47202 Specific learning objectives for the individual sessions

Version 14-03-2022. Subject to changes.

A student who has met the objectives of the sessions will be able to:

1. Introduction

- Earth is a space ship
- Exponential growth & "sustainable growth"
- Coupling between economic output, energy flow and efficiency
- Orders of magnitude for energy and power
- Current energy mix and primary energy demand
- Material demands
- Bi-products and elasticity of supply

2. Wind

- List the main components of a modern wind turbine
- Explain the number of rotational degrees of freedom of a wind turbine
- Determine the Weibull distribution of IEC wind class I, II and III
- Explain the scaling of the turbine power production as function of wind speed
- Choose a power curve of a wind turbine and calculate the Annual Energy Production (AEP) of a wind turbine
- Estimate the Cost of Energy (CoE) of a wind turbine producing at a site, where the wind speed distribution is given by a Weibull distribution with a shape and a scale parameter
- Estimate the number of hours per year that a wind turbine is not expected to produce power and determine the corresponding energy compared to rated power of the turbine

3. Solar

- Scale of the terrestrial solar resource
- AM1.5 and the solar spectrum
- Swanson's law / Wright's law
- IV-curves and photovoltaic figures of merit (I_sc, U_oc, FF)
- CSP
- Tandem solar
- Direct solar-to-chemical approaches

4. Water

- Explain the principle of and the ways to utilize/harvest hydro power
- Explain why different head heights require different turbines
- Calculate kinetic and potential energy from height, velocity and from pressure
- Explain the principle of and the ways to utilize/harvest wave power
- Explain the principle of and the ways to utilize/harvest tidal power
- Explain the principle of and the ways to utilize/harvest salinity gradient energy
- Explain the principle of and the ways to utilize/harvest geothermal energy (for heating and power generation)
- Explain the principle of and the ways to utilize/harvest ocean thermal energy conversion (OTEC)
- Calculate the maximum thermal to work efficiency based on Carnot's law
- Explain in which parts of the world the different water based energy sources are most relevant for utilization
- Convert between the power units W, Wh/y, J/y as well as between the energy units J, Wh, Wy (including the pre-factors k, M, G, T, P and E)

5. Nuclear

- Explain nuclear energetics and nuclear binding energies
- Describe neutron interactions and the fission process
- Explain fission reactor principles and design
- Describe the nuclear fuel cycle
- Discuss the role of nuclear power in the energy system

6. Biomass

- Describe relevant biomass types
- Explain the conflict between land use for food production and land use for biomass production
- Describe the possible roles bio energy can have in an energy system
- Explain the role and characteristics of a biomass gasifier
- Explain the role and characteristics of a synthesis reactor
- Calculate the conversion energy efficiency from syngas to fuel
- Calculate the fuel production potential based on a given carbon input

7. Thermodynamics and Electrochemistry

- Calculate the maximum efficiency of power generation (electricity) from a flow of heat
- Explain how standard enthalpy of formation and standard free energy of formation are defined.
- Calculate the change in thermodynamic functions of a chemical reaction
- Calculate energy values of fuels (Enthalpy of combustion)
- Explain the difference between higher and lower heating value
- Determine the maximum work obtainable form a fuel (Free energy of combustion)

- Calculate the minimum loss/gain of energy when converting one fuel to another
- Explain the principles of a heat pump and its advantage over simple electrical heating

- Explain the main principles of an electrochemical cell including the role of the electrodes and the electrolyte
- Balance electrochemical half-cell reactions
- Explain the definition of anode and cathode
- Calculate the reversible cell voltage based on thermodynamics of the reaction taking place
- Calculate the dependency of the cell voltage on pressures and concentrations of the reactants and products
- Explain the difference between thermodynamics and kinetics
- Explain qualitatively the term overvoltage (or overpotential)

8. Energy Storage

- Discuss the scalability and limits for different energy storage technologies
- Calculate the energy storage capacity in different types of mechanical and thermal energy storage systems
- Discuss and compare the advantages and disadvantages of mechanical, thermal and electrochemical energy storage technologies
- Calculate the levelized cost of storage (LCOS)
- Explain the working principle of thermal energy storage using a phase change materials (PCM)
- Explain the working principle of Compressed Air Energy Storage (CAES)
- Discuss the technical considerations for pumped hydro storage (PHS)
- Assess the relevant time scales for energy storage in flywheels

9. Fuel cells and hydrogen

- Explain the main principles of a fuel cell
- Outline the characteristics of the most common types of fuel cell (AEC, PEMEC, DMFC, PAFC, MCFC and SOFC)
- Explain the function of the components in a stack (electrodes, catalysts, electrolyte, bipolar plates)
- Explain the shape of a polarization curve
- Calculate the current, voltage, electrical power and thermal power of a fuel cell stack with given dimensions and number of cells, at a given working point (voltage an current density)
- Calculate the electrical conversion efficiency and the heat evolved at a given cell voltage
- Outline the concept of hydrogen as an energy carrier
- Explain the principles of the different ways to store hydrogen
- Evaluate advantages and disadvantages of hydrogen as fuel in different applications

10. Batteries

- Discuss the volumetric and gravimetric storage capacities of different battery chemistries (lead-acid, Ni-Cd, Ni-MH and Li-ion)
- Explain the working principle