solution.

DENSYS aims at training engineers, researchers, but also ambassadors of new energy technologies and of the energy transition and citizens of a world that must urgently shift towards a climate neutral one.

Welcome to DENSYS program and all the team wish you the best success…

Fabrice Lemoine, Chair of DENSYS, and ***Heathcliff Demaie***, Vice-Chair at the University of Lorraine, France.
Justin Chiu, Local Coodinator *at the Royal Institute to Technology, Sweden.*
Massimo Santarelli, Local Coordinator *at the Politecnico di Torino, Italy.*
Asensi Oliva and ***Joaquim Rigola***, *Local coordinators at the Universitat Politècnica di Catalunya, Spain.*

TABLE OF CONTENT

REVISION TABLE OF THIS DOCUMENT

Version	Comment
v0	Contains only the first year
v1	Contains the two years

TWO YEARS IN 4 LEADING EUROPEAN UNIVERSITIES

1st Semester	2nd Semester	3rd Semester	4th Semester
UL *(Nancy, France)*	**UL** *(Nancy, France)*	**KTH** *(Stockholm, Sweden)* **POLITO** *(Torino, Italy)* **UPC** *(Barcelona, Spain)*	**Company or Research laboratory**
Harmonization *3 ECTS* Energy conversion process *3 ECTS*	Smart flexible energy management incl. 1-week immersive session on digitalization and artificial intel. at Uni. Liège, Belgium *12 ECTS*	Specialization track *12 ECTS*	Master thesis / Internship *30 ECTS*
Key technologies of DES 9 *ECTS*	Challenge based module *6 ECTS*	*6 ECTS*	
Case based Module 3 *ECTS*	Breadth courses *6 ECTS*	Breadth courses *6 ECTS*	
Elective courses 6 *ECTS*	Elective courses *6 ECTS*	Elective courses *6 ECTS*	
Language and Culture	Language and Culture	Language and Culture	
	Joint Summer Session (1)	*Challenge based module defence*	Joint Summer Session (2) *Master thesis defence and job fair*
30 ECTS	*30 ECTS*	*30 ECTS*	*30 ECTS*

DENSYS

MASTER ERASMUS MUNDUS DECENTRALISED SMART ENERGY SYSTEMS

YEAR 1

SEMESTER 1 (UNIVERSITY OF LORRAINE) - TOTAL 30 ECTS

Teaching units	Content summary	Main learning outcomes	ECTS
Harmonization	• Basics of Fluid Mechanics, Thermodynamics, Heat & Mass transfers • The different operating modes of electric circuits. Transformers. Power calculations. Electromechanical power conversion principle	• Master the prerequisites for the advanced courses of the master • Master the conservation principles in Mechanical and Chemical • Engineering Understand the basics of Electric Circuits, Magnetic circuit and direct applications in power exchanges.	**3 ECTS**
Energy conversion processes	• Heat and fluid for energy • Chemical and electrochemical processes involved in energy • Electricity conversion and distribution	• Master the principles of energy conversion involving fluid and heat • Master the principles and processes of chemical and electrochemical energy transformation • Master mechanical energy conversion into electricity and grid interface	**9 ECTS**
Key technologies of DES	• Renewable energy sources • Energy storage • Interconversion of energy carrier processes	• Master the principles of the key renewable energy resources • Master the different ways of storing electrical and thermal energy • Master the different ways of interconversion processes between energy carriers • Be able to implement simplified dynamic models	**9 ECTS**
Case based module	• Bottom up study of a real life problem (for which several solutions exist) that include the key technologies of DES (RES, storage, carriers interconversion) • Supervised team work	• Explore a real-life case and design a usable model • Be capable to have in mind other systemic points: e.g. costs of the technologies, availability of the resources (material), recyclability, social acceptance, …	**3 ECTS**
Language, culture	French	Initiation to the local language and cultural tips	
Elective #1	• Critical resources for energy and recyclability • Materials for energy conversion • Energy transition and territories • Economy for energy	2 courses over 4 (3 ECTS/course)	**6 ECTS**

Teaching Unit:
"Harmonization"

3
ECTS

Content summary:

- Basics of Fluid Mechanics, Thermodynamics, Heat & Mass transfers
- The different operating modes of electric circuits.
  Transformers.
  Power calculations.
  Electromechanical power conversion principle

Main learning outcomes:

- Master the prerequisites for the advanced courses of the master
- Master the conservation principles in Mechanical and Chemical Engineering
- Understand the basics of Electric Circuits, Magnetic circuit and direct applications in power exchanges.

COURSE:
BASICS OF FLUID MECHANICS, THERMODYNAMICS, HEAT & MASS TRANSFERS

Teaching Unit (for year 1):
"Harmonization"

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Guillain MAUVIEL
University / lab.
Université de Lorraine / ENSIC - LRPG

Pedagogic Team

Christel METIVIER
Université de Lorraine
LEMTA

Guillain MAUVIEL
Université de Lorraine
ENSIC - LRPG

Jean-Noël JAUBERT
Université de Lorraine
LRPG

Aims of the teaching

This harmonization course is directed specifically to the students that have obtained electrical engineering bachelor. It is intended to provide students with a comprehensive knowledge on chemical and mechanical engineering basis. More specifically the balance principles will be taught and applied to Mass, Energy and Momentum conservation. The different modes of mass and heat transfer will be introduced. These skills are necessary for the forthcoming modules of DENSYS.

Intended Learning outcomes (measured by the assessment)

- Have acquired knowledge and understanding on the treated topics
- Be able to establish an integral balance of mass, species or energy for open & closed systems
- Be able to establish a local balance of mass, energy and momentum.
- Master the Bernouilli equation to determine the link between potential, kinetic and pressure energy.
- Determine the pressure losses in tubes and valves
- Be able to size pumps to transport liquids
- Distinguish the different modes for heat & mass transfer (conduction, convection, radiation)
- Be able to utilize a proper scientific language

Learning activities and approach

E-learning (online)	Lectures (onsite) 15h	Tutorials (onsite) 15h
None		Exercises

Practical work equipment and location

No practical work is planned.

Assessment method

Written exam on the theoretical and applicative content of the course

Useful information

Prerequisites: None

Related literature:

- Handbook of Heat Transfer (W. Rohsenow; J.P. Hartnett, Y.I. Cho), Ed. Mc-Graw-Hill Handbooks
- Fundamentals of Engineering Thermodynamics, M. J. Moran, H. N. Shapiro, D. D. Boettner, John Wiley & Sons, 2010.
- Documents provided by teachers

COURSE:
THE DIFFERENT OPERATING MODES OF ELECTRIC CIRCUITS

Teaching Unit (for year 1):
"Harmonization"

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Thierry BOILEAU
University / lab.
Université de Lorraine / ENSEM - LEMTA

Pedagogic Team

Noureddine TAKORABET
Université de Lorraine
ENSEM - GREEN

Thierry BOILEAU
Université de Lorraine
ENSEM - LEMTA

Aims of the teaching

This harmonization course is addressed specifically to the students that have obtained mechanical engineering bachelor or chemical engineering bachelor. It is intended to provide them with a comprehensive knowledge on electrical engineering basis. More specifically the method to study DC circuits, AC circuits and circuits in transient operations. The basics on electromagnetics and electromechanical power conversion will also be introduced. These skills are necessary for the forthcoming modules of DENSYS.

Intended Learning outcomes (measured by the assessment)

- Be able to study a DC circuit
- Be able to study an AC circuit with complex formalism
- Be able to calculate active power
- Be able to study and simulate circuits in transient operations

- Understand the basics of electromagnetics
- Be able to study a magnetic circuit
- Understand the operation of a transformer and the constraints of its implementation
- Understand electromechanical power conversion principle

Learning activities and approach

E-learning (online)	Lectures (onsite)	Tutorials (onsite)
None	The lectures are given by teachers belonging to the pedagogic team	Exercises and simulations

Practical work equipment and location

Location: ENSEM
Practical work equipment: Computing rooms with dedicated software (Matlab-Simulink)

Assessment method

Written exam on the theoretical and applicative content of the course

Useful information

Prerequisites: None

Related literature:

- Schaum's Outline of Basic Electricity, Second Edition (M. Gussow), Ed. Mc-Graw-Hill Handbooks
- Documents provided by teachers

Teaching Unit:
"Energy conversion processes"

9 ECTS

Content summary:

- Heat and fluid for energy
- Chemical and electrochemical processes involved in energy
- Electricity conversion and distribution

Main learning outcomes:

- Master the principles of energy conversion involving fluid and heat
- Master the principles and processes of chemical and electrochemical energy transformation
- Master mechanical energy conversion into electricity and grid interface

COURSE:
HEAT AND FLUID FOR ENERGY

Teaching Unit (for year 1):
"Energy conversion processes"

Face-to-face time	Student workload	ECTS
36 hours	**36 hours**	**3**

Responsible teacher

Pr David LACROIX
University / lab.

Université de Lorraine / FST - LEMTA

Pedagogic Team

Jean-Noël JAUBERT
Université de Lorraine
ENSIC - LRPG

Silvia LASALA
Université de Lorraine
ENSIC - LRGP

Julia MAINKA
Université de Lorraine
FST - LEMTA

Romain PRIVAT
Université de Lorraine
ENSIC - LRGP

Aims of the teaching

- The teaching aims at providing solid knowledge to enable the analysis of unit operations used in power and refrigeration technologies (turbines, compressors, pumps, heat exchangers, etc.)
- The proposed lectures and hands-on training will provide the necessary theoretical background and an overview of dedicated software for practising and carrying out projects (case-based project & challenge-based project).
- Among covered topics, teaching will address: i) Unit operations in mechanical and chemical engineering; ii) Thermodynamic cycles; iii) Phase change; iv) Heat exchanger calculations.
- Numerical skills will be encouraged through the use of dedicated mechanical and chemical engineering software as: Prosim Plus, Aspen, Fluent, Comsol.
- Lecture by industry specialists of these fields are also scheduled (EDF, FiveCryo, …).

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
- Demonstrate knowledge of key technologies that operate according to a thermodynamic cycle, with heat and mass transport.
- Demonstrate the ability to: formulate, analyse, model and solve an applied engineering problem dealing with heat and fluid.
- Master principles of energy conversion involving: fluid, heat and phase change.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Tutorials (onsite)
Courses and demo related to thermodynamic cycles and heat exchangers	*Unit operation (4h CM); Thermodynamic cycles (5h CM); Phase change (5h CM); Heat exchangers (5h CM)*	*Unit operation (3h TD); Thermodynamic cycles (4h); Phase change (8h TD); Heat exchangers (4h TD) - through exercises & mini-projects*

Practical work equipment and location

Location: Faculty of Sciences and Technologies, ENSIC
Practical work equipment: Computing rooms with dedicated software

Assessment method

- Written & oral exams (including quiz)
- Mini-project for group of 2 to 3 students related to the use of numerical tools and software

Useful information

Prerequisites: Basics of Fluid Mechanics, Thermodynamics, Heat & Mass transfers

Related literature:

- **Handbook of Heat Transfer** (W. Rohsenow; J.P. Hartnett, Y.I. Cho), Ed. Mc-Graw-Hill Handbooks
- **Fundamentals of engineering thermodynamics** (M.J. Moran and H.N. Shapiro), Ed. John Wiley & Sons
- **Energy, Entropy and Engines: An introduction to thermodynamics** (Sanjeev Chandra), John Wiley & Sons, 2016 (ISBN: 9781119013150)

COURSE:

CHEMICAL AND ELECTROCHEMICAL PROCESSES INVOLVED IN ENERGY

Teaching Unit (for year 1):
"Energy conversion processes"

Face-to-face time	Student workload	ECTS
24 hours	**48 hours**	**3**

Responsible teacher

Francois LAPICQUE
University / lab.
Université de Lorraine / LRGP - CNRS UMR 7274

Pedagogic Team

Pierre MILLET
Université Paris Sud
CNRS

Marie BASIN
Air Liquide R&D

Olivier HERBINET
Université de Lorraine
LRGP

Jean-François PORTHA
Université de Lorraine
LRPG

Aims of the teaching

The series of lectures is aimed first at providing a common ground knowledge on reaction kinetics, for processes occurring in a gas phase, on a catalyst or at an electrode surface. Then, the presentation will focus on the reactions involved in hydrogen production or used for energy production: therefore, first elements on hydrogen production by hydrocarbon reforming or by water electrolysis will be presented, together with the description of fuel cells for energy production from hydrogen fuel. The series of lectures will cover the main reactions involved, the constraints of the processes in terms of mass and energy yields, and the description of current technology. These elements will be completed by energy integration and optimisation in further modules.

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
  - Demonstrate knowledge in chemical kinetics (gas phase, catalytic processes), thermodynamical equilibrium in a gas phase, and basic electrochemistry
  - Demonstrate knowledge in hydrocarbons reforming and partial oxidation, in particular at industrial scale
  - Demonstrate ability to pre-design industrial installations of hydrocarbon reforming for hydrogen production, taking into account energy requirements and management

- Demonstrate knowledge in electrochemical reactions occurring in hydrogen fuel cells and water electrolysis
- Demonstrate capacity to pre-design industrial installations of energy conversion by hydrogen fuel cells, and electrolysers, taking into account mass and energy balances

Learning activities and approach

E-learning (online)	Lectures (onsite) 14h	Tutorials (onsite) 12h
None	The lectures are given by the members of the pedagogic team	*Exercices on the various lectures or covering the set of lectures*

Practical work equipment and location

No practical work is planned.

Assessment method

Written exam on the theoretical and applicative content of the course

Useful information

Prerequisites: None.

Related literature:

- Written documents prepared by the teachers
- F. Barbir, A. Basile, N. Veziroglu, Compedium in Hydrogen Energy: Hydrogen Energy Conversion (vol. 3), Woolhead Publish. (2015)
- A. Savall and F. Lapicque, Electrochemical engineering for a sustainable development, in Green Process Engineering, from Concepts to industrial applications, M. Poux et al. eds, CRC Press, Boca Raton (2015)

COURSE:

ELECTRICITY CONVERSION AND DISTRIBUTION

Teaching Unit (for year 1):
"Energy conversion processes"

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Thierry BOILEAU
University / lab.

Université de Lorraine / ENSEM - LEMTA

Pedagogic Team

Stéphane DUFOUR
Université de Lorraine
ENSEM - LEMTA

Farid MEIBODY-TABAR
Université de Lorraine
ENSEM - LEMTA

Thierry BOILEAU
Université de Lorraine
ENSEM - LEMTA

Aims of the teaching

The objective of this course is to provide basic knowledge about electrical grids and the connections of these grids with loads.
The three-phase grid will be covered, but also the modelling tools and models useful for the study of microgrids.

Intended Learning outcomes (measured by the assessment)

- Be able to study a 3 phases circuit
- Be able to calculate active and reactive power in 3phase circuit
- Understand the operation of 3 phase transformers
- Be able to realize a power system analysis (Load Flow analysis with MatPower Software)
- Understand basics of power electronics

- Be able to model an inverter/rectifier for control purposes
- Be able to model a synchronous generator for control purposes

Learning activities and approach

E-learning (online)	Lectures (onsite) 15h	Tutorials (onsite) 15h
None	The lectures are given by teachers belonging to the pedagogic team	Exercises and simulations

Practical work equipment and location

Location: ENSEM
Practical work equipment: Computing rooms with dedicated software (Matlab-Simulink+Matpower Software)

Assessment method

Written exam on the theoretical and applicative content of the course

Useful information

Prerequisites: Content of Harmonization course electricity part.

Related literature:

- Schaum's Outline of Basic Electricity, Second Edition (M. Gussow), Ed. Mc-Graw-Hill Handbooks
- J. Grainger, JW Stevenson, CW Chang "Power System Analysis" McGraw-Hill (2015)
- J.D. Glover, T Overbye, M.S. Sarma "Power System Analysis and Design" Cengage Learning (2016)
- Chee-Mun Ong “Dynamic Simulation of Electric Machinery: Using MATLAB/Simulink” Prentice Hall (1998)
- Documents provided by teachers

Teaching Unit:
“Key energy technologies in Decentralized Energy Systems”

9
ECTS

Content summary:

- Renewable energy sources
- Energy storage
- Interconversion of energy carrier processes

Main learning outcomes:

- Master the principles of the key renewable energy resources
- Master the different ways of storing electrical and thermal energy
- Master the different ways of interconversion processes between energy carriers
- Be able to implement simplified dynamic models

COURSE:

RENEWABLE ENERGY SOURCES

Teaching Unit (for year 1):

"Key energy technologies in Decentralized Energy Systems"

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Gaël MARANZANA

University / lab.

Université de Lorraine / LEMTA

Pedagogic Team

SOLAR

Justin CHIU

KTH Royal Institute of Technology
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BIOENERGY

Guillain MAUVIEL

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WIND

Justin CHIU

KTH Royal Institute of Technology
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GEOTHERMAL ENERGY & MARINE ENERGY

Silvia LASALA

Université de Lorraine
LRGP

HYDRO

Alexandre LABERGUE

Université de Lorraine
LEMTA

Aims of the teaching

The purpose of this teaching module is to draw up an inventory of the various renewable energy production sectors – bioenergy (8h), hydro (5h), wind (6h), solar (6h), marine energies (2h) and geothermal energy (3h) - to understand the associated issues and to envisage the perspectives (development, economy, insertion of the energy mix). Students will be able to approach the practical aspect by carrying out a practical work of their choice on hydraulic or wind turbines

Intended Learning outcomes (measured by the assessment)

- At the end of the course, the student should:
  - Demonstrate knowledge about the different technologies themselves and their readiness level
  - Demonstrate ability to size a system (roughly) and to value its efficiency

Learning activities and approach

E-learning (online)	Lectures (onsite) 15h	Tutorials (onsite) 15h
None		Exercises

Practical work equipment and location

No practical work is planned.

Assessment method

Bibliographic review, homework (mini case based or series of exercises), final exam.

Useful information

Prerequisites: Notions of energetics, general scientific culture

Related literature:

- Advances in Renewable Energies and Power Technologies, eBook ISBN: 9780128132173
- Renewable Energy System Design, eBook ISBN: 9780080961675

COURSE:
ENERGY STORAGE

Teaching Unit (for year 1):
“Key energy technologies in Decentralized Energy Systems”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Silvia LASALA

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Université de Lorraine / LRGP

Pedagogic Team

Alexandre CHAGNES
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GeoRessources

Sophie DIDIERJEAN
Université de Lorraine
LEMTA

Alexandre LABERGUE
Université de Lorraine
LEMTA

Joaquim RIGOLA
Universistat Politecnica de Catalunya / CTTC

Massimo SANTARELLI
Politecnico di Torino
Energy Department

Aims of the teaching

The teaching intends to provide students with a comprehensive knowledge on several types of energy storage technologies and specific skills needed to optimally design and manage storage systems in light of techno-economic and environmental considerations. Following an introduction to the historical development of energy storage systems, the course thoroughly explores different storage technologies, among which Li-ion batteries, redox-flow batteries, electrolyzers, fly wheels, pumped-storage hydro-electricity, compressed air, phase change materials, etc. Both stationary and mobile applications are treated, also addressing their potential future development with respect to envisaged international energy strategies. During this course, students will have the opportunity to train their research and communication skills by properly exploiting the content of research papers, either in support to their assertions animating planned debates or to enhance the scientific impact of group projects that they will be asked to develop.

Intended Learning outcomes (measured by the assessment)

- Have acquired knowledge and understanding on the treated topics
- Be able to optimize storage systems according to multiple optimization criteria

- Be able to select one (or more) of the possible energy storage technologies according to specific energy production / utilization scenarios
- Be able to implement models with relevant physical contents at the relevant scale to describe storage technologies or systems
- Be able to utilize a proper scientific language
- Be able to engage dialog with specialists
- Be able to identify and formulate R&D questions

Learning activities and approach

E-learning (online)	Lectures (onsite) 15h	Tutorials (onsite) 15h
None	Most of lectures are given by teachers belonging to the pedagogic team. Topics concerning the most promising storage technologies are treated in detail by expert visiting lecturers.	Exercises Debates Project on the analysis and design of storage systems Visit of an Energy Storage Company

Practical work equipment and location

No practical work is planned.

Assessment method

Written exam and oral exam (optional) on the theoretical and applicative content of the course.
Project group (evaluation of the delivered report and of its oral presentation)

Useful information

Prerequisites: Established knowledge in thermodynamics, fluid mechanics, heat and mass transfer, basics of chemical and electrochemical processes. Knowledge acquired in the courses of Renewable Energy Sources and Interconversion of Energy Carrier Processes, delivered in parallel to Energy Storage, are also required.

Related literature:

- Engineering Energy Storage, Odne Stokke Burheim, Academic Press
- Electrochemical Engineering Principles, Geoffrey Prentice, Prentice-Hall International
- Documents provided by teachers
- Literature research papers

COURSE:

INTERCONVERSION OF ENERGY CARRIER PROCESSES

Teaching Unit (for year 1):
“Key energy technologies in Decentralized Energy Systems”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Romain PRIVAT

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Université de Lorraine / ENSIC - LRGP

Pedagogic Team

Olivier HERBINET
Université de Lorraine
LRGP

Silvia LASALA
Université de Lorraine
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Julia MAINKA
Université de Lorraine
LEMTA

Romain PRIVAT
Université de Lorraine
ENSIC - LRGP

Massimo SANTARELLI
Politecnico di Torino
Energy Department

Aims of the teaching

The teaching intends to provide students with a comprehensive knowledge on the different types of energy conversion processes in the frame of Decentralized Energy Systems.
The main topics treated in this course are:

- Fundamentals of combustion and smart energy carriers
- Heat to power technologies:
  - Centralized power systems based on the use of fossil fuels (gas turbines, natural gas combined cycles, integrated gas combined cycles, ultra-supercritical cycles) and power to heat (heat pumps …)
  - Decentralized heat-to-power systems (closed power cycles for waste heat recovery, co- and tri-generation)
- Gas to power technologies:
  - Fuel cells (gas = H2) (note that basics of electrochemistry are introduced in another course: “Chemical and electrochemical processes involved in energy”),
  - Gas engines and gas turbines (gas = fuel).
- (Note that power to gas technologies are introduced in the course “energy storage”)
  - Tools for cycle performance evaluation and heat-exchange optimization: exergy analysis and pinch analysis.
-

Intended Learning outcomes (measured by the assessment)

- Have acquired knowledge and understanding on the treated topics
- Be able to optimize storage systems according to multiple optimization criteria
- Be able to select one (or more) of the possible energy storage technologies according to specific energy production / utilization scenarios
- Be able to implement models with relevant physical contents at the relevant scale to describe storage technologies or systems
- Be able to utilize a proper scientific language
- Be able to engage dialog with specialists
- Be able to identify and formulate R&D questions

Learning activities and approach

E-learning (online)	Lectures (onsite) 15h	Tutorials (onsite) 15h
None		Exercises Visit of a combined cycle power plant

Practical work equipment and location

No practical work is planned.

Assessment method

Written exams and Oral exams

Useful information

Prerequisites: Established knowledge in thermodynamics, fluid mechanics, heat and mass transfer, basics of chemical and electrochemical processes.

Related literature:

- Fundamentals of Engineering Thermodynamics, M. J. Moran, H. N. Shapiro, D. D. Boettner, John Wiley & Sons, 2010.
- Cleaner Combustion, Green Energy and Technology. Battin-Leclerc, F., Simmie, J.M., Blurock, E. (Eds.), 2013. Springer London, London.
- Documents provided by teachers
- Literature research papers

Teaching Unit:
"Case based module"

3
ECTS

Content summary:

- Bottom up study of a real life problem (for which several solutions exist) that include the key technologies of DES (RES, storage, carriers interconversion)
- Supervised team work

Main learning outcomes:

- Explore a real-life case and design a usable model
- Be capable to have in mind other systemic points: e.g. costs of the technologies, availability of the resources (material), recyclability, social acceptance, …

COURSE:
THE CASE BASED MODULE

Teaching Unit (for year 1):
"Case based module"

Face-to-face time	Student workload	ECTS
-	**90 hours**	**3**

The case based module will rely on the learnings of the block of modules "Key technologies in Decentralized Smart Energy Systems", composed by three modules:

- Renewable energy sources
- Energy storage
- Interconversion of energy carrier processes

They students (by groups of 4 to 5) will have to integrate and apply the knowledge acquired in these three module to a real life case. The approach, mainly based on engineering, is bottom-up, going from the particular example to the general concept. Remote team working, dedicated lectures and practical approach can be combined.

Students are invited to analyze and solve an existing case emerging from a real-life problem. On the basis of a preliminary analysis, they propose a technological solution to the problem, based on either already existing or innovative technologies. By this way, student acquires knowledge, is able to formulate the problem, provide and design solutions to solve the case.

Overall aims

- Students are invited to analyze an existing case emerging from a real-life problem.
- Students propose improvements to the existing solution or new/innovative solutions. Therefore, students acquire knowledge on the case by "a learning by doing" process, they acquire the ability to formulate the problem, provide and design solutions to solve the case. They should be able to formulate clearly the problem, find solutions and justify them with scientific arguments: hypothesis, modelling, calculations, analysis of results, conclusions.
- Development of soft skill: working in a team by leading and sharing responsibilities, reaching collaborative and collective decisions.

The case topics

The case topics will be proposed jointly by teachers of the 3 modules composing the module block "Key technologies in Decentralized Smart Energy Systems ".

The supervising team will be composed by two teachers from UL. As the module is co-designed and co-taught together by UL teachers and teachers from the consortium partners, teachers from UPV, KTH or PoliTo participating to this course can be invited to participate to the case design and supervision.

Module structure

Course is given as a problem based learning which has practical interest and value. Learning and skill development activities are organized collectively by the supervising team.

An optimal solution as well as alternative solutions are expected to be provided as final outcome: they have to be well argued and justified.

The module is scheduled in semester 1 between fall and Christmas breaks, after the module block "Key technologies in Decentralized Smart Energy Systems".

Assessment of the module consists of a synthetic report and a presentation falling in the scope of ILO4 in front of a board of at least three teachers, each of them being involved in one the 3 modules of the module bock "Key technologies in Decentralized Smart Energy Systems".

Intended Learning Outcomes (ILOs) of the course

After the course, the student should be able to:

- **ILO1:** Formulate and analyze a well-defined problem emerging from real life.
- **ILO2:** Be able to integrate and apply background knowledge delivered mainly in the
- blocks “Energy conversion processes” and “Key technologies in Decentralized Smart Energy Systems”.
- **ILO3:** Make hypothesis with supporting justification, describe the problem through models, perform calculations and analyze the results to provide solutions to the problem.
- **ILO4:** Present the objectives of the work, the methodology and results in a synthetic and usable report and orally.

Learning materials and assistance

- Learning material from the DENSYS programme
- Specific lectures, seminars, workshops organized in the framework of the case based module
- Assistance as well as continuous assessment of the work is provided by the supervising team
- Students are strongly encouraged to deeply learn by their own thanks to provided materials during DENSYS courses and any other available reliable open source materials of their own selection.

Report

The final synthetic report must contain an executive summary, formulation and analysis of the problem, justification of the hypothesis, supporting methodology to find the solution and conclusions together with perspectives. The scopes of specific ILOs 1 to 3 must be addressed.

Assessment and grading

The grading scale for the case based module is the following:

A	C	E	F
Excellent	Satisfactory	The minimum acceptable level has just been reached	Fail No report or no presentation delivered.

ILO1: Formulate and analyze a well-defined problem emerging from real life

- E: Analyze the problem and formulate assumptions to solve it.
- C: Same as E, and identify sub-problems.
- A: Same as C, and propose possible relationships between identified problems.

ILO2: Be able to integrate and apply background knowledge delivered mainly in the module blocks “Energy conversion processes” and “Key technologies in Decentralized Smart Energy Systems”

- E: Propose a basic solution to the problem.
- C: Propose a solution based on the sound use of multiple technologies.
- A: Propose a solution based on the sound use of multiple technologies and optimize the design and operating conditions of the energy system.

ILO3: Make hypothesis with supporting justification, describe the problem through models, perform calculations and analyze the results to provide solution to the problem.

- E: Provide sound hypothesis and perform correct modelling.
- C: Same as E, and perform correct calculations.
- A: Same as C, and perform a thorough analysis of results, proposing alternative solutions.

ILO4: Present the objectives of the work, the methodology and results in a synthetic and usable report and orally.

- E: Present the performed work in the report and orally.
- C: Present the performed work in the report and orally, with high synthetic and language quality.
- A: Present the performed work in the report and orally, with excellent synthetic and language quality.

Teaching Unit:
“Elective #1”

3
ECTS

Content summary:

- Critical resources for energy and recyclability
- Materials for energy conversion
- Energy transition and territories
- Economy for energy

Main learning outcomes:

- 2 courses over 4 (3ECTS/course)

COURSE:

CRITICAL RESOURCES FOR ENERGY AND RECYCLABILITY

Teaching Unit (for year 1):
"Elective #1"

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Alexandre CHAGNES

University / lab.
Université de Lorraine / GéoRessources

Aims of the teaching

The teaching intends to provide students with a comprehensive knowledge on the sustainable management of mineral resources to ensure an optimal supply of raw materials for the development of energy transition technologies. After briefly describing technologies and their composition, a discussion about the need of strategic and critical metals will be engaged with the students. It will pave the way to address the challenges in the development of processes for the extraction and valorisation of metals contained in primary (mining) and secondary resources (electronic waste, tailings, etc.). The physicochemistry and the unit operations and technologies involved in these processes will be introduced. A special attention will be paid on raw material production and recycling process for the sustainable production of electric energy storage such as lithium-ion batteries, fuel cells, solar panels.

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
- Have acquired knowledge and understanding on the treated topics
- Be able to understand the operations involved in flowsheets for recycling processes
- Be able to utilize a proper scientific language
- Be able to engage dialog with specialists
- Be able to identify and formulate R&D questions

Learning activities and approach

E-learning (online)	Lectures (onsite) 24h	Tutorials (onsite) 6h
-	-	Exercises Conference/debates in the presence of industrial(s)

Practical work equipment and location

-

Assessment method

Written report and oral exam about analysis of an academic research paper.

Useful information

Prerequisites: None

Related literature:

- Apostol D., Palmer J., Pasqualetti M., Smardon R., Sullivan R., (2017). The *Renewable Energy Landscape: Preserving Scenic Values in our Sustainable Future*, Routledge.
- Brücher, W. (2009). Energiegeographie: Wechselwirkung zwischen Ressourcen, Raum und Politik. Berlin: Borntraeger.
- Frolova M., Prados M.-J., Nadaï A., (2015). *Renewable Energies and European Landscapes*, Springer.
- Smil V. (2017). *Energy Transitions*, 2nd edition, Praeger.
- Smil V. (2015). *Power Density*, The MIT Press

COURSE:
MATERIALS FOR ENERGY CONVERSION

Teaching Unit (for year 1):
“Elective #1”

Face-to-face time	Student workload	ECTS
30 hours	**30 hours**	**3**

Responsible teacher

Hervé RINNERT

University / lab.
Université de Lorraine / Institut Jean Lamour

Pedagogic Team

Christophe CANDOLFI
Université de Lorraine
Institut Jean Lamour

Sébastien CAHEN
Université de Lorraine
Institut Jean Lamour

Nicolas PORTHA
VIESMAN GROUP
(Industrial Partner)

Aims of the teaching

The course aims at giving some knowledge on the materials used for some energy conversion devices. The course will address the physical and chemical properties of these materials which render them suitable for the dedicated application. In addition, the course will address the economic and social issues related with abundance, toxicity and cost of materials.
Program:

- **Photovoltaic solar conversion (6H)**
  Introduction to semiconductors, Doping, P-N junction, Solar cells, Different generations of solar cells, Materials for solar cells
- **Thermal solar conversion (6 H)**
  Flat solar collector and thermal regulation, thermochromic properties, ThermProtect technology (developed between 2011 and 2016, commercialized since 2016), Smart materials (vanadium oxides)
- **Thermoelectricity (6H)**
  Introduction to thermoelectric effects (Peltier, Seebeck, Thomson) and to the design of thermoelectric devices for thermoelectric refrigeration (based on Peltier effect) or thermoelectric power generation (based on Seebeck effect)

- **Materials for batteries (6H)**
  Presentation of historical electrochemical conversion systems, Detailed description of Li-ion technologies, Different electrode materials (principle, performances, security)

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
- Demonstrate knowledge on basic physical and chemical properties of materials required for some applications related to energy conversion
- Demonstrate ability to analyse the different issues related to a specific application in energy conversion, taking into account of properties of matter but also of social et economic issues

Learning activities and approach

E-learning (online)	Lectures (onsite) 12h	Tutorials (onsite) 12h
-	Lectures	Exercises

Practical work equipment and location

- Two visits will be organised:
- A visit of a manufacturing plant dedicated to solar energy conversion (half a day) – Faulquemont (70 km from Nancy)
- A visit of a platform for elaboration of materials with ultrahigh vacuum chambers (half a day) - Institut Jean Lamour, Nancy

Assessment method

Written report and oral exam about analysis of an academic research paper.

Useful information

Prerequisites: Some basic knowledge on physical properties of condensed matter like absorption, electrical properties, thermal properties, and on electrochemistry

Related literature:

- Physics of semiconductor devices - S.M. Sze and NG. Kwok, WILEY
- Solid State Physics - Ashcroft and Mermin
- Fundamentals of Thermoelectricity, K. Behnia, Oxford University Press (2015)
- Electrochemical Energy Storage – J.-M. Tarascon and P. Simon, Wiley-ISTE, ISBN: 978-1-848-21720-1
- Electrodes for Li-Ion Batteries: Materials, Mechanisms and Performance – L. Monconduit, L. Croguennec, R. Dedryvère, May 2015, Wiley-ISTE, ISBN:9781848217218
-

COURSE:
ENERGY TRANSITION AND TERRITORIES

Teaching Unit (for year 1):
"Elective #1"

Face-to-face time	Student workload	ECTS
30 hours	**30 hours**	**3**

Responsible teacher

Michel DESHAIES

University / lab.
Université de Lorraine / LOTERR

Pedagogic Team

Michel DESHAIES
Université de Lorraine
LOTERR

Vincent BERTRAND
Université de Lorraine
LOTERR

Aims of the teaching

- The teaching aims at training the students for improving their employability in the private or research sector by developing their ability to understand the multiple territorial challenges of the energy transition and the geographical consequences of the implementation of new energy systems: organization and functioning of the territory, real or perceived landscapes and environmental impacts.…
- The purpose of this course is to present the concept of the energy transition and the different geographical consequences that result from the modification of the energy system according to the types of energy (wind, sun, biomass, geothermal) used. Students will be trained in a framework of critical analysis of the energy transition and its consequences on the territories through the study of numerous examples in different countries, on various geographical scales. The course will provide the basis for evaluating the advantages and disadvantages of the different types of energy systems proposed according to the geographic characteristics of the territories and will make it possible to propose different scenarios of energy transition.
- The energy transition in urban areas will be approached from various examples of European eco-districts.

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should be capable of:
  - Defining and illustrating the territorial consequences of the energy transition at different geographical scales (local, regional, national).
  - Assessing the difficulties that are specific to the implementation of a new energy system in a territory.

- Assessing the advantages and disadvantages of different types of renewable energy based on the geographical characteristics of the territories.
- Defining energy transition scenarios in different types of territory.
- Criticize different energy transition scenarios in research papers in the field.

Learning activities and approach

E-learning (online) 2h	Lectures (onsite) 12h	Tutorials (onsite) 16h
-	-	Exercises, debate, workshop, 2 field visits: 1 eco-district and 1 renewable energy project

Practical work equipment and location

-

Assessment method

Written report and oral exam about analysis of an academic research paper.

Useful information

Prerequisites: None.

Related literature:

- Apostol D., Palmer J., Pasqualetti M., Smardon R., Sullivan R., (2017). The Renewable Energy Landscape: Preserving Scenic Values in our Sustainable Future, Routledge.
- Brücher, W. (2009). Energiegeographie: Wechselwirkung zwischen Ressourcen, Raum und Politik. Berlin: Borntraeger.
- Frolova M., Prados M.-J., Nadaï A., (2015). Renewable Energies and European Landscapes, Springer.
- Smil V. (2017). Energy Transitions, 2nd edition, Praeger.
- Smil V. (2015). Power Density, The MIT Press.

COURSE:
ENERGY ECONOMICS

Teaching Unit (for year 1):
"Elective #1"

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Verónica ACURIO VÁSCONEZ

University / lab.
Université de Lorraine / BETA

Pedagogic Team

Olivier DAMETTE

Université de Lorraine
BETA

Aims of the teaching

- The teaching aims at training the students for improving their employability in the private or research sector by developing her/his ability to understand the economic sensitivity of the implementation of energy projects and policies and using it in the decision-making process.
- The purpose of the lectures is to present the main concepts and the basic economics models used in the field of energy economics, with the aim to provide the students a referential framework that helps them to achieve a critical analysis of the energy problems of our environment. It aims as well to study the links that these problems have with the development of our society. This lecture will approach the fundamental economic aspect of primary energy (supply, demand, market and prices), it will study the links between energy consumption and economic growth and it will analyse the impact of different energy policies in the economy.

Intended Learning outcomes (measured by the assessment)

At the end of the teaching module, the student should:

- Be capable of illustrate the evolution of different economic and energy consumption aggregates.
- Describe and interpret econometrics equations and charts in a situation of energy consumption evaluation of a region.
- Be able to choose, among different proposals, the best energy project from an economic and a financial perspective.
- Argue the advantages and disadvantages of fossil fuel energy and/or nuclear energy consumption versus renewable energy consumption.

- Evaluate the impact of energy policies in the economy.
- Criticize the hypothesis and the conclusions of research papers in the field.

Learning activities and approach

E-learning (online) 9h	Lectures (onsite) 12h	Tutorials (onsite) 9h
-	incl. 8h given by invited scholars	-

Practical work equipment and location

-

Assessment method

Dossier with an analysis of an academic research paper and exercises.

Useful information

Prerequisites: An intermediate level of mathematics (algebra and calculus) is required in order to understand the mathematical models..

Related literature:

- Energy Economics: Concepts, Issues, Markets and Governance, Subhes C. Bhattacharyya
- The Economic Growth Engine, Robert U. Ayres et Benjamin Warr
- Energie: Economie et politiques, Jean-Pierre Hansen et Jacques Percebois (in French)

SEMESTER 2 (UNIVERSITY OF LORRAINE) - TOTAL 30 ECTS

Teaching units	Content summary	Main learning outcomes	ECTS
Smart and flexible energy management	• Sizing and optimizing a local energy network • Energy management strategy • Smart energy networks	• Be able to formulate and solve the optimization problem of the design of an energy network • Be able to implement an energy management strategy in both centralized and decentralized mode and related control/command issues • Be able to understand the basis and the specific needs of a communication network and the use of the information network to reach consensus in smart energy grids	**12 ECTS**
Immersive week in University of Liège (Digitalization and Artificial intelligence)			
Challenge based module (First part)	• To discover solutions of an open problem and mobilize knowledge for practical applications (technological objects, systems, services). • To carry out a systemic analysis that takes into account economical, business and societal aspects. • Elective lectures (ac. to the challenge topic) • Supervised team work	• Be capable to propose solutions of an open real life problem • Be able to design technological solutions, size and optimize with a large range of criteria, design a smart energy management strategy. • Be able to take into account the non-technological issues: regulatory, territorial, social, political framework • Be able to develop a systemic approach of the design of an energy network	**6 ECTS**
Breadth courses (mandatory)	• Project management • Sustainable collaborative interdisciplinary project management • System Engineering		**6 ECTS**
Elective #2	• Co-simulation of processes • Social acceptance of energy projects • Scientific, social and human context in the elaboration of energy policies • Public awareness, education in energy transition • Life cycle analysis • Energy and environment: terminological issues	2 courses over 6 (3 ECTS/course)	**6 ECTS**
Summer session (1)			

Teaching Unit:
“Smart and flexible energy management”

12
ECTS

Content summary:

- Sizing and optimizing a local energy network
- Energy management strategy
- Smart energy networks

Main learning outcomes:

- Be able to formulate and solve the optimization problem of the design of an energy network
- Be able to implement an energy management strategy in both centralized and decentralized mode and related control/command issues
- Be able to understand the basis and the specific needs of a communication network and the use of the information network to reach consensus in smart energy grids

COURSE:

OPTIMAL DESIGN OF A LOCAL ENERGY NETWORK

Teaching Unit (for year 1):
“Smart and flexible energy management”

Face-to-face time	Student workload	ECTS
20 hours	**40 hours**	**2**

Responsible teacher

Julien FONCHASTAGNER

University / lab.
Université de Lorraine / ENSEM - GREEN

Aims of the teaching

This course aims at introducing the fundamental concepts of how sizing and optimizing a local energy network : formulation of an inverse problem design (i.e. optimization problem), resolution of such problems.

Intended Learning outcomes (measured by the assessment)

At the end of the teaching module, the student should:

- Demonstrate knowledge on how to formulate the sizing of a local energy network into an optimization problem;
- Demonstrate ability to solve corresponding problems thanks to well-chosen optimization algorithms.

Learning activities and approach

E-learning (online)	Lectures (onsite) 2h	Tutorials (onsite) 18h
-	Lectures	Lab exercise

Practical work equipment and location

Practice on computer, based on a microproject. Implementation and resolution of a complete problem using MATLAB (and its Global Optimization Toolbox).

Assessment method

Project outcomes 100%

Useful information

Prerequisites: Electrical circuit, power electronics, numerical analysis (optimization)

Related literature:

- Power Electronics in Renewable Energy Systems and Smart Grid: Technology and Applications by Bimal K. Bose (Wiley), 2019.
- Introduction to nonlinear and global optimization by E. M. T. Hendrix and B. G. Toth (Springer), New York, 2010.

COURSE:

ENERGY MANAGEMENT STRATEGY

Teaching Unit (for year 1):
“Smart and flexible energy management”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Serge PIERFEDERICI

University / lab.
Université de Lorraine / ENSEM - LEMTA

Aims of the teaching

This course aims at introducing the fundamental concepts of energy management strategies in both centralized, decentralised and distributed modes and related control/command issues.
Course content:

- Modelling and control of power electronic converter used as interface converter between renewable energy sources (PV plant, wind farm, Fuel Cell,..) and DC / AC microgrids, power flow calculation in microgrids, centralized - distributed control strategies applied to microgrids, hierarchical control strategies

Keynotes lectures on microgrid applications delivered by guest scholars

Intended Learning outcomes (measured by the assessment)

At the end of the course, students should:

- Demonstrate knowledge both on the connection of renewable energy sources into the electrical grid and energy management strategies applied to microgrids;
- Demonstrate ability to understand, use, analyse, model and control the energy flows in microgrids.

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 10h
-	-	Exercise lab

Practical work equipment and location

10 hours of practice labs: modelling and simulation of a renewable energy system connected to grid, implementation of a distributed control strategy applied to AC microgrids in the simulation lab room of ENSEM with Matalb/Simulink software (Location at ENSEM).

Assessment method

Written exam 50%, project outcomes 50%

Useful information

Prerequisites: Electrical circuit, power electronics, linear automatic

Related literature:

- Microgrids: Control and Operation by Josep Guerrero, Juan Vasquez (Wiley-Blackwell), 2016
- Power Electronics in Renewable Energy Systems and Smart Grid: Technology and Applications by Bimal K. Bose (Wiley), 2019

COURSE:

DISTRIBUTED CONTROL IN MICROGIDS

Teaching Unit (for year 1):
"Smart and flexible energy management"

Face-to-face time	Student workload	ECTS
20 hours	**40 hours**	**2**

Responsible teacher

Constantin MORARESCU

University / lab.
Université de Lorraine / ENSEM - CRAN

Aims of the teaching

This course aims at introducing the model of microgrid in multi-agent's formalism.

Course content:

- Generic tools for synchronisation and consensus in microgrids
- Synchronisation by means of distributed control strategy

Application: local management of energy production and consumption

Intended Learning outcomes (measured by the assessment)

At the end of the teaching module, the student should:

- Demonstrate knowledge on modelling of the electric grid as a large number of interconnected systems and ability to provide a suitable analysis of the corresponding overall system;
- Demonstrate ability to design decentralized controllers able to synchronize the behaviour of all subsystems by using the local information provided by the neighbours.

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 10h
-	Lectures	Lab exercise

Practical work equipment and location

10 hours of practice labs: Modelling and simulation of the network of interconnected systems. Decentralized control design for synchronization and Matlab simulation of the resulted closed-loop system.

Assessment method

Written exam 50%, project outcomes 50%

Useful information

Prerequisites: Control of linear systems, power electronics, Matlab skils

Related literature:

- Distributed supply–demand balancing and the physics of smart energy systems by J. M.A. Scherpen
- Smart Grid Architectures and the Multi-Agent System Paradigm, by Cagri Yilmaz, Sahin Albayrak, and Marco Lutzenberger

COURSE:
COMPUTER NETWORKING FOR MICROGRIDS

Teaching Unit (for year 1):
"Smart and flexible energy management"

Face-to-face time	Student workload	ECTS
20 hours	**40 hours**	**2**

Responsible teacher

Ye-Qiong SONG

University / lab.
Université de Lorraine / ENSEM - LORIA

Aims of the teaching

This course aims at introducing the fundamental concepts of the computer networking (Internet and industrial IoT) for smart grids.

Course content: Introduction to Python language, network architectures and communication protocol concepts (layering, data units, services, protocol, OSI and TCP/IP models), Internet technology (IP addressing and routing, DNS, TCP/UDP, SMTP, HTTP), LANs (Ethernet, VLAN and switching, WiFi), distributed applications (client-server model, socket programming), case studies (e.g., real-time Ethernet and TSN in IEC61850 substation automation, CAN network for distributed real-time applications, wireless and wired IoT with MQTT, etc.)

Intended Learning outcomes (measured by the assessment)

At the end of the teaching module, the student should:

- Demonstrate knowledge on computer communication fundamental architectures, concepts and technologies;
- Demonstrate ability to understand, use, analyse, model, design and implement networking solutions for the data communication needs of smart energy grids.

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 10h
-	Lectures	Lab exercises

Practical work equipment and location

10 hours of practice labs: cabling, switching, routing with networking equipment (hub, switch, router), socket programming and IoT applications (linux workstations and Raspberry nodes), at networking lab room (206 red) of ENSEM.

Assessment method

Written exam 50%, project outcomes 50%

Useful information

Prerequisites: Algorithmic and programming

Related literature:

- Computer Networking: A Top-Down Approach (7th Edition)

  by James Kurose, Keith Ross (Pearson), 2016
- Communication Networks for Smart Grids: Making Smart Grid Real (Computer Communications and Networks) 2014th Edition

  by Kenneth C. Budka, Jayant G. Deshpande, Marina Thottan (Springer), 2014

Digitalization and Artificial intelligence (Immersive week in University of Liège)

LIÈGE université

A one-week immersive session is organized in University of Liège (Belgium), acting as an associated partner of DENSYS, on the topic of digitalization and artificial intelligence applied to energy network management.

The session will lead by Prof. Damien Ernst, a world-class expert in the field.

COURSE:
DIGITALIZATION AND ARTIFICIAL INTELLIGENCE (IMMERSIVE WEEK IN UNIVERSITY OF LIÈGE)

Teaching Unit (for year 1):
“Smart and flexible energy management”

Face-to-face time	Student workload	ECTS
40 hours	**included**	**3**

Responsible teacher

Bertrand CORNELUSSE

University / lab.
University of Liège / EE&CS Department

Pedagogic Team

Jonathan DUMAS

University of Liège
EE&CS Department

Selmane DAKIR

University of Liège
EE&CS Department

Aims of the teaching

The teaching intends to provide students with a knowledge on several types of planning and operations problems faced by actors of electrical power and energy systems, such as market operators, microgrid operators, or distribution system operators. Following an introduction on the organization of current power and energy systems, the course explores some of the main operation and planning problems such as consumption and generation forecasting, day-ahead electricity market clearing, microgrid planning and control, and optimal power flow in distribution systems. Each notion will be carefully introduced and followed by coding assignments. Basic notions of optimization, supervised learning and power system modelling will be recalled, but prior exposure to these is a plus.

Intended Learning outcomes (measured by the assessment)

At the end of the course, the student will understand what are some of the main planning and operation problems faced by the stakeholders in decentralized power and energy systems. The student will also be able to implement standard solution techniques adapted to each of these problems, what are their advantages and limitations.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Tutorials (onsite)
None	Short lectures given by teachers belonging to the pedagogic team.	Implementation projects with the help of the pedagogic team.

Practical work equipment and location

Implementation of algorithms on a personal computer.

Assessment method

Projects along the week.

Useful information

Prerequisites:

- Basics of electric circuits in a sinusoidal steady-state regime
- Basics of electric power and energy systems Organization
- Scientific programming in Python
- Basics of data structures and algorithms

Related literature:

- Cornélusse, B. (2014). How the European day-ahead electricity market works. Inst. Montefiore, Liège, Belgium, Tech. Rep. ELEC0018-1.

Challenge based module
(First part)

6
ECTS

Content summary:

- To discover solutions of an open problem and mobilize knowledge for practical applications (technological objects, systems, services).
- To carry out a systemic analysis that takes into account economical, business and societal aspects.
- Elective lectures (ac. to the challenge topic)
- Supervised team work

Main learning outcomes:
- Be capable to propose solutions of an open real life problem
- Be able to design technological solutions, size and optimize with a large range of criteria, design a smart energy management strategy.
- Be able to take into account the non-technological issues: regulatory, territorial, social, political framework
- Be able to develop a systemic approach of the design of an energy network

COURSE:

THE CHALLENGE BASED MODULE

Teaching Unit (for year 1):
"Challenge based module"

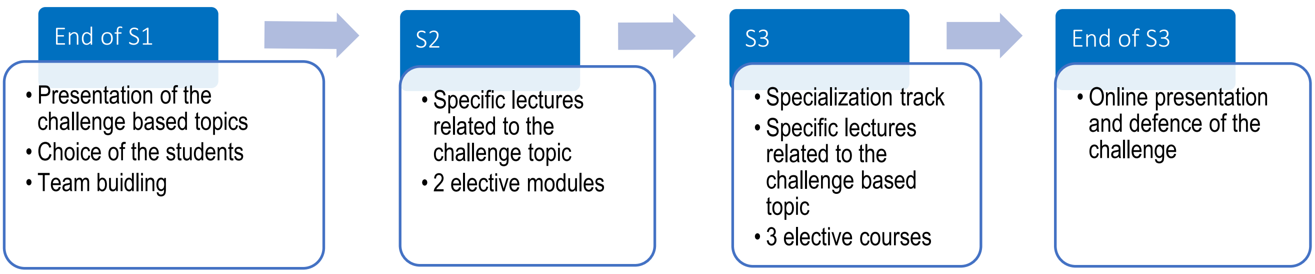
Face-to-face time	Student workload	ECTS
-	**360 hours / year**	**12 or 11**

- **12 ECTS**: 6 ECTS in S2 and 6 ECTS in S3 for tracks in KTH and PoliTo
- **11 ECT**: 6 ECTS in S2 and 5 ECTS in S3 for track in UPC

This **challenge based module follows "Smart and Flexible Energy Management in Decentralized Smart Energy Systems"** taken in a broader context, including energy networks, demand side management and optimization according to technical, market, regulation, human and societal constraints. Participants will integrate knowledge learnt in the whole programme, including the breadth and the elective courses.

The module architecture of DENSYS is related to the challenge driven outcome:

- Elective courses are selected according to the topic of this module
- The challenge benefits from the expertise of two universities: Université de Lorraine for semester 2 and one of the three universities for semester 3, during the specialization track.
- The organization of the challenge based module is presented below (S: Semester).



The students (by groups of 4 to 5) will look for solutions for an open ended problem and mobilize knowledge for a practical application: this may include technical solutions, systems, or services. A comprehensive systemic analysis that takes into account scientific, technological, economical, business and societal aspects is covered in this module.

Overall aims

- Students are invited to work on a non-solved, real-life challenge, by applying theoretical knowledge and hands on approach
- Students are expected to propose solutions, approaches to solve the problem. The result is a proposal of a non-existing product, service or solution to address the specific challenge at hand.
- The solution must include the development of scientific, technological and non-technological approaches, combined with a systematic analysis which includes the societal, environmental, policy and business implications.
- Development of soft skill: working in a team by leading and sharing responsibilities, reaching collaborative and collective decisions.

The challenge topics

The challenge based topic will be proposed jointly by teachers of the 4 partner universities and researchers through a collaborative approach between the pedagogical teams, STEM (Science, Technology, Engineering, and Mathematics) and SSH (Social Sciences and Humanities) disciplines, industrial and/or civil society partners when relevant. The challenge will be supervised by an intersectorial, interdisciplinary, international team.

The supervising team will be composed of one/two teachers from UL in technological disciplines, one teacher from UL in human and economics sciences, one/two teachers from one of the partner universities (KTH, UPC, PoliTo), one external adviser (coming from industry or civil society). Guest-scholars (e.g. in the framework of DENSYS scholar's scholarships) may also be invited to propose challenge based topics and to participate in the supervision.

Module structure

This course is given as a problem based learning which has practical interest and value. Learning and skill development activities are organized collectively by the supervising team.

Non-conventional alternative solutions are encouraged: they have to be well argued and justified.

The module is divided into two phases:

1) **Semester 2:** from the end of February to the end of June (in UL)
Students groups present an interim project report (R1) and a pitch of the results of the phase 1 during the 1st joint summer session. The report as well as the pitch will be assessed by a cross-sector (academics, industry), multidisciplinary and international board (including the 4 consortium partners). Advices and potentially re-orientation of the project may be proposed at this stage.
2) **Semester 3:** from the beginning of September to the end of February (in KTH, UPC or PoliTo)
The final results of the project will give rise to a final project report (R2) and will be orally presented during an online meeting. Final assessment on the report and the oral presentation will be performed by a cross-sector (academics, industry), multidisciplinary and international board (including the 4 consortium partners).

Intended Learning Outcomes (ILOs) of the course

After the course, the student should be able to:

- **ILO1:** Design a system based on a given set of problem description.
- **ILO2:** Perform analyses on decentralized (smart) energy systems which include different key technologies (renewable energy sources, energy storage devices, interconversion between energy carriers, final energy uses, energy management, and smart operation)
- **ILO3:** Integrate, beyond purely economic point of view, the environmental, social, societal, territorial impact in relation to the project
- **ILO 4:** Implement project management strategy, taking care of social responsibility and sustainability.
- **ILO5:** Perform an overall economic analysis of the prospective product or service, in relation to the project object or service.
- **ILO6:** Present the objectives of the work, the methodology and results in a synthetic and usable report and orally.

Learning materials and assistance

- Learning material from the DENSYS programme.
- Specific lectures, seminars, workshops organized in the framework of the challenge based module (by academic and non-academic partners).
- Assistance as well as continuous assessment of the work is provided by the supervising team
- Students are strongly encouraged to deeply learn on their own thanks to the provided materials during DENSYS courses and other recommended reliable opensource materials of their own selection.

Report

R1: The report must contain an executive summary, through analysis of the problem, well justifiable solution criteria. The scopes of specific ILOs 1 to 4 must be partially addressed.

R2: The report must an Executive Summary, a complete description of the problem, the selection and the presentation of the solution(s), sensitivity and risk analysis. The scopes of specific ILOs 1 to 5 must be fully addressed, especially by benefiting from the courses followed during the specialization track.

Assessment and grading

The grading scale for the challenge based module is the following:

F	E	C	A
Fail No report or no presentation delivered	The minimum acceptable level has just been reached	Satisfactory	Excellent

ILO1: Design a system based on a given set of problem description.

- E: Find a system design solution.
- C: Same as C, and find multiple system design solutions.
- A: Same as B, and exemplify the differences between the different design solutions.

ILO2: Perform analyses on decentralized (smart) energy systems which include different key technologies (renewable energy sources, energy storage devices, interconversion between energy carriers, final energy uses, energy management, and smart operation).

- E: Perform analysis on one system
- C: Same as C and perform analysis on multiple systems
- A: Same as B and rank the solutions based on the key technological performance analyses

ILO3: Integrate, beyond purely economic point of view, the environmental, social, societal, territorial impact in relation to the project.

- E: Perform analysis on one system
- C: Same as C and perform analysis on multiple systems
- A: Same as B and rank the solutions based on the key non techno/economic performance analyses

ILO 4: Implement project management strategy, taking care on social responsibility, sustainability.

- E: Implement project management strategy on one system
- C: Same as C and implement project management strategy on multiple systems
- A: Same as B and rank the solutions based on the key social responsibility and sustainability performance analyses

ILO5: Perform an overall economic analysis of the prospective product or service, in relation to the project object or service [Note: This ILO is mandatory for students attending KTH or PoliTo during the 2nd year and facultative for students attending UPC].

- E: Perform analysis on one system
- C: Same as C and perform analysis on multiple systems
- A: Same as B and rank the solutions based on the key economic performance analyses

ILO6: Present the objectives of the work, the methodology and results in a synthetic and usable report and orally.

- E: Present the performed work in the report and orally
- C: Same as C and with high synthetic and language quality
- A: Same as B and with excellent synthetic and language quality

Teaching Unit:
"Breadth courses (mandatory)"

6
ECTS

Content summary:

- Project management
- Sustainable collaborative interdisciplinary project management
- System Engineering

COURSE:
PROJECT MANAGEMENT

Teaching Unit (for year 1):
"Breadth courses (Mandatory)"

Face-to-face time	Student workload	ECTS
20 hours	**40 hours**	**2**

Responsible teacher

Delphine WANNENMACHER
University / lab.
IUT Nancy Charlemagne
Université de Lorraine / CEREFIGE

Pedagogic Team

Jean-Pierre HENRY
STAN Institute

Laurent DUPONT
Université de Lorraine
ENSGSI-ERPI

Aramis MARIN
Université de Lorraine
CEREFIGE

Delphine WANNENMACHER
Université de Lorraine
CEREFIGE

Aims of the teaching

The teaching aims:

- at knowing the main steps and tools of project management.
- at teaching the students to communicate on the project, and to manage a project team.
- at teaching the students to identify the stakeholders' needs, constraints, relations and context.
- at training the students to co-design the goods or services for a better use and acceptability.

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should demonstrate knowledge and ability:
  - To analyse the needs, the constraints, and the context of each stakeholder of a project.
  - To understand and analyse the main issues of project management.
  - To manage a project.

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 10h
E-mail exchanges and videos	Lectures based on books	Debate, simulation exercise

Practical work equipment and location

No practical work is planned.

Assessment method

Written record and pitch on a project

Useful information

Prerequisites: Some notions about companies and business.

Related literature:

- Boutinet J.-P. (1993), Anthropologie du projet, PUF, rééd. 2004.
- Cicmil S. et Hodgson D. (2006), « New possibilities for project management theory », Project Management Journal, vol. 37, n°3, p. 111-122.
- Fernez-Walch (S.). – The Multiple Facets of Innovation Project Management, ISTE Ltd, London and John Wiley & Sons, New York (2017).
- Garel G. (2011), Le management de projet, La Découverte, Coll. Repères, 128 pages.

COURSE:

SUSTAINABLE COLLABORATIVE INTERDISCIPLINARY PROJECT MANAGEMENT

Teaching Unit (for year 1):
"Breadth courses (Mandatory)"

Face-to-face time	Student workload	ECTS
20 hours	**40 hours**	**2**

Responsible teacher

Delphine WANNENMACHER
University / lab.
IUT Nancy Charlemagne
Université de Lorraine / CEREFIGE

Pedagogic Team

Oriane MARCHAL
HYDREOS

Klaus-Peter SCHULZ
ICN Business School

Frédéric ROUSSEAU
VINCI, ESTP Paris

Delphine WANNENMACHER
Université de Lorraine
CEREFIGE

Aims of the teaching

The teaching aims at:

- becoming aware of the specificity of the interdisciplinary collaborative projects, and the languages and methods peculiar to each community involved in a project.
- making a dynamic assessment of the project, by using principles of the societal responsibility.

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should demonstrate ability:
  - to understand the tensions and knowledge boundaries that exist between communities.
  - to use methods and tools to facilitate the collaboration between disciplinary communities.
  - to implement assessment tools based on societal responsibility during the project life.
  - to lead a sustainable collaborative interdisciplinary project.

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 10h
E-mail exchanges and videos	Lectures based on papers	Debate, case study

Practical work equipment and location

No practical work is planned.

Assessment method

Written record and oral presentation on the case study

Useful information

Prerequisites: Some notions about organizations and management.

Related literature:

- Bouchez J.-P. (2016), L'entreprise à l'ère du digital. Les nouvelles pratiques collaboratives, De Boeck, Collection : Méthodes & Recherches, 334 pages
- Burger-Helmchen T., Hussler C., Cohendet P. (2016), Les grands auteurs en management de l'innovation et de la créativité, EMS ed., 644 pages.
- Carlile, P.R. (2002). A pragmatic view of knowledge and boundaries: Boundary objects in new product development. Organization Science, 13, 442–455.
- Carlile, P.R. (2004). Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries, Organization Science, 15(5), p.555 568.
- Collins, H. (2010). Tacit and Explicit Knowledge. University of Chicago Press, Chicago.
- Grice, H.P., 1981. "Presupposition and Conversational Implicature", in P. Cole (ed.), Radical Pragmatics, Academic Press, New York, pp. 183–198.
- Polanyi, M. (1966), The Tacit Dimension, Doubleday & Co, New York.
- Wannenmacher D., Antoine A. (2016), "Management of innovative collaborative projects: Moments of tension and the Peer-Mediation Process—a case-study approach". Knowledge Management Research & Practice. Vol. 14, N°1, 35-45
- Wannenmacher D. (2019), Obstacles and levers of interdisciplinary collaborative work. The case of ALLIBEAS, Knowledge Management Research & Practice, DOI: 10.1080/14778238.2019.1701960

COURSE:
SYSTEMS ENGINEERING

Teaching Unit (for year 1):
"Breadth courses (Mandatory)"

Face-to-face time	Student workload	ECTS
20 hours	**40 hours**	**2**

Responsible teacher

Eric LEVRAT

University / lab.
Université de Lorraine / CRAN – UMR CNRS 7039

Pedagogic Team

Eric BONJOUR

Université de Lorraine
ENSGSI - ERPI

Jean-Marc DUPONT

Université de Lorraine
CRAN – UMR CNRS 7039

Aims of the teaching

The aim of this teaching is to:

- educate students in system thinking, to perceive and act on the world around them, provide them with some methods and tools for system thinking (conceptagon, systemigram, causal loop diagrams, system dynamics)
- introduce them to Systems Engineering processes (ISO 15288, ISO 29110) and Model-Based Systems Engineering approach (MBSE with SysML) through a case study.

Intended Learning outcomes (measured by the assessment)

At the end of the teaching module, the student should:

- Demonstrate ability to understand and modelling a complex situation with adapted tools (systemigram, causal loop diagrams, system dynamics)
- Demonstrate ability in modelling with SysML, for System Engineering according to System Engineering processes

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 10h
All the lectures materials will be posted on the collaborative platform of the University (Arche) and students will have to prepare the lectures	Lectures will be given with a high level of interaction, by answering questions about lectures, developing in depth essential concepts and applying them on case studies	Learning by doing System Engineering with MBSE approach on a case study, guided by the teachers, with personal work between each lecture, on the Virtul Platform (10 h in computer room)

Practical work equipment and location

All the practical work will be situated at AIPL, a research and teaching platform of the sciences et technologies faculty campus

Assessment method

Project outcomes (System Model in SysML) on System engineering case study and oral defence of the project

Useful information

Prerequisites: None.

Related literature:

- Sustainable Tomorrow A Teachers' Guidebook for Applying Systems Thinking www.fishwildlife.org/application/files/1715/1373/1187/ConEd-Sustainable-Tomorrow-Systems-Thinking-Guidebook.pdf
- Boardman, J., & Sauser, B. (2008). Systems thinking: Coping with 21st century problems. CRC Press.
- Boardman, J., & Sauser, B. (2013). Systemic thinking: building maps for worlds of systems. John Wiley & Sons.
- J. Boardman, B. Sauser, L. John and R. Edson, "The conceptagon: A framework for systems thinking and systems practice," 2009 IEEE International Conference on Systems, Man and Cybernetics, San Antonio,
- Faisandier, A. (2015). System notion and engineering of systems. Lulu. com.
- Faisandier, A. (2012). Systems opportunities and requirements (Vol. 2). Lulu. com.
- Faisandier, A. (2013). Systems architecture and design. Belberaud, France: Sinergy'Com.
- Systems Engineering Body of Knowledge (SEBoK) www.sebokwiki.org
- OMG System Modeling Language www.omg.org

Teaching Unit:
“Elective #2”

6
ECTS

Content summary:

- Co-simulation of processes
- Social acceptance of energy projects
- Scientific, social and human context in the elaboration of energy policies
- Public awareness, education in energy transition
- Life cycle analysis
- Energy and environment: terminological issues

Main learning outcomes:

- 2 courses over 6 (3 ECTS/course)

COURSE:

CO-SIMULATION OF PROCESSES

Teaching Unit (for year 1):
“Elective #2”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Vincent CHEVRIER

University / lab.
Université de Lorraine / ENSEM - LORIA

Pedagogic Team

Vincent CHEVRIER

Université de Lorraine
ENSEM - LORIA

Denis NETTER

Université de Lorraine
CRAN – UMR CNRS 7039

Aims of the teaching

The teaching aims at providing

- a global picture of what is co-simulation and why this approach is necessary for the modelling and simulation of energy systems.
- knowledge and skills for designing and implementing co-simulation of energy system.
- Course content:
- Principal of the theory of modelling and simulation, concepts, what are co-simulation and multi-modelling?
- Hybrid (discrete and continuous) co-simulation, synchronization of simulators, DEVS formalism
- Standard of industry: Modelica language and FMI norm
- Co-simulation in practice: a) algorithm with FMU and python; b) port based description, system of systems and (de)composition of systems application with Mecsyco software.

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
- Demonstrate knowledge about fundamental concepts, challenges and solution for co-simulation,
- Demonstrate ability to use some co-simulation tools for implementing energy systems as a multi-model (multiphysics and multi-domain systems)

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 20h
		Supervised project

Practical work equipment and location

- Courses, labs and supervised project (20 h)

60h personal work (project)

Assessment method

Project oral defence (40%) written report (60%)

Useful information

Prerequisites:

- Fundamental equational models in energy and mechanics
- Basis of algorithm and python programming

Related literature:

- Theory of Modelling and Simulation: Discrete Event & Iterative System Computational Foundations, BP Zeigler, A Muzy, E Kofman – Academic Press, 2012.
- FMI: fmi-standard.org
  - Modelica: modelica.org

COURSE:
INTERACTION BETWEEN SOCIAL AND INDIVIDUAL ACCEPTANCE OF ENERGY PROJECTS

Teaching Unit (for year 1):
“Elective #2”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Jérôme DINET
University / lab.
Université de Lorraine / 2LPN (EA 7489)
PSYCHOLOGY AND NEUROSCIENCES LAB
HTTP://2LPN.UNIV-LORRAINE.FR/

Pedagogic Team

Anne PIGNAULT-HOUSSEMAND
Université de Lorraine
2LPN

Valérie SAINT DIZIER
Université de Lorraine
2LPN

Jérôme DINET
Université de Lorraine
2LPN

Aims of the teaching

- The course aims mainly at teaching the students to develop competencies related to the assessment of individual and social factors influencing acceptance and adoption (or not !) of new systems, by presenting and analysing different methods and tools used to collect behavioural, emotional and cognitive indicators.
- It also aims at presenting recent historical and theoretical frameworks (related to work analysis, human factors, ergonomics, engineering and psychology) to better understand relationships between individual and social factors influencing acceptance and acceptability

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
- Demonstrate theoretical knowledge about the impact of individual and collective factors influencing acceptance and acceptability.
- Demonstrate ability to choose relevant methods and tools to collect (quantitative and qualitative) data related to behaviours, attitudes, opinions, emotions and cognitive processes related to acceptability and acceptance.
- Demonstrate ability to conduct a study based on a research design.
- Demonstrate ability to consider individual and social factors in projects related to energy systems.
- Demonstrate ability to propose adapted methods to help and accompany energy transition by mobilising a human-factor approach and a user-centred approach.

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 20h
		Case analyses, debates and simulation exercise to prepare and produce the written production (see “Assessment method” below”)

Practical work equipment and location

-

Assessment method

Students are asked to produce a written production (max. 10 pages), performed by dyad or triad, about an analysis of a case study extracted from real life. An interdisciplinary approach is recommended according to the initial background of each member of the dyad or triad. A template will be provided by the teachers to produce this written production with separate parts (analysis of the question, local and global context, theoretical framework proposed, methodology and protocol).

Useful information

Prerequisites: None.

Related literature:

- Abrahamse, W., & Steg, L. (2013). Social influence approaches to encourage resource conservation: a meta-analysis. *Global Environmental Change*, *23*, 1773–1785. doi: 10.1016/j.gloenvcha.2013.07.029
- Lowe, B.D., Dempsey, P.G., & Jones, E.W. (2019). Ergonomics assessment methods used by ergonomics professionals. *Applied Ergonomics*, *81*, https://doi.org/10.1016/j.apergo.2019.102882
- Stanton, N., Hedge, A., Brookhuis, K., Salas, E., & Hendrick, H. (2005). *Handbook of Human Factors and Ergonomics Methods*. New York, CRC Press. Online: https://moodle.ufsc.br/pluginfile.php/748673/mod_resource/content/1/ERGO%20-%20Handbook%20of%20Human%20Factors%20and%20Ergonomics%20Methods.pdf
- Steg, L., & Perlaviciute, G. & van der Werff, E. (2015). Understanding the human dimensions of a sustainable energy transition. *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2015.0080

COURSE:
LIFE CYCLE ASSESSMENT

Teaching Unit (for year 1):
“Elective #2”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Fabrice PATISSON

University / lab.
Université de Lorraine / MINES – Institut Jean Lamour

Pedagogic Team

Olivier MIRGAUX

Université de Lorraine
MINES – Institut Jean Lamour

Aims of the teaching

This course offers the chance to examine how products, processes or services impact on the environment, using the most comprehensive approach: Life Cycle Assessment (LCA). This methodology is internationally recognised by institutions like United Nations Environment Program (UNEP), Society of environmental Toxicology and Chemistry (SETAC) as well as by major companies, such as TOTAL, EDF, VEOLIA... Students taking this course will analyse this methodology in detail, within a normative framework (ISO14040 series), and will also study real-life cases in practical lessons. LCA is a powerful tool for decision making, strategy and lobbying.

- Course outline:
- Introduction, life cycle thinking, standards for LCA, the four main steps.
- Goal and scope definition, function and functional unit, types of fluxes.
- Life Cycle Inventory, mono and multifunctional processes, recycling, matrix approach.
- Introduction to consequential LCA.
- Impacts: main environmental impacts, impact assessment, characterization factors, midpoint and endpoint approaches.
- Result interpretation, critical assessment.

Intended Learning outcomes (measured by the assessment)

By the end of the module, students will know the principles of LCA, its vocabulary and main steps of the analysis. They will have discovered the Life Cycle thinking. They will master the methods for producing an inventory, tackling a multifunctional process. They will be able to analyse LCA results, evaluate the impacts, compare scenarios, assess the methodological choices and limits. Globally they will be able to evaluate and produce Life Cycle Assessment up to industry standards.

Learning activities and approach

E-learning (online)	Lectures (onsite) 10h	Tutorials (onsite) 20h
		Exercises and supervised project with LCA software

Practical work equipment and location

Classroom with specific LCA software (computer room)

Assessment method

Written exam and oral presentation

Useful information

Prerequisites: No prerequisites

Related literature:

- G. Rebitzer et al. 'Life cycle assessment Part 1...' Environment International 30 (2004), 5, 701-720. doi 10.1016/j.envint.2003.11.005
- G. Finnveden et al. Journal of Environmental Management 91 (2009) 1–21. doi:10.1016/j.jenvman.2009.06.018

COURSE:

SCIENTIFIC, SOCIAL AND HUMAN CONTEXT IN THE ELABORATION OF ENERGY POLICIES

Teaching Unit (for year 1):
“Elective #2”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Responsible teacher

Cyrille IMBERT

University / lab.
Université de Lorraine / Archives Poincaré, philosophie et recherches sur les sciences et les technologies

Pedagogic Team

Cyrille IMBERT

Université de Lorraine
CNRS – Archives Poincaré

Anna C. ZIELINSKA

Université de Lorraine
Archives Poincaré

Aims of the teaching

The energy transition requires solving a difficult democratic problem. It implies making various difficult decisions that combine sharp scientific information and strong political will, and are backed up by a large consensus if they are to be adopted and really put at work. While there is a general agreement about the need of an energy transition, one cannot but notice the current inability to follow the adopted orientations. Further, various tensions or controversies often hamper potential advances.

This teaching aims at introducing the students to key concepts within political science and epistemology to analyse these tensions and to investigate why such decisions are difficult to make and apply within democratic societies. The course will also include lectures devoted to the environmental philosophy and environmental ethics, anthropocene, as well as to anthropological, ontological and moral consequences of human transformations of the surrounding world.

The course will engage students into a series of normative considerations, including the place of norms and values within technoscience, the role of experts at the interface between science and society, the critical analysis of technological controversies, anti-science rhetoric, the strategies of merchants of doubt to propagate scientific denial, and the difficult interactions between the political and scientific spheres and their actors, who are neither organized nor prepared to interact directly and fruitfully around these issues.

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
- understand which types of actors need to interact to elaborate energy policies and what their roles should be, if these interactions are to be successful;
- be more attentive to the scientific, social, and human dimensions of the processes, decisions, policies or technologies that come with the energetic transition;
- be capable of singling out the norms and/or preferences that are implicitly built in scientific and technological studies and in energy policies and the crucial technological or scientific facts that should frame democratic discussions about energetic choices;
- be able to present balanced and argued descriptions of democratic controversies concerning energy policies and related technologies;
- understand what political problems and pitfalls the launching of energy policies raises for democratic societies and which factors favour or deter transversal interactions between actors;
- be perceptive of distinct ways of organizing expertise and elaborating energy policies at the institutional level across countries.

Learning activities and approach

E-learning (online) 10h	Lectures (onsite) 10h	Tutorials (onsite) 10h
Analysis of relevant texts, multiple-choice questions about the texts and discussion of answers	• - values in science & technology • - scientific responsibility • - public expertise and its ways • - technological debates in democratic societies: how? • - environmental ethics	• - discussion of problems related to the analysed texts • - group presentations, controversial technologies with local implantation, simulated debates.

Practical work equipment and location

Personal computer with an internet connection

Assessment method

- 2 reports about material relevant to the topic of the class (typically scientific papers), one possibly about a film (700 words + 300-word discussion)
- an oral group presentation about a subject-matter relevant to the class, typically about controversial technologies
- a final written exam

Useful information

Prerequisites: None

Related literature:

- Douglas, Heather E. *Science, policy, and the value-free ideal*. Pittsburgh (Pa.), Etats-Unis d'Amérique: University of Pittsburgh Press, 2009.
- Fishkin, James S., et Robert C. Luskin. « Experimenting with a Democratic Ideal: Deliberative Polling and Public Opinion ». *Acta Politica* 40, nº 3 (2005): 284-98.
- Gardiner, Stephen, Simon Caney, Dale Jamieson, et Henry Shue. 2010. *Climate Ethics: Essential Readings*. Oxford University Press.
- Jasanoff, Sheila. Designs on nature: science and democracy in Europe and the United States. Princeton, N.J., Etats-Unis, 2007.
- Controversies in Science and Technology, series edited by Daniel Kleinman.
- Malm, Andreas. 2016. Fossil Capital: The Rise of Steam Power and the Roots of Global Warming. London: Verso.
- Oreskes, Naomi, and Erik M. Conway. Merchants of doubt: how a handful of scientists obscured the truth on issues from tobacco smoke to global warming. 1st U.S. ed. New York: Bloomsbury Press, 2010

COURSE:

ENERGY AND THE ENVIRONMENT: TERMINOLOGICAL ISSUES

Teaching Unit (for year 1):
“Elective #2”

Face-to-face time	Student workload	ECTS
30 hours	**60 hours**	**3**

Pedagogic Team

Francesca INGROSSO

Université de Lorraine
FST - LPCT UMR 7019 UL-CNRS

Alain POLGUÈRE

Université de Lorraine
ATILF CNRS

Aims of the teaching

The teaching aims at:

- (i) developing the student’s awareness of the importance of terminological issues in the fields of energy and the environment,
- (ii) making the student acquire core knowledge about technical and scientific vocabulary and its use in texts,
- (iii) train the student to master current techniques in terminological study and modelling.

The field of green (or sustainable) chemistry will be used to provide concrete terminological data for case studies.

The dual purpose of the course is:

- Training the student to improve her/his employability in the research sector (public or private).
- Increasing the student’s mastering of the language used in the fields of energy and the environment for (i) better access to core notions, (ii) comprehension of textual material, (iii) communication in technical/scientific as well as general public settings (these skills being professionally applicable both in R&D and industrial contexts).

Intended Learning outcomes (measured by the assessment)

- At the end of the teaching module, the student should:
- understand the role of language/terminological issues in scientific/technical fields, and in particular in the fields of energy and the environment;
- be capable of reasoning on linguistic material concerning energy and the environment;
- use standard methods for acquiring and analysing terminological data.

Learning activities and approach

E-learning (online) On line material	Lectures (onsite) 15h	Tutorials (onsite) 15h
• On-line interviews and conferences. • Serious games (e.g. doi.org/10.1080/17518253.2018.1434566, doi.org/10.1021/acs.jchemed.9b00278).	• Dual teaching, from the perspectives of lexical sciences and chemistry. • Interactive teaching (computer lab).	• discussion of problems related to the analysed texts • group presentations, controversial technologies with local implantation, simulated debates.

Practical work equipment and location

15 hours (computer lab included in lectures and tutorials)

Assessment method

- Terminological analysis of documents (scientific, technical and non-specialized) using specialized linguistic tools (word indexing, etc.) presented in technical report format.
- On-line video material writing of short syntheses by students with emphasis on the use of terminology.

Useful information

Prerequisites: Basic chemistry.

Related literature:

- Anastas P., Warren J. C. (2000). *Green Chemistry: Theory and Practice*. Oxford University Press, Oxford.
- Cadeddu A. *et al.* (2014). Organic Chemistry as a Language and the Implications of Chemical Linguistics for Structural and Retrosynthetic Analyses. *Angew. Chem. Int. Ed.*, 53, 8108–8112.
- *IUPAC Compendium of Chemical Terminology* (Gold Book) (https://goldbook.iupac.org/)
- L'Homme M.-C. (2020). *Lexical Semantics for Terminology. An introduction.* Terminology and Lexicography Research and Practice Series 20, Benjamins, Amsterdam/Philadelphia.

Summer session (1)

3 Summer schools

The opportunity to deepen topics, like entrepreneurship and finance in the energy field (in ESADE Barcelona), hydrogen energy (UL, Nancy), power-to-X energy storage (PoliTo, Turin) and energy systems modelling (KTH, Stockholm).

During the summer schools, students will meet industrial and societal actors.

ESADE Business School

One summer school of one week will be focused on finance and business at ESADE Business School, Barcelona.

DENSYS

MASTER ERASMUS MUNDUS DECENTRALISED SMART ENERGY SYSTEMS

YEAR 2

SEMESTER 3 (KTH) - TOTAL 30 ECTS

Specialization track ”Decentralized smart energy systems in a global energy system ”

Teaching units	Content summary	Main learning outcomes	ECTS
Global energy markets and systems in transition	• Function of energy systems with a strong focus on the relationship between the structure of the technical systems and their respective economical boundary conditions (pricing, market, etc.), as well as the function and transformation of energy markets.	• Be able to analyse the function and structure of the global energy system regarding energy type and industrial and political structure • Be able to analyse the function and price formation mechanisms of energy markets - globally as well as locally • Be able to assess the effect of climate changes on the transformation of the energy systems and energy markets	**6 ECTS**
Energy Data, Balances and Projections	• Project based course (lectures delivered by local and external experts, practical via computer labs) • Exposure to energy data classification, collection and projections activities of the International Energy Agency (IEA), the UN Statistical Division (UN Stats) as well as the International Atomic Energy Agency	• Be able to understand the links between human activities, the need for energy services • Be able to understand the mechanics of a national energy balance. • Master various methodologies used to project future energy demand. • Be able to apply relevant software tools and use the gathered data for future energy scenario assessment	**6 ECTS**
Challenge based module	• Follow-up 2 nd semester module- content is similar	• Follow-up 2 nd semester module- LO are similar, and work will be oriented according to the specialization track	**6 ECTS**
Language, culture	Swedish	Initiation to the local language and cultural tips	
Breadth courses (mandatory)	• Theory and Methodology of Science for Energy Research	• Master the theory and methodology of science to prepare for the development of their Master’s thesis	**6 ECTS**
Elective #3	• Renewable Energy Technology • Green Building - Concept, Design, Construction and Operation • Energy System Economics, Modelling and Indicators for Sustainable Energy Development	1 course over 3 (6 ECTS/course)	**6 ECTS**
Challenge based module presentation			

Teaching Unit:
"Global energy markets and systems in transition"

6
ECTS

Content summary:

- Function of energy systems with a strong focus on the relationship between the structure of the technical systems and their respective economical boundary conditions (pricing, market, etc.), as well as the function and transformation of energy markets.

Main learning outcomes:

- Be able to analyse the function and structure of the global energy system regarding energy type and industrial and political structure
- Be able to analyse the function and price formation mechanisms of energy markets - globally as well as locally
- Be able to assess the effect of climate changes on the transformation of the energy systems and energy markets

COURSE:
GLOBAL ENERGY MARKETS AND SYSTEMS IN TRANSITION [ME2086]

Teaching Unit (for year 2):
"Global energy markets and systems in transition"

Face-to-face time	Student workload	ECTS
1.5 ECTS amounts to **1 full week work**		**6**

Responsible teacher

Frauke URBAN

University / lab.
KTH, Stockholm / ITM - Industrial Economics and Management

Aims of the teaching

The course that is held by the Division of Sustainability and Industrial Dynamics at the Industrial Economics and Management Department. The course is aimed for students interested in how energy systems and markets function, what are their economic, political, climatological and technical conditions.

The course design and structure aim to give course participants the best possible conditions for active learning. This includes lecture material, seminar activities, including group case solving and business game, and project activity where you can apply your knowledge.

Course contents
The course treats the functioning of global energy systems. The course will deal with the relationship between the structure of the technical systems and their respective economic boundary conditions (market, pricing etc.), as well as the function and transformation of energy markets.
The course contains a series of lectures with an in-depth review and analysis of conditions and driving forces behind the transformation of the intertwined global energy system from the following perspectives:

- Socio-technical
- economic
- political
- institutional
- climatological

The course also offers insights into theories, concepts and tools from industrial dynamics to analyse global energy markets and technical changes in energy systems. These theories, concepts and tools will be applied in the group work.

Intended Learning outcomes (measured by the assessment)

On completion of the course the students should be able to:

- Analyze the structure of the global energy system
- Critically discuss the mechanisms that drive systems transitions in relation to global energy markets and their implications
- Evaluate theoretical concepts and current research from the field of industrial dynamics for managing technological and industrial change processes in relation to global energy markets
- Write an analysis related to industrial and technological change and independently discuss problem formulations and their solutions to tackle complex change in global energy markets
- Present results and conclusions based on a scientific investigation for different types of audiences

Learning activities and approach

E-learning (online)	Lectures (onsite) 30h	Seminars (onsite) 6h
-	-	-

Practical work equipment and location

On campus activities

Assessment method

- INL1 - Assignment, 3.0 credits, Grading scale: A, B, C, D, E, FX, F
- SEM2 - Seminars, 3.0 credits, Grading scale: A, B, C, D, E, FX, F

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

The course is examined through a written examination (take-home examination) and a project work (with seminars) with a focus on the ability to critically analyze and discuss the consequences of technical and industrial processes of change from economic, political, social and ethical aspects and to independently formulate and define problems to tackle complex processes of change by means of data from various types of sources.

Useful information

Prerequisites: Achieved the requirements for a Bachelor's degree
ME1003 Industrial management, basic course completed.

Related literature: -

Teaching Unit:
“Energy Data, Balances and Projections”

6
ECTS

Content summary:

- Project based course (lectures delivered by local and external experts, practical via computer labs)
- Exposure to energy data classification, collection and projections activities of the International Energy Agency (IEA), the UN Statistical Division (UN Stats) as well as the International Atomic Energy Agency.

Main learning outcomes:

- Be able to understand the links between human activities, the need for energy services
- Be able to understand the mechanics of a national energy balance.
- Master various methodologies used to project future energy demand.
- Be able to apply relevant software tools and use the gathered data for future energy scenario assessment

COURSE:

ENERGY DATA, BALANCES AND PROJECTIONS [MJ2382]

Teaching Unit (for year 2):
"Energy Data, Balances and Projections"

Face-to-face time	Student workload	ECTS
1.5 ECTS amounts to **1 full week work**		**6**

Responsible teacher

Francesco FUSO-NERINI

University / lab.
KTH, Stockholm / ITM - Energy Technology

Aims of the teaching

Given the central role of energy in sustainable development, decision-makers need well-grounded insights about the current status and future developments of the energy systems to plan accordingly. The course MJ2382 Energy Data, Balances and Projections gives an in-depth look at how energy demand (electricity and all fuels) in diverse countries can be studied, understood and projected in the future. Key topics of the course are 1) Why strategic national energy analysis, policy and planning require a reliable energy - balance and projections of future energy demand. 2) How to find and deal with energy demand data, 3) How to interpret and use a national energy balance and 4) How to project future energy demand.

The course uses real data and case studies of country energy systems, and will give the student a practical view of how energy systems can be analyzed by looking at energy demands. Lectures and labs by KTH teachers are complemented by seminars given by external experts in the field, such as from the International Energy Agency and the International Atomic Energy Agency.

The course will combine lectures, computer-based laboratory sessions, compulsory seminars and project work. Lectures and labs will be delivered by some local and external experts from various research organizations. The course will be taught both by KTH lecturers and guest lecturers from organizations such as the International Energy Agency (IEA) and UN-DESA. After completion of all computer labs, students will be required to attend two seminars, followed by a detailed project report and an exam at the end of course.

The course instructors will provide lists of relevant projects during the first week of the course. Each project will be completed by group of 3 to 4 students. The project should be documented in a written report (in English). Each project group should also deliver a peer review report as opponent group for another project. This should also be in English. For the mandatory seminar during the course, the students will prepare the presentation of their progress in the computer lab exercises they performed. For the compulsory seminars, each group will prepare presentations of the progress of the project, based on the contents of each computer-based laboratory session.
During the course, the students will be exposed to energy data classification, collection and prognosis work from the International Energy Agency (IEA), the UN´s statistical commission (UN Stats) and the

UN's International Atomic Energy Agency (IAEA). The students should also interact with IEA, UN Stats and IAEA.

Intended Learning outcomes (measured by the assessment)

After passing the course, the students should be able to:

- **ILO 1:** Explain why political decisions and planning for the development of sustainable national energy systems require a reliable energy balance and prognoses for future energy requirements.
- **ILO2:** Interpret the most important aspects of a national energy balance and its application.
- **ILO 3:** Make assessments concerning the use of 'bottom up' or 'top down' methods to project the energy requirements, with relevance for specific applications.
- **ILO 4:** Collect relevant energy-related data to analyse current and future energy requirements in a country.
- **ILO 5:** Based on a national energy balance, create the structure in a model for energy need projections
- **ILO 6:** Develop prognoses for the future energy requirements in a country through the use of "bottom up" methods
- **ILO 7:** Develop prognoses for the future energy requirements in a country through the use of "top down" methods

Learning activities and approach

E-learning (online) 6h	Lectures (onsite) 10h	Seminars (onsite) 4h
-	-	-

Practical work equipment and location

Practical work equipment and location

Assessment method

- PRO1 - Project, 3.0 credits, Grading scale: A, B, C, D, E, FX, F
- SEM1 - Seminar, 0.5 credits, Grading scale: P, F
- SEM2 - Seminar, 0.5 credits, Grading scale: P, F
- TEN1 - Written exam, 2.0 credits, Grading scale: A, B, C, D, E, FX, F

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

Useful information

Prerequisites:

Related literature:

Lecture handouts and laboratory instructions will be distributed by the course coordinator

The students will also carry out an individual literature search for material relevant to their independent project.

Challenge based module
(Second part)

6
ECTS

Content summary:

- Follow-up 2nd semester module- content is similar

Main learning outcomes:

- Follow-up 2 nd semester module - LO are similar, and work will be oriented according to the specialization track

Teaching Unit:
“Breadth courses (mandatory)”

6
ECTS

Content summary:

- Theory and Methodology of Science for Energy Research.

Main learning outcomes:

- Master the theory and methodology of science to prepare for the development of their Master’s thesis

COURSE:
THEORY AND METHODOLOGY OF SCIENCE FOR ENERGY RESEARCH
[MJ2475]

Teaching Unit (for year 2):
“Breadth courses (mandatory)”

Face-to-face time	Student workload	ECTS
1.5 ECTS amounts to **1 full week work**		**6**

Responsible teacher

Viktoria MARTIN

University / lab.
KTH, Stockholm / ITM - Energy Technology

Pedagogic Team

Viktoria MARTIN
KTH, Stockholm
ITM - Energy Technology

Dilip KHATIWADA
KTH, Stockholm
ITM - Energy Technology

Aims of the teaching

The course introduces the Master students to theory and methods in the science and prepares them to develop their Master thesis in accordance with KTH requirements. The course introduces basic concepts and understanding of philosophic and methodological problems that arise in research and encourages reflection over research subjects and procedures in the student's own study field. The course functions as a scientific initiation for applied research in energy-related subjects in particular. The course also introduces critical assessment of methods and results of research that can help students to evaluate and analyse research material.

Intended Learning outcomes (measured by the assessment)

After passing the course, the students should be able to:
1. Discuss theories and methods for research design critically
2. Describe and analyse the choice of research methods in relation to research goals and interpret result.
3. Design, justify and communicate the complete research proposal according to scientific principles
4. Demonstrate ability to identify methods, technologies and tools to carry out robust energy research
5. Identify and discuss how one should handle sustainability and ethical dimensions when designing and developing research projects in energy research

Learning activities and approach

E-learning (online) 10h	Lectures (onsite) 26h	Seminars (onsite) 8h
-	-	-

Practical work equipment and location

Practical work equipment and location

Assessment method

- INLA - Hand in assignment, 1.0 credits, Grading scale: A, B, C, D, E, FX, F
- INLB - Hand in assignment, 2.0 credits, Grading scale: A, B, C, D, E, FX, F
- SEMA - Seminars, 0.5 credits, Grading scale: P, F
- SEMB - Seminars, 1.0 credits, Grading scale: P, F
- TENA - Written exam, 1.5 credits, Grading scale: A, B, C, D, E, FX, F

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.
To pass the course, it is required that student is present in all seminars and carry out all course components (INLA, INLB, SEMA, SEMB and TENA).

Useful information

Prerequisites: Degree of Bachelor or at least three years of first-cycle courses on course relevant subjects.
Documented knowledge in English B or the equivalent.

Related literature: -

Teaching Unit:
“Elective #3”

6
ECTS

Content summary:

- Renewable Energy Technology
- Green Building - Concept, Design, Construction and Operation
- Energy System Economics, Modelling and Indicators for Sustainable Energy Development.

Main learning outcomes:

- 1 course over 3 (6 ECTS/course)

COURSE:
RENEWABLE ENERGY TECHNOLOGY [MJ2411]

Teaching Unit (for year 2):
"Elective #3"

Face-to-face time	Student workload	ECTS
1.5 ECTS amounts to **1 full week work**		**6**

Responsible teacher

Andrew MARTIN

University / lab.
KTH, Stockholm / ITM - Energy Technology

Pedagogic Team

Andrew MARTIN
KTH, Stockholm
ITM - Energy Technology

Rafael GUEDEZ
KTH, Stockholm
EGI

Miroslav PETROV
KTH, Stockholm
EGI

Justin CHIU
KTH, Stockholm
EGI

Aims of the teaching

The purpose of this course is to provide an engineering assessment of renewable energy resources, including technologies for harnessing them within the framework of simple to advanced energy systems. Course content is divided into the following blocks:

- Biomass & Biofuels
- Wind Power
- Solar Energy
- Hydropower
- Energy Storage

Intended Learning outcomes (measured by the assessment)

Upon successful completion of the course, the student will be able to:

1. Analyze the characteristics of renewable energy sources, and contrast these with fossil fuels
2. Identify and quantify the means of harnessing renewable energy sources in terms of fundamental energy conversion
3. Design renewable energy systems that meet specific energy demands and are sustainable

Learning activities and approach

Tutorials (onsite)	Lectures (onsite)	Seminars (onsite)
10h	26h	8h
Projects (onsite)	**Study visit (onsite)**	
28h	16h	

Practical work equipment and location

-

Assessment method

- INLA - Home assignment, 0.5 credits, Grading scale: P, F
- INLB - Home assignment, 0.5 credits, Grading scale: P, F
- INLC - Home assignment, 0.5 credits, Grading scale: P, F
- INLD - Home assignment, 0.5 credits, Grading scale: P, F
- KONA - Partial exam, 2.0 credits, Grading scale: A, B, C, D, E, FX, F
- KONB - Partial exam, 2.0 credits, Grading scale: A, B, C, D, E, FX, F

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.
Final grade determined as weighted average of KONA and KONB

Useful information

Prerequisites:

B.Sc. in Engineering with prerequisite in MJ1112 Thermodynamics 9 ECTS or corresponding knowledge. Minimum 5 ECTS thermodynamics.

Documented proficiency in English B or equivalent.

Related literature:

- Nick Jenkins and Janaka Ekanayake, Renewable Energy Engineering, Cambridge University Press (2017).
- Hans Havtun, Applied Thermodynamics: Collection of Formulas, Studentlitteratur (2014).

COURSE:
THEORY AND METHODOLOGY OF SCIENCE FOR ENERGY RESEARCH
[MJ2460]

Teaching Unit (for year 2):
"Elective #3"

Face-to-face time	Student workload	ECTS
1.5 ECTS amounts to **1 full week work**		**6**

Responsible teacher

Jaime ARIAS HURTADO

University / lab.
KTH, Stockholm / ITM - Energy Technology

Pedagogic Team

Jaime ARIAS HURTADO

KTH, Stockholm
ITM - Energy Technology

Joachim CLAESSON

KTH, Stockholm
ITM - Energy Technology

Aims of the teaching

The course is divided into lectures, seminars and lessons. The lectures present the essential parts of sustainable buildings and give a foundation for further specialisation in the group project. The seminars, where the different parts in project are presented and discussed, are prepared by students. In the lessons, different questions are analysed and discussed related to the project, building design, the model in the programme IDA ICE and the implementation of the environmental certification method LEED V4.

The different concepts, the definitions and the methods that are presented in lectures are:
- Sustainable buildings and passive houses.
- Environmental certification method LEED V4 for new buildings.
- The construction process and project management.
- Sustainable building design
- Environmental certification method for buildings as BREEAM, Miljöbyggnad, WELL, Green Building, etc
- Modelling of energy performance and indoor climate by means of the energy calculation software IDA ICE

Intended Learning outcomes (measured by the assessment)

After the course, the students should be able to:

- design and describe an environmentally sustainable building in Stockholm and dimension building components as well as energy efficient systems that are suitable, in order to achieve the smallest possible environmental impact
- develop a model of the sustainable building designed in Stockholm in an energy calculation software for buildings, to analyse energy performance, indoor climate and environmental impact
- use an environmental certification method to evaluate the sustainable building designed in Stockholm
- discuss and describe strengths and weaknesses in different environmental certification methods, such as Miljöbyggnad, LEED, Green Building, BREEAM, etc.
- clearly and logically present the project in a report and in the final review

Learning activities and approach

Computer lab (onsite) 12h	Lectures (onsite) 10h	Seminars (onsite) 7h
-	-	-

Practical work equipment and location

-

Assessment method

- PRO1 - Project, 4.5 credits, Grading scale: A, B, C, D, E, FX, F
- TEN1 - Written exam, 1.5 credits, Grading scale: A, B, C, D, E, FX, F

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

The results of the project that is discussed in the report should also be presented at the final review.

Project (4.5 credits): Design and evaluate a sustainable building in Stockholm. The building will be evaluated by means of an environmental certification method for buildings. A grade (A-F) is assigned per group. Examination (1.5 credits): Describe and discuss the definitions, concepts and methods that are discussed in lectures and in the project. A grade (A-F) is assigned per individual.

Useful information

Prerequisites: [MJ2407] Sustainable Energy Utilisation, or the equivalent knowledge (assessed by the course coordinator)
Recommended: [MJ2422] Thermal Comfort and Indoor Climate, and [MJ2437] Modelling of Energy Systems

Related literature:

- Anteckningar från föreläsningar, rapporter och dokument om hållbara byggnader och miljöcertifieringsmetoder LEED, BREEAM, WELL och Miljöbyggnad.

COURSE:

ENERGY SYSTEM ECONOMICS, MODELLING AND INDICATORS FOR SUSTAINABLE ENERGY DEVELOPMENT [MJ2383]

Teaching Unit (for year 2):
"Elective #3"

Face-to-face time	Student workload	ECTS
1.5 ECTS amounts to **1 full week work**		**6**

Responsible teacher

William USHER

University / lab.
KTH, Stockholm / ITM - Energy Technology

Aims of the teaching

The overall objective of the course is to explore basic energy system economic concepts related to energy infrastructure investments, energy-environment economics and the role of indicators for sustainable development. The students will gain practical experience in the use of a range of economic tools and models. These include basic linear programming techniques, the economic interpretation of energy models and economic indicators relating to policy and technology scenarios.

In a group project, they will use an energy system model to map key economic indicators to sustainable development goals, and further develop their critical skills in modelling and results interpretation.

Intended Learning outcomes (measured by the assessment)

After the course, the students should be able to:

- Explain key concepts in energy economics.
- Evaluate economic tools and apply them to examine energy investments and operation.
- Describe the economic drivers of long term energy transitions and critique how these are modelled.
- Develop and apply a techno-economic model to policies, technologies and other interventions using scenario analysis.
- Analyze key outputs of techno-economic models, including system costs and shadow prices, in combination with off-model data and interpret in terms of their social, economic and environmental dimensions and sustainable development.
- Communicate concepts of energy economics using written, spoken and visual media.

Learning activities and approach

Lab 8h	Lectures (onsite) 8h	Seminars (onsite) 4h
-	-	-

Practical work equipment and location

The course will be conducted in a combination of lectures, computer labs, a mandatory seminar, a project report and an exam. The course responsible will provide a list of projects at the beginning of the course. After completion of all the computer labs, students will be required to present their preliminary group work at a seminar. The project report should be written in English. Each group will review the work of one of the other groups. The course is concluded by an exam.

Assessment method

- LABA - Labb, 0.5 credits, Grading scale: P, F
- PROA - Project, 3.0 credits, Grading scale: A, B, C, D, E, FX, F
- SEMA - Seminars, 0.5 credits, Grading scale: P, F
- TENA - Exam, 2.0 credits, Grading scale: A, B, C, D, E, FX, F

Based on recommendation from KTH's coordinator for disabilities, the examiner will decide how to adapt an examination for students with documented disability.

The examiner may apply another examination format when re-examining individual students.

Useful information

Prerequisites: None

Related literature:

SEMESTER 3 (POLITO) - TOTAL 30 ECTS

Specialization track "Energy-to-X: innovative pathways for energy storage"

Teaching units	Content summary	Main learning outcomes	ECTS
Polygeneration and advanced energy systems	• Description, modelling, analysis of advanced energy systems based on the integration of power, thermo-chemical and electro-chemical processes for purposes of energy management and storage.	• Be able to design of complex energy systems based on thermo-chemical and electro-chemical processes Be able to design of power-to-X processes Be able to design of technologies and processes for CO2 recovery and re-utilization and poly-generation systems.	**6 ECTS**
Smart electricity systems	• Evolution of the electricity systems, with the ongoing transition towards a growing utilization of electricity in many applications.	• Be able to use the correct terminology in addressing the problems concerning smart grid applications Be able to interpret the problems concerning the introduction of distributed energy resources in the smart grids	**6 ECTS**
Challenge based module	• Follow-up 2nd semester module- content is similar	• Follow-up 2nd semester module- LO are similar, and work will be oriented according to the specialization track	**6 ECTS**
Language, culture	Italian	Initiation to the local language and cultural tips	
Breadth courses (mandatory)	• Digital humanities	• The expected learning outcomes of the course concern notions on the main area of the Digital History especially applied to the history of the built and humanized environment.	**6 ECTS**
Elective #3	• Models and scenarios for energy planning Advanced materials for energy Thermal design and optimization	1 course over 3 (6 ECTS/course)	**6 ECTS**
Challenge based module presentation			

Teaching Unit:
“Polygeneration and advanced energy systems”

6
ECTS

Content summary:

- Description, modelling, analysis of advanced energy systems based on the integration of power, thermo-chemical and electro-chemical processes for purposes of energy management and storage.

Main learning outcomes:

- Be able to design of complex energy systems based on thermo-chemical and electro-chemical processes
- Be able to design of power-to-X processes
- Be able to design of technologies and processes for CO2 recovery and re-utilization and poly-generation systems.

COURSE:

POLYGENERATION AND ADVANCED ENERGY SYSTEMS

Teaching Unit (for year 2):
“Polygeneration and advanced energy systems”

Face-to-face time	Student workload	ECTS
75 hours	**180 hours**	**6**

Responsible teacher

Massimo SANTARELLI

University / lab.
Politecnico di Torino / Energy Department

Pedagogic Team

Andrea LANZINI
Politecnico di Torino
Energy Department

Marta GANDIGLIO
Politecnico di Torino
Energy Department

Domenico FERRERO
Politecnico di Torino
Energy Department

Tonia TOMMASI
Politecnico di Torino
Energy Department

Aims of the teaching

The description, modelling, analysis of advanced energy systems based on the integration of power, thermo-chemical and electro-chemical processes for poly-generation purposes. The course develops topics related to electrochemical systems (fuel cells, electrolyzers, flow batteries), thermo-chemical systems (gasification, production of biogas, chemical looping systems), concepts of chemical storage for the production of synthetic fuels (CO2 recovery, power-to-gas, power-to-liquid, in general power-to-X processes) and complete this with the analysis of some examples of complex poly-generation systems. Some activities at the lab level (mainly on electrochemical and thermochemical systems applied to energy) will be developed along the course. A group work, making use of a commercial software (ASPEN+) is also mandatory.

Intended Learning outcomes (measured by the assessment)

Applications of fundamentals of chemical thermodynamics and electrochemistry to energy systems. Understanding and design of complex energy systems based on thermo-chemical and electro-chemical processes and technologies. Understanding and design of power-to-X processes. Understanding and design of technologies and processes for CO2 recovery and re-utilization. Understanding and design of poly-generation systems.

Learning activities and approach

E-learning (online)	Lectures (onsite) 63h	Tutorials (onsite) 21h
Could be the whole course	-	Exercises

Practical work equipment and location

18h lab activities

Assessment method

Homework (mini case based), final exam.

Useful information

Prerequisites: Preliminary knowledge acquired in the courses of Thermodynamics and Heat Transfer, Chemical Plants, Material Science

Related literature:

- Mostly supplied by the teachers.
- CHEMICAL THERMODYNAMICS: 1. Advanced Engineering Thermodynamics, Adrian Bejan, Editore: John Wiley & Sons Inc; 3 ed. (August 18, 2006) 2. Thermodynamics: Foundations and Applications, Elias P. Gyftopoulos and Gian Paolo Beretta, Editor: Macmillan Publishing Company
- ELECTROCHEMISTRY: 1. Electrochemical Engineering Principles, Geoffrey Prentice, Editor: Prentice-Hall International
- FUEL CELLS: 1. Fuel Cells Systems Explained, James Larminie and Andrew Dicks, Editor: John Wiley & Sons Ltd 2. High Temperature Solid Oxide Fuel Cells: Fundamentals, Design and Applications, Subash Singhal and Kevin Kendall, Editor: Elsevier Ltd 3. Advanced Methods of Solid Oxide Fuel Cells Modeling, Jaroslaw Milewski, Konrad Swirski, Massimo Santarelli, Pierluigi Leone, Editor: Springer

Teaching Unit:
“Smart electricity systems”

6
ECTS

Content summary:

- Evolution of the electricity systems, with the ongoing transition towards a growing utilization of electricity in many applications..

Main learning outcomes:

- Be able to use the correct terminology in addressing the problems concerning smart grid applications
- Be able to interpret the problems concerning the introduction of distributed energy resources in the smart grids

COURSE:
SMART ELECTRICITY SYSTEMS

Teaching Unit (for year 2):
"Smart electricity systems"

Face-to-face time	Student workload	ECTS
60 hours	**120 hours**	**6**

Responsible teacher

Gianfranco CHICCO

University / lab.
Politecnico di Torino / Energy Department

Pedagogic Team

Ettore BOMPARD

Politecnico di Torino
Energy Department

Tao HUANG

Politecnico di Torino
Energy Department

Aims of the teaching

The course presents a wide view on the emergent aspects in the evolution of the electricity systems, with the on-going transition towards a growing utilization of electricity in many applications. The concept of "smartness" in electricity and energy systems is related to the new ways in which a system can operate and also interoperate with other systems (e.g., transportation) for assuring a socially desirable performance in terms of sustainability (energy efficiency and environmental impacts reduction), economic efficiency and affordability, electricity security and reliability. The course starts from an overview on the structure and operation of modern and future electrical networks (smart grids), with a special focus on Low-Voltage and Medium-Voltage distribution and utilization systems. A conceptual model of the smart grids is presented, in which various aspects (technologies, energy, data, markets, etc.) are analysed, along with their interactions, in a comprehensive way. Some of the most important "smart functions" in the emerging operation of the electricity distribution systems are illustrated, highlighting the concept of interoperability of various systems and actors over the smart grid, e.g., electric vehicles, prosumers, network operators, distributed energy resources (DER), etc. The impact of the DER introduction in the electrical networks is studied by addressing theoretical aspects and application examples concerning distributed generation, distributed storage and demand response.

Intended Learning outcomes (measured by the assessment)

The student who passes the exam will gain skills for interacting with the operators of the electrical system by using the right terminology and by showing appropriate knowledge to discuss the basic issues concerning smart grid and distributed energy resources. The student will also become aware of the technological evolution in progress and of the impact of this evolution on the present and future smart electricity systems. The minimum objectives to be reached as learning outcomes include the ability to use the correct terminology in addressing the problems concerning smart grid applications, and the ability to interpret the problems concerning the introduction of distributed energy resources in the smart grids.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Tutorials (onsite)
Could be the whole course	60h	

Practical work equipment and location

Assessment method

Final exam: written test of duration 1 hour. During the written exam, the students may use only clean paper, pen and pocket calculator. Personal computers, laptops, tablets, phones or equipment for taking photos are not allowed. The course material, clothes and the personal belongings must be located in a position in which the contents relevant to the exam cannot be reached. Contacting other persons during the exam is not admitted.

Useful information

Prerequisites: The prerequisites include the knowledge of matrix calculations, complex numbers, basic electrotechnics (direct current circuits, single-phase and three-phase alternating current circuits), and the principles of operation of the electrical machines (synchronous machine and transformer).

Related literature: The material (slides and handouts) used during the lectures and course activities will be available on the web portal, as well as additional material taken from papers and reports.
There is no commercial book covering the contents of this course.
Reference material can be found in:

- Nick Jenkins, Ron Allan, Peter Crossley, Daniel Kirschen, Goran Strbac, 'Embedded generation', IET (ISBN 978-0-85296-774-4), 2000.
- D.N. Gaonkar (ed.), Distributed Generation, Intech (ISBN 978-953-307-046-9), 2010. Freely available at the web address http://sciyo.com/books/show/title/distributed-generation.

Challenge based module
(Second part)

6
ECTS

Content summary:

- Follow-up 2nd semester module- content is similar

Main learning outcomes:

- Follow-up 2nd semester module - LO are similar, and work will be oriented according to the specialization track

Teaching Unit:
“Breadth courses (mandatory)”

6
ECTS

Content summary:

- Digital humanities

Main learning outcomes

- The expected learning outcomes of the course concern notions on the main area of the Digital History especially applied to the history of the built and humanized environment, the notion of historical urban landscape, the dynamics of change as well as notions of 19th and the first decade of the 20th century urban and architectural history and its various sources (especially applied to theme of the course).

COURSE:
DIGITAL HUMANITIES

Teaching Unit (for year 2):
“Breadth course”

Face-to-face time	Student workload	ECTS
60	**40**	**6**

Responsible teacher

Elena Gianasso

University / lab.
Politecnico di Torino / Architecture Department

Aims of the teaching

The course is an introduction to the Digital Humanities. It presents how research on the Humanities, and more specifically in the History field related to the built environment, the urban space and the landscape, can be improved by a digital approach and the use of digital technologies. The teaching deals with the methodologies of Digital Humanities applied to the history of the architecture, the history of the city and the territory.

On the matter of the Master this course focuses on cultural and social sustainable development: it is aimed to analyse how the use of the Information and Communication Technologies (ICTs) can help to access information and make more understandable cultural data and architecture in an historical perspective, and to experience a digital approach the research on the process of change of the built environment and the urban space. The purpose is to conceive how to collect and share historical data, create a digital historical product by improving interpretation and allowing the access to architectural information. The main purpose aims to achieve a sustainable approach to the research and re-use of data by a collaborative approach. The theme of the course with its contents also adds an analytical approach to a matter both urban and social useful to reflect on the consequences of governance and planning for democracy and sustainable development. The teaching includes both a theoretical and a practical learning. On one hand students will learn methodologies through case studies of Digital History by analysing various kind of digital product of the historical research which use digital tools for collecting, managing and/or communicating historical cultural data. The course will present also the related literature. On the other hand, students will have a practical experience on the use of a digital approach to the historical research. The teacher and the teacher’s assistant will train students in this practical approach to the research by allowing them applying these methodologies to a case study.

Intended Learning outcomes (measured by the assessment)

The expected learning outcomes of the course concern notions on the main area of the Digital History especially applied to the history of the built and humanized environment, the notion of historical urban landscape, the dynamics of change as well as notions of 19th and the first decade of the 20th century urban and architectural history and its various sources (especially applied to theme of the course). Students will develop abilities in a strict approach to the matter of a digital approach to historical and cultural data, in implement research, and creativity in conceiving and presenting their research at large.

More specifically students are expected to develop peculiar abilities in understanding and conceiving how to how to visualise historical information and create coherent narratives with Digital Humanities methodologies, how to analyse and present space-temporal dynamics, how to recognise and interpret historical sources, how to connect them to digital research elaborations, how to develop keys of interpretations and synthetic digital vision at different scales. Students will become able to research digital sources, study an area with a digital historical approach in a diachronic perspective by using direct and indirect sources, interpreting data into an historical framework, conceiving a virtual re-constructions of historical processes of the changes, and finally create a basic or more complex digital historical product according with their previous digital abilities. The final expected learning outcomes of the practice concern a digital historical research product on the case study demonstrating the research of sources and their interpretation, the conception of a visual representation of data of these research, the correct integration of digital data and the coherent use of tools for the historical narrative and visual reconstruction, as well as the oral presentation and discussion of the final outcomes.

Learning activities and approach

E-learning (online)	Lectures (onsite) 60h	Tutorials (onsite)
-	-	-

Practical work equipment and location

The exam will verify the learning of methodologies, the historical contents and a strict approach of making digital history. It includes an oral public presentation of the outcome of the practice. The student will deliver for the exam: all digital products of his/her research including a report on sources and methodologies.

Assessment method

Compulsory oral exam.

Useful information

Prerequisites: A background on the fundamentals of all major energy technologies (oil, coal, gas, renewables, nuclear, etc.) is taken for granted.

Related literature:

- Burdick, J. Drucker, P. Lunenfeld, And T. Presner, J. Schnapp, Digital_Humanities, Cambridge: MIT Press, 2012
- R. Tamborrino (ed.), Telling the history of the city in the Age of the ICT Revolution, Rome: CROMA- Università di Roma Tre, 2014

Teaching Unit:
“Elective #3”

6
ECTS

Content summary:

- Models and scenarios for energy planning
- Advanced materials for energy
- Thermal design and optimization

Main learning outcomes:

- 1 course over 3 (6 ECTS/course)

COURSE:
MODELS AND SCENARIOS FOR ENERGY PLANNING

Teaching Unit (for year 2):
"Elective #3"

Face-to-face time	Student workload	ECTS
60 hours	**180 hours**	**6**

Responsible teacher

Laura SAVOLDI

University / lab.
Politecnico di Torino / Energy Department

Pedagogic Team

Alfonso CAPOZZOLI
Politecnico di Torino
Energy Department

Daniele LEREDE
Politecnico di Torino
Energy Department

Giuseppe PINTO
Politecnico di Torino
Energy Department

Riccardo NOVO
Politecnico di Torino
Energy Department

Aims of the teaching

The course focuses on the modeling of the dynamics of energy systems and markets at different spatial scales and on medium-long terms under a complex set of constraints. This modeling is crucial today for the planning of sustainable energy strategies at regional, national and international level. The objective of the course is to provide the students the capability to discriminate between different models and scenarios for energy planning, as well as to develop their own simplified models, and to analyze and compare the results of complex energy models and different development scenarios. The course is inter-disciplinary in nature, being culturally located at the crossroads between economics and engineering.
The main topics addressed in the course are:

- The context of climate changes, the UN sustainability goals, the Paris Agreement, the needs for energy modeling and the different classifications of the existing models (top-down vs. bottom-up, partial vs. global equilibrium models; optimization vs. simulation, …)
- Micro-scale energy models - deterministic / statistical models, machine learning and stochastic models
- Meso-scale energy models, with particular reference to Multi-Criteria Decision Algorithms and data classification learning processes.
- Macro-scale energy models: assumptions in input, interconnections between energy demand, energy supply and technologies, mathematical methods adopted for the solutions, assessment of the propagation of uncertainties from input to output.
- eMergy analysis and indices.

In parallel with these theoretical developments, the students have the opportunity to develop their own macro-scale model with a hands-on approach and to apply it to the analysis of a case study (a country or a region), divided in small groups.

Intended Learning outcomes (measured by the assessment)

After this course, the students will understand the rationale behind energy models at local/regional/world level, they will know the structure of the different models existing in the literature and will be able to distinguish and classify them. They will know the input needed for the different energy models (e.g. the MARKAL – TIMES models), with special attention to the main scenarios (business-as-usual, normative, explorative), and they will be able to properly comment and compare the relative outputs, and in particular the outlook of the main energy markets for the next few decades. The student will also know the main algorithms adopted for the solution of the constrained optimization problems hidden in the models, and be able to apply them in order to develop the model of a regional energy balance in small teams, empowering their capabilities to work in a group and improving their communication skills.

Learning activities and approach

E-learning (online)	Lectures (onsite) 45h	Tutorials (onsite) 9h
Could be the whole course	-	Tutorial on the Reference Energy System

Practical work equipment and location

The final grade is obtained combining two different assessments:

1. A written exam, contributing up to 18/30 to the final grade, including 3-4 questions on different theoretical topics addressed during the lectures, for a duration of 2h. The written exam aims at verifying the student’s capability to personally summarize and discuss the main features and issues of the energy modeling at the different spatial scales, presented in the course.
2. The preparation of a short report, and its presentation in oral or poster form, on the analysis of a regional balance of a selected country, and on the simulation of alternative scenarios for its energy mix evolution up to 2050, to be submitted by the end of the course. The individual project, contributing up to 12/30 to the final grade, aims at assessing the student’s capability to select and use the most suitable numerical models and tools, among those presented during the course, for the energy modeling at the macroscale.

Assessment method

Homework (mini case based), final exam.

Useful information

Prerequisites: A background on the fundamentals of all major energy technologies (oil, coal, gas, renewables, nuclear, etc.) is taken for granted.

Related literature: Selected up-to-date papers published in International Journals on the topic subject of the course.

COURSE:
ADVANCED MATERIALS FOR ENERGY

Teaching Unit (for year 2):
“Elective #3”

Face-to-face time	Student workload	ECTS
60 hours	**180 hours**	**6**

Responsible teacher

Monica FERRARIS

University / lab.
Politecnico di Torino / Department of Applied Science and Technology

Pedagogic Team

Federico SMEACETTO

Politecnico di Torino
Department of Applied Science and Technology

Silvia BODOARDO

Politecnico di Torino
Department of Applied Science and Technology

Aims of the teaching

The course has two main objectives: first, to provide additional knowledge to what acquired in the course “Materials Science and Technology” (Bachelor); second, to help the future engineer in selecting the most suitable material/technique for efficient use of energy resources (renewable and not), with particular attention to materials’ recycling and to the reduction of environmental impact.
In particular, the course will provide specific knowledge on a broad range of novel materials used in different energy applications for production and energy saving, already available on the market or under development. These include composite materials used in energy applications, on their joining and integration with traditional materials, glasses and aerogels as insulating systems for energy saving, innovative ceramics for conversion and saving of energy by using solid oxide fuel cells;
(video and complete program at https://didattica.polito.it/pls/portal30/gap.pkg_guide.viewGap?p_cod_ins=01RXHND&p_a_acc=2021&p_header=S&p_lang=.)

The students will be involved in hands-on laboratory activities and training aimed at improving their problem-solving skills, also in synergistic activities with other master level courses. Additionally, the course will organize visits to selected energy companies and research centres (also to facilitate ideas for collaborative projects and internships) in Italy and abroad, with particular interest for activities focused on renewable energies. A part of the course will be dedicated to international research programs suitable to promote and/or fund students’ placements in research institutes operating in the energy sector.

Intended Learning outcomes (measured by the assessment)

The student is expected to enter the labor market with a thorough preparation, innovative and comprehensive approach and updated knowledge of new materials (either already available on the market or under development) for energy production and saving.
In particular, the student will be able to exploit his/her skills by projects/case-studies, industrial problem-solving examples to funding institution, stakeholders and companies involved in the energy field.

The knowledge will focus on several advanced materials not studied in other courses, which are mandatory for the professional career of a future engineer.

Learning activities and approach

E-learning (online)	Lectures (onsite) 55h	Tutorials (onsite) 5h
The whole course is already online	-	virtual lab

Practical work equipment and location

9h hands-on lab activities per student; class will be divided in groups of max 10 persons

Assessment method

Individual oral test, 3 questions on the whole program. Two questions can be replaced by the presentation of an individual case study, on a voluntary basis.

Useful information

Prerequisites: Preliminary knowledge acquired in the courses of Materials Science and Technology, Physics, Chemistry

Related literature: Mostly supplied by the teachers as slides and review papers

COURSE:
SOLAR PHOTOVOLTAIC SYSTEMS

Teaching Unit (for year 2):
“Elective #3”

Face-to-face time	Student workload	ECTS
60 hours	**180 hours**	**6**

Responsible teacher

Filippo SPERTINO

University / lab.
Politecnico di Torino / Energy Department

Pedagogic Team

Alessandro CIOCIA
Politecnico di Torino
Energy Department

Stefania FICHERA
Politecnico di Torino
Energy Department

Francesco GIORDANO
Politecnico di Torino
Energy Department

Gabriele MALGAROLI
Politecnico di Torino
Energy Department

Aims of the teaching

Solar energy is predicted to provide the majority of energy needs in the near future. The photovoltaic technology is the most reliable way to convert solar energy into electricity. The course is devoted to present the photovoltaic power systems starting from their operating principles, in which general aspects of power electronics are included. The knowledge of the solar resource, the methods to correctly design and choose the main components, to evaluate the energy production, with the economic analysis of investment, are the primary goals of the course. Some specific topics are: the current-voltage characteristic (I-V curve) and the equivalent circuit of the solar cell; its dependence on solar irradiance and temperature; the focus on an application problem: series/parallel connection of real cells; mismatch of their I-V curves due to production tolerance, defects and shading effect; conventional calculation of energy production: evaluation of solar irradiation, loss sources in the productivity; innovative procedure to assess the energy production: automatic data acquisition systems, experimental tests and results on operating PV plants; economic analysis by the Net Present Value (NPV) method.

Intended Learning outcomes (measured by the assessment)

At the end of the course the students will know the main technologies about the photovoltaic generators and systems (including general aspects of power electronics). Then, they will be able: to calculate the evolution of the electrical parameters and the energy production, according to the daily variations of solar irradiance and cell temperature, and to correctly design and choose the main components of these power systems. Finally, they will be able to experimentally test the actual performance of these components.

Learning activities and approach

E-learning (online)	Lectures (onsite) 39h	Tutorials (onsite) 1.5h
Could be the whole course	-	Guided tour to the PV plants inside the Politecnico

Practical work equipment and location

- 13.5 h Classroom exercises 1st Usage of PVGIS software for solar radiation 2nd Calculation of the electrical parameters of the PV modules in conditions different from the rated STC. 3rd Calculation of reverse currents in a shaded PV string supplied by irradiated strings. 4th Optimal coupling between PV array and inverter: constraints of power/voltage/current. 5th Calculation of the energy production in a PV system from SO-DA database.
- 6 h lab activities divided in 4 labs: 1st Measurement of the I-V curve of a solar cell in dark conditions by multimeters. 2nd Measurement of the I-V curve of a solar cell by digital oscilloscope. 3rd Measurement of the I-V curve for a transistor as a switch. 4th Measurement of efficiency and power quality for single-phase inverter.

Assessment method

Written exam, 1 h duration, with theoretical questions for a total of 20 points (short discussions, drawings and formulas) and numerical exercises regarding the classroom exercises for a total of 10 points. During the written exam it is possible to use a pocket electronic calculator, but it is not permitted to use handouts or notes regarding the program of the course. The space at disposal for the answers, on the single sheet of the written exam (front and back sides), is limited to test the ability of the student to summarize the concepts. It is possible to reject the grade.

Useful information

Prerequisites: Basic knowledge about electric circuit theory (electrical circuit analysis).

Related literature:

- Teaching documents (handouts on photovoltaic power systems and slides on the lectures) on the POLITO portal of the teacher.
- For deepening, it is suggested to read the books "T. Markvart, Solar Electricity, 2nd Edition, 2000, J. Wiley & Sons, USA" and “M. Patel, Wind and Solar Power Systems, 2006, CRC Press, USA”.

SEMESTER 3 (UPC) - TOTAL 32 ECTS

Specialization track ” Thermal Energy Engineering”

Teaching units	Content summary	Main learning outcomes	ECTS
Thermal equipment for heat and cold generation	• Techniques for generating heat and cold. • Methodologies that allow the calculation and design of thermal systems using softwares	• Master advanced methods of numerical simulation analysis of items of equipment (incl. with phase change, transient). • Master the most advanced calculation methods of items of equipment generating heat and cold • Comprehensive analysis systems	**5 ECTS**
Computational methods in thermal energy technology	• Training in the numerical solution of the governing equations of fluid dynamics and heat and mass transfer.	• Master the basic mathematical formulations of fluid dynamics and heat and mass transfer phenomena. • Master the different numerical integration methodologies of the Navier-Stokes equations, the resolution of turbulent flows based on methods like RANS, LES and DNS.	**5 ECTS**
Turbulence: phenomenology, simulation	• Phenomenology of turbulent flows • Statistical tools for turbulent flows • Basics of modelling turbulence	• Master basic knowledge of turbulence and its energy spectrum, statistical treatment of turbulent flows • Be able to model and solve turbulent flows	**5 ECTS**
Challenge based module	• Follow-up 2 nd semester module- content is similar	• Follow-up 2 nd semester module- LO are similar, and work will be oriented according to the specialization track	**6 ECTS**
Language, culture	Spanish	Initiation to the local language and cultural tips	
Breadth courses (mandatory)	• Energy Resources	• Be able to understand the need for energy and its relationship to sustainable human development, the transformations from an "energy source" to its use as "energy service".	**5 ECTS**
Elective #3	• Intensification on Heat and Mass transfer • Heat Exchanges • Heat Engines and Combustion • Experimental measurement techniques	1 course over 4 (5 ECTS/course)	**5 ECTS**
Challenge based module presentation			

Teaching Unit:

“Thermal equipment for heat and cold generation”

5
ECTS

Content summary:

- Techniques for generating heat and cold.
- Methodologies that allow the calculation and design of thermal systems using softwares

Main learning outcomes:

- Master advanced methods of numerical simulation analysis of items of equipment (incl. with phase change, transient).
- Master the most advanced calculation methods of items of equipment generating heat and cold
- Comprehensive analysis systems

COURSE:
THERMAL EQUIPMENT FOR HEAT AND COLD GENERATION [820760]

Teaching Unit (for year 2):
"Thermal equipment for heat and cold generation"

Face-to-face time	Student workload	ECTS
40 hours	**85 hours**	**5**

Responsible teacher

Carles OLIET

University / lab.
Universistat Politècnica de Catalunya /
Heat and mass transfer technological center (CTTC)
Thermal engines department

Pedagogic Team

Jesús CASTRO
Universistat Politecnica de Catalunya / CTTC

Joaquim RIGOLA
Universistat Politecnica de Catalunya / CTTC

Aims of the teaching

The purpose of this course is to have deep knowledge from the basic, phenomenological, and numerical point of view about actual thermal equipment for heat and cold generation.
The structure is divided in two main blocks, one related to compression systems, and the second on absorption systems. Both oriented with an approach combining the study of the system and its components, while considering the variants related to the final application.
Heating and cooling systems by vapour compression:
Fundamentals and background, baseline system and its variants related to performance improvement (internal receivers, vapor injection, internal heat exchangers) and the application (transcritical cycle, cascade, liquid-overfeed systems, etc.).
Multi-level engineering analysis of a particular application (domestic refrigerator), combining thermal systems simulation, advanced models for components, CFD, experiments.
Heat pumps: fundamentals, applications/configurations, high temperature heating (new refrigerants), drying applications (combining heat and cold).
Heating and cooling systems by air compression: Brayton cycles and their particular implementation as cooling/heating of aircrafts. Innovative layouts combining with vapor compression cycles. More electrical aircraft system evolution.

Ejectors: concept, phenomenology and 1D modelling (gas-gas). .Applications in refrigeration, vapor compression systems, air-to-air applications. Innovation trends about variable geometry and combination with other technologies like absorption systems.

Cooling and Heating systems by absorption: Deep analysis of physical principle, thermodynamic analysis of absorption cycles. Fluid refrigerants. Analysis of main components and auxiliary elements. Full system scan and absorption cycle: design and prediction. Use of zero-dimensional models and global balances. Study of the influence of external conditions on the system. The course will introduce the main solar heating options, while emphasizing the link of absorption systems with solar heat sources.

It aims at teaching the students:
Review the basics of thermodynamics and heat transfer phenomena and mass (second law of thermodynamics, conservation equations, etc.), in the context of the technological field of thermal systems and equipment generating heat and cold.
Description of the main technical options for refrigeration systems/heating. Technological peculiarities depending on the application. The main approach is to show the different systems, while understanding the underlying reason of such configuration, and the fundamental phenomena related to its components. Meanwhile, the lessons will be plenty of references to research projects and the tools used therein, numerical and/or experimental depending on the case. In this sense, it will be highlighted the application of advanced methods of numerical simulation analysis of items of equipment with one-dimensional fluids, considering transient effects and specific phenomena like phase change on the refrigerant or condensation/frost formation on the airside. The subject will also introduce the most advanced calculation methods of items of equipment generating heat and cold when the multidimensional analysis of fluids is unavoidable or necessary.
Regarding the analysis of the systems, different tools and examples will be analysed as well to capture their approach to provide system-level design conclusions. Cycle thermodynamic analysis will be also performed by the student considering variable properties, trying to incorporate programming skills to foster the future application of intensive computation or optimization techniques.

Intended Learning outcomes (measured by the assessment)

- Learn the basics of thermodynamics and heat and mass transfer taking place in thermal systems and equipment generating heat and cold.
- Demonstrate knowing the different techniques for generating heat and cold, including their fundamental/phenomenology background.
- Demonstrate knowing the different methodologies that allow the calculation and design of thermal systems.
- Demonstrate the capacity to select the smartest combination of numerical and experimental tools to analyse and characterize these systems and components (using commercial, or developed by Heat and Mass Transfer Technological Centre (CTTC UPC) codes).

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
	30h	10h

Practical work equipment and location

-

Assessment method

Practical work group, proposed exercises, written exam

Useful information

Prerequisites: Fundamentals of thermodynamics, fluid mechanics and heat transfer necessary to understand the operation of thermal equipment generating heat and cold.

Related literature:

- Cengel, Y. “Heat and Mass Transfer: Fundamentals and Applications” Mac Graw Hill, ISBN: 9780077654764
- Pita, E.G. “Refrigeration Principles and Systems: An Energy Approach”, e-Book ISBN 9780912524610

Teaching Unit:

“Computational methods in thermal energy technology”

5
ECTS

Content summary:

- Training in the numerical solution of the governing equations of fluid dynamics and heat and mass transfer.

Main learning outcomes:

- Master the basic mathematical formulations of fluid dynamics and heat and mass transfer phenomena.
- Master the different numerical integration methodologies of the Navier-Stokes equations, the resolution of turbulent flows based on methods like RANS, LES and DNS.

COURSE:

COMPUTATIONAL METHODS IN HEAT AND MASS TRANSFER [820757]

Teaching Unit (for year 2):
“Computational methods in thermal energy technology”

Face-to-face time	Student workload	ECTS
40 hours	**85 hours**	**5**

Responsible teacher

Carlos David PÉREZ-SEGARRA

University / lab.
Universistat Politècnica de Catalunya /
Heat and mass transfer technological center (CTTC)
Thermal engines department

Pedagogic Team

Francesc Xavier TRIAS

Universistat Politecnica de Catalunya / CTTC

Aims of the teaching

The purpose of this course is to acquire basic training in the numerical solution of the governing equations of fluid dynamics and heat and mass transfer. Furthermore, acquiring a first practical experience in programming, verification and validation of CFD&HT codes (Computational Fluid Dynamics and Heat Transfer). Become familiar with the use of CFD & HT codes and acquire the ability to critically judge the quality of the simulations (mathematical formulation and numerical solutions).
The main contents are:

- Introduction to numerical methods in fluid dynamics and heat and mass transfer
- Resolution of pure conduction heat transfer problems in irregular domains. Steady and unsteady analysis.
- Numerical integration of the generic convection diffusion equation
- Verification of codes and numerical solutions. Review of different solvers.
- Resolution of the Navier-Stokes equations for laminar and turbulent flows.

Intended Learning outcomes (measured by the assessment)

Consolidation of basic mathematical formulations of fluid dynamics and heat and mass transfer phenomena. Knowledge of different numerical integration methodologies of the Navier-Stokes equations. Introduction to the resolution of turbulent flows based on methods like RANS, LES and DNS. Application of code verification techniques, verification and validation of numerical solutions of mathematical formulations.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
	30h	10h

Practical work equipment and location

-

Assessment method

Practical work group, proposed exercises, written exam

Useful information

Prerequisites: Basic knowledge of fluid dynamics and heat transfer, as well as a programming language.

Related literature:

- Incropera, Frank Paul; DeWitt, David P. Fundamentals of Heat and Mass Transfer . ISBN 978119582786.
- Patankar, Suhas V. Numerical heat transfer and fluid flow. Washington : New York: Hemisphere ; McGraw-Hill, cop. 1980. ISBN 0070487405.
- Ferziger, Joel H; Peric, Milovan. Computational methods for fluid dynamics. 3rd, rev. ed. Berlin [etc.]: Springer, cop. 2002. ISBN 3540420746.
- Versteeg, H. K; Malalasekera, W. An Introduction to computational fluid dynamics : the finite volume method. Harlow, Essex
- : New York: Longman Scientific & Technical ; Wiley, 1995. ISBN 0470235152.
- Roache, Patrick J. Fundamentals of computational fluid dynamics. Albuquerque, New Mexico: Hermosa, cop. 1998. ISBN 0913478091.

Teaching Unit:
“Turbulence: phenomenology, simulation”

5
ECTS

Content summary:

- Phenomenology of turbulent flows
- Statistical tools for turbulent flows
- Basics of modelling turbulence

Main learning outcomes:

- Master basic knowledge of turbulence and its energy spectrum, statistical treatment of turbulent flows
- Be able to model and solve turbulent flows

COURSE:
TURBULENCE: PHENOMENOLOGY, SIMULATION AND AERODYNAMICS [820762]

Teaching Unit (for year 2):
"Turbulence: phenomenology, simulation and aerodynamics"

Face-to-face time	Student workload	ECTS
40 hours	**85 hours**	**5**

Responsible teacher

Francesc Xavier TRIAS

University / lab.
Universistat Politècnica de Catalunya /
Heat and mass transfer technological center (CTTC)
Thermal engines department

Pedagogic Team

Carlos David PÉREZ-SEGARRA

Universistat Politecnica de Catalunya / CTTC

Aims of the teaching

The purpose of this course is to know and understand the phenomenology of turbulent flows. Understand and correctly interpret statistical tools for turbulent flows. Learn the basics of modelling turbulence. Performing various practical exercices to better understand the theoretical aspects of the course.

The main contents are:

- Introduction-review of the governing equations: Navier-Stokes and energy conservation. Basic concepts. Theory of boundary layer
- Introduction to turbulence. Energy spectrum. Averaged Navier-Stokes equations. Average flow and Reynolds tensor terms. Statistical treatment: autocorrelations, PDF
- Numerical methods for solving the governing equations. Conservative discretisation. Temporary integration of equations. Solvers
- Direct turbulence resolution (DNS). Different forms of modelling turbulence: LES and models of regularisation
- Application of simulation techniques in the study of flows around obstacles, around a cylinder, around an aerodynamic profile and around a simplified car.

Intended Learning outcomes (measured by the assessment)

At the end of the course, the student has to acquire knowledge on:

- Basic knowledge of turbulence and its energy spectrum.
- Statistical treatment of turbulent flows.
- Modelling and resolution of turbulent flows.
- Application of basic numerical methods and turbulence to improve energy efficiency by means of efficient aerodynamic designs.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
	30h	10h

Practical work equipment and location

-

Assessment method

Practical work group, proposed exercises, written exam

Useful information

Prerequisites: Fundamentals of thermodynamics, fluid mechanics and heat transfer necessary to understand the operation of the motor thermal machines.

Related literature:

- Pope, S. B. Turbulent flows. Repr. with corr. Cambridge [etc.]: Cambridge University Press, 2000. ISBN 0521591252.
- Berselli, Luigi Carlo; Iliescu, T.; Layton, W. J. Mathematics of large eddy simulation of turbulent flows [on line]. Berlin: Springer, cop. 2006 Available on: http://dx.doi.org/10.1007/b137408. ISBN 3540263160.
- Patankar, Suhas V. Numerical heat transfer and fluid flow. New York: McGraw-Hill, cop. 1980. ISBN 0891165223.
- Sagaut, Pierre. Large eddy simulation for incompressible flows : an introduction. 3rd ed. Berlin [etc.]: Springer, cop. 2006. ISBN 3540263446.

Challenge based module
(Second part)

6
ECTS

Content summary:

- Follow-up 2nd semester module- content is similar

Main learning outcomes:

- Follow-up 2nd semester module - LO are similar, and work will be oriented according to the specialization track

Teaching Unit:
“Breadth courses (mandatory)”

5
ECTS

Content summary:

- Energy Resources

Main learning outcomes:

- Be able to understand the need for energy and its relationship to sustainable human development, the transformations from an "energy source" to its use as "energy service".

COURSE:
ENERGY RESOURCES
[820730]

Teaching Unit (for year 2):
“Breadth courses (mandatory)”

Face-to-face time	Student workload	ECTS
40 hours	**80 hours (Total 125)**	**5**

Responsible teacher

Lluis BATET

University / lab.
Universistat Politècnica de Catalunya /
Heat and mass transfer technological center (CTTC)
Thermal engines department

Aims of the teaching

The course intends to provide an overarching outlook of the energy systems from different standing points. In order to do so, during the course, transversal concepts complementing and synthesising the contents of other courses will be introduced. Moreover, the analyses will encompass a broad spectrum of disciplines, from science and technology to economics, and to other social sciences and humanities.

The course is structured around a series of conferences and practical sessions, which provide the skeleton supporting the other course activities. The conferences will equip the students with elements of thought and reflection about several aspects of the energy systems. A number of "practical" sessions will be programmed, which will be of two types. In some sessions students (working in teams) will try to solve a set of exercises related to the contents of the course, under the guidance of the teacher. In other sessions, students will participate in workshops, discussions, and debates related to some Social Sciences and Humanties aspects of Energy (this part of the course is aligned with the TEACHENER project, http://www.teachener.eu/, an ERASMUS+ project partnered by UPC).

Upon the completion of the course, the student should be able to:

- Explain the need for energy and its relationship to sustainable human development.
- Describe all the transformations that energy suffers from its state as "energy source" to its use as "energy service".
- Highlight the multiple implications (for society, environment, economy, etc.) of an energy system's structure.
- Perform basic calculations about the performance of different energy systems: energy balances (input-output), environmental impact, economic cost, energy storage needs, etc.
- To raise students' awareness of aspects such as energy efficiency, environmental impact minimization, security of supply, etc.
- To raise students' awareness of social aspects of energy use.

To develop in the students the values of justice, solidarity and equality from the fact of relating conflict and underdevelopment situations with the global energy needs.

Intended Learning outcomes (measured by the assessment)

Limiting the list of objectives to those of high level in Bloom's Taxonomy, at the end of this course, students will be able to:

- Explain a certain energy conversion chain from the source to the product and make calculations of varying complexity related to it (e.g. how much energy is required to produce a tin can?).
- Determine the suitability of a particular energy solution (expressed as pros and cons) for a particular need (e.g. use of natural gas to produce electricity, future use of electric vehicles vs. hybrid vehicles ...) from global data on energy economy and from environmental impact and energy efficiency analyses.
- Explain the relationship between the energy use and the human development, providing examples of different World regions (e.g. comparing per capita energy consumption vs. HDI).
- Compare the environmental impact of different energy solutions.
- Explain the relationship, expressed in terms of energy intensity, between energy consumption and economy in a country.
- Analyse the security of energy supply in a region from cyclical and structural data.
- Give a reasoned opinion on the projections and scenarios of future global and regional trends in energy, considering the demand, production capacity and reserves.
- Give a reasoned opinion on the energy demand and the adequacy of the present coverage of energy services (e.g. railroad vs. automobile mobility) and on the essence of these services themselves (e.g. mobility vs. urban planning).
- Draw energy flowcharts (synthesis) combining diverse statistical data

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
85h	30h	10h

Practical work equipment and location

-

Assessment method

The course evaluation is based in the student self-learning activities (40%), in the tutored course team project (30%), in small activities done in the classroom (10%) and in a final exam (20%).

The self-learning activities are split into exercises (10% - 20%) and other (20% - 30%). There will be a validation exam of these activities and of the course team project. Only after positive validation the mark obtained for the activity will be considered definitive.

In summary:

- 20% Final exam
- 30% Tutored course project
- 40% Other individual or team activities along the semester
- 10% Attendance and participation in theoretical and practical sessions

Participation in synchronous activities is mandatory (face-to-face or online). In order to be evaluated of the course, a minimum 75% attendance is required.

The qualification corresponding to the self-learning activities done during the semester (40% in total) will be built as a weighted average of the different marks, using as a weighting factor the time allocated for each activity.

Useful information

Prerequisites:

Related literature:

- Smil, Vaclav. Energy at the crossroads: global perspectives and uncertainties. Cambridge, Massachusetts; London: The MIT Press, cop. 2003. ISBN 0262194929.
- Smil, Vaclav. Power Density: A Key to Understanding Energy Sources and Uses. Boston: The MIT Press, 2015. ISBN 9780262029148.
- Rifkin, Jeremy. The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World. New York: Palgrave MacMillan, 2013. ISBN 9780230341975.

Teaching Unit:
“Elective #3”

6
ECTS

Content summary:

- Intensification on Heat and Mass transfer
- Heat Exchanges
- Heat Engines and Combustion
- Experimental measurement techniques

Main learning outcomes:

- 2 course over 4 (3 ECTS/course)

COURSE:
ADVANCED COURSE ON HEAT AND MASS TRANSFER [820761]

Teaching Unit (for year 2):
"Elective #3"

Face-to-face time	Student workload	ECTS
40 hours	**85 hours**	**5**

Responsible teacher

Jesús CASTRO

University / lab.
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Heat and mass transfer technological center (CTTC)
Thermal engines department

Pedagogic Team

Carlos David PÉREZ-SEGARRA

Universistat Politecnica de Catalunya / CTTC

Aims of the teaching

The purpose of this course is the formation, at a medium level, in heat transfer by conduction, convection and radiation, and fluid dynamics: phenomenological aspects, mathematical formulation (basic conservation laws and constitutive laws), and analytical and numerical resolution techniques. Methodologies of resolution of problems of technological interest in which different forms of combined heat transfer are presented.

The main contents are:

- Mathematical formulation of heat transfer and fluid dynamics
- Introduction to turbulence.
- Zonal resolution of convection. Boundary layer and potential zone
- Heat transfer by radiation.
- Vapour-liquid phase change

Intended Learning outcomes (measured by the assessment)

- Intensification in the physical description of the phenomena of heat and mass transfer and its mathematical formulation.
- Application of different computational techniques for the numerical solution of these phenomenologies.
- Development of in-house numerical codes to the study of fluid dynamic and thermal behavior of different cases of technological interest and motivating for students. Emphasis is placed on aspects of code verification, verification of numerical solutions obtained and validation of the mathematical formulation used.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
	30h	10h

Practical work equipment and location

-

Assessment method

Practical work group, proposed exercises, written exam

Useful information

Prerequisites: The general aspects of thermodynamics, fluid mechanics and heat, and mass transfer.

Related literature:

- Bergman, Theodore [et al.]. Fundamentals of heat and mass transfer. 7th ed. Hoboken, NJ: John Wiley & Sons, cop. 2011. ISBN 9780470501979.
- Eckert, E. R. G.; Drake, Robert M. Heat and mass transfer. 2nd ed. New York [etc.]: McGraw-Hill, cop. 1959.
- Schlichting, Hermann; Gersten, Klaus. Boundary-layer theory. 8th ed. Berlin [etc.]: Springer-Verlag, cop. 2000. ISBN 3540662707.

COURSE:
HEAT EXCHANGERS
[820764]

Teaching Unit (for year 2):
“Elective #3”

Face-to-face time	Student workload	ECTS
40 hours	**85 hours**	**5**

Responsible teacher

Carles OLIET

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Thermal engines department

Pedagogic Team

Carlos David PÉREZ-SEGARRA

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Aims of the teaching

The purpose of this course is the acquirement of basic training in understanding the types and usefulness of different types of heat exchanger. Acquire a very solid and yet flexible (adaptation to different geometries or phenomenology) in the calculation of heat exchangers by the conventional methods, integrating the knowledge of calculation algorithms with the basics of heat transfer competition. Know the different levels of calculation of heat exchangers (porosity method, detailed calculation dimensional flows through ducts, solving the Navier-Stokes) and their combination. It aims to provide the tools and criteria to adapt the level of simulation/ analysis to the needs of the company or researcher/engineer involved.

The main contents are:

- Introduction to heat exchangers
- Theoretical basis for thermal and hydraulic designing
- Heat exchangers without phase change: double-pipe, plates, shell and tuve
- Heat exchangers with phase change: evaporators, condensers
- Compact exchangers: fin-tube, regenerators
- Micro heat exchangers.

Intended Learning outcomes (measured by the assessment)

At the end of the course, the student has to acquire knowledge on:

- Consolidation of basic aspects of phenomena of heat and mass transfer (mathematical formulation, analytical techniques and numerical resolution, ...), as part of a technological application of large industrial and social importance are like heat exchangers
- Consolidation of conventional methods of calculation of heat exchangers (F factor methods, e-NTU NTU P, etc.). Description of the main technical characteristics and peculiarities of calculation of heat exchangers different regarding geometry (double pipe, shell and tube, plates, compact fin-tube) and phenomenology (evaporators, condensers, heat by combustion).
- Application of advanced methods of numerical simulation of heat exchangers dimensional fluid analysis, in case of steady state or transient flow and with or without phase change (condenser, evaporator).
- Introduce the most advanced methods of calculation of heat exchangers where the fluid analysis is multidimensional, by methods with macro control volumes (porosity type methods) or more advanced methods based on detailed multidimensional solving Navier-Stokes equations.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
	30h	10h

Practical work equipment and location

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Assessment method

Practical work group, proposed exercises, written exam

Useful information

Prerequisites: Knowledge of fluid dynamics and heat and mass transfer, necessary to understand the operation of heat exchangers.

Related literature:

- Kakaç, S. [et al.]. Heat exchangers: selection, rating, and thermal design. 3rd ed. Boca Raton, FL: CRC, 2012. ISBN 9781439849903.
- Schlünd er, Ernst U. Heat exchanger design handbook. New York [etc.]: Hemisphere, 1983. ISBN 0891161252. Fraas, Arthur P. Heat exchanger design. 2nd ed. New York: John Wiley & Sons, cop. 1989. ISBN 0471628689.
- Kays, W. M.; London, A.L. Compact heat exchangers. 3rd ed. New York: McGraw-Hill Company, cop. 1984. ISBN 0070334188.
- Kandlikar, S. G. [et al.]. Heat transfer and fluid flow in minichannels and microchannels [on line]. Amsterdam [etc.]: Elsevier, cop. 2006 Available on: http://www.sciencedirect.com/science/boo k/9780080445274. ISBN 9780080445274.

COURSE:
HEAT ENGINES AND COMBUSTION
[820765]

Teaching Unit (for year 2):
“Elective #3”

Face-to-face time	Student workload	ECTS
40 hours	**85 hours**	**5**

Responsible teacher

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Pedagogic Team

Jordi MUELA

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Aims of the teaching

The aim of the course is to introduce advanced methodologies (semi-analytical and numerical) for the analysis and simulation of heat engines, mainly axial thermal turbomachinery. Based on a detailed description of the fluid dynamics and heat and mass transfer phenomena present in these systems, the mathematical formulation and solution techniques at different levels are presented.

The first part of the course is focused on the thermodynamic analysis of gas and steam turbines at system level (regenerative cycles, cogeneration, gas turbines in aeronautic applications, etc.). The cycle analysis is performed both under design and prediction criteria.

The second part of the course presents the detailed analysis of system components. This level of analysis involves the detailed analysis of the fluid dynamic and thermal aspects that affect each component. First study the flow behavior in ducts of constant and variable cross sections (nozzles and diffusers), and also heat exchangers. Combustors are studied from a detailed analysis of the combustion phenomena and its numerical resolution in constant pressure combustion chambers. Furthermore, a detailed analysis of the flow in blade cascades in axial compressors and turbines is presented. Aspects related to blade cooling in turbines are also considered.

Intended Learning outcomes (measured by the assessment)

At the end of the course, the student has to acquire knowledge on:

- Consolidation basics of heat transfer phenomena and mass (mathematical formulation, analytical and numerical techniques for solving ...) within the framework of a technological application of industrial and social importance such as heat engines.
- Consolidation of conventional methods of calculation of thisçese equipment (e.g. triangle of velocities in gas and steam turbines, combustion thermodynamic equilibrium, etc.) and methodologies from the point of view of design and prediction.
- Application of advanced methods of numerical simulation engine (mainly axial compressors and turbines), from global models to advanced multidimensional simulations. Application to the resolution gas turbines considering different levels of analysis of the combustion phenomena.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
	30h	10h

Practical work equipment and location

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Assessment method

Practical work group, proposed exercises, written exam

Useful information

Prerequisites: Knowledge of fluid dynamics and heat and mass transfer, necessary to understand the functioning of heat engines.

Related literature:

- Bergman, T. L.; Incropera, Frank P. Fundamentals of heat and mass transfer. 7th ed. Wiley: Hoboken, NJ, cop. 2011. ISBN 9780470501979.
- Eckert, E. R. G.; Drake, Robert M. Analysis of heat and mass transfer. Washington: Hemisphere Pub. Corp, cop. 1972. ISBN 0891165533.
- Shapiro, Ascher H.. The dynamics and thermodynamics of compressible fluid flow. New York: The Ronald Press Company, cop. 1954.
- Pope, S. B. Turbulent flows. Repr. with corr.. Cambridge [etc.]: Cambridge University Press, 2000. ISBN 0521591252.
- Warnatz, J.; Maas, U.; Dibble, Robert W. Combustion: physical and chemical fundamentals, modelling and simulation, experiments, pollutant formation [on line]. 4th ed. Berlin [etc.]: Springer, 2006 [Consultation: 07/11/2016]. Available on: http://dx.doi.org/10.1007/978-3-540-45363-5. ISBN 9783540259923.
- Patankar, Suhas V. Numerical heat transfer and fluid flow. Washington: McGraw-Hill, cop. 1980. ISBN 9780891165224.
- Ferziger, Joel H.; Peric, Milovan. Computational methods for fluid dynamics. 3rd, rev. ed. Berlin [etc.]: Springer, cop. 2002. ISBN 3540420746.
- Saravanamuttoo, H. I. H.; Rogers, G. F. C.; Cohen, H. Gas turbine theory [on line]. 7th ed. Harlow, England: Prentice Hall, 2017 [Consultation: 31/05/2019]. Available on: https://ebookcentral.proquest.com/lib/upcatalunya-
- Ferguson, Colin R.; Kirkpartrick, Allan T. Internal combustion engines: applied thermosciences. 3rd ed. New York [etc.]: John Wiley & Sons, 2015. ISBN 9781118533314.
- Benson, Rowland S. The Thermodynamics and gas dynamics of internal-combustion engines. Oxford: Oxford University Press, 1982-1986. ISBN 0198562101.

COURSE:

EXPERIMENTAL MEASUREMENT TECHNIQUES AND THERMOENERGETICAL DATA TREATMENT [820758]

Teaching Unit (for year 2):
"Elective #3"

Face-to-face time	Student workload	ECTS
40 hours	**85 hours**	**5**

Responsible teacher

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Aims of the teaching

The purpose of this course is to obtain basic training in the development of types of measurement sensors and their integration into experimental systems (data acquisition and software, regulation, and control). Acquiring a very active competence in terms of physical principles that determine the time response. Then, a certain sensor can be detected, as well as the possible interactions that may exist between the measuring probe and the reading to be done (distortion effects of the probe intrusion problem, effects of thermal inertia on transient measurements, etc.). Learn treatment of the experimental data obtained, filtering or post-processing when necessary, evaluation of the corresponding measurement errors, etc.

The main contents are:

- Data Acquisition and Control System.
- Temperature, pressure, and mass flow rate measurements
- Hot-wire anemometry.
- Humidity
- Vacuum measurements.

Intended Learning outcomes (measured by the assessment)

At the end of the course, the student has to acquire knowledge on:

- Introduction to the basic aspects of experimental techniques in thermal energy, seeking the utmost rigor, possibilities, and limitations.
- Introduction to the analysis of experimental data, acquisition, and control, as well as analysis and measurement.
- Deepening in experimental measurement techniques such as temperature, pressure, flow, speed, humidity, gas analysis, etc.
- Application to the detailed experimental validation of basic transfer phenomena of heat and mass. Application to the contrast of numerical results and tests experiments on thermal systems and equipment of great industrial and social importance: compression refrigeration, heat exchangers, airtight compressors, absorption refrigeration, HVAC (ventilation, air conditioning in buildings, optimization of glazed facades, etc.), active and passive solar systems, heat accumulators, etc.
- Carrying out laboratory practices that allow the student to become aware of the concrete applications, of the possibilities developed, as well as of the experimental techniques and for measuring and estimating experimental errors in the units available.

Learning activities and approach

E-learning (online)	Lectures (onsite)	Seminars (onsite)
	30h	10h

Practical work equipment and location

-

Assessment method

Practical work group, proposed exercises, written exam

Useful information

Prerequisites: Fundamentals of thermodynamics, fluid mechanics, and heat transfer necessary to understand the phenomena involved in the measurements.

Related literature:

- Benedict, R.P., Fundamentals of temperature, pressure and flow measurements, John Wiley & Sons, 3rd edition, 1984.
- Holman, J.P, Experimental Methods for Engineers, McGraw-Hill, New York, 5th edition, 1989.
- Northrop, R. B., Introduction to instrumentation and measurements, CRC Press, Boca Raton, 2nd edition, 2005.
- Baker, H.D., Ryder, E.A., Baker, N.H., Temperature measurement in engineering, vol.I i II, Omega Press, 1975.
- P.R. Wiederhold, Water vapor measurement: methods and instrumentation, Marcel Dekker Inc., New York, 1997.
- ASHRAE HANDBOOK – Fundamentals, Capítol Psychrometrics, ASHRAE, USA, 2005.
- Herold, K. E. ,Radermacher, R., Klein, S. A., Absorption chillers and heat pumps, CRC Press, 1996.

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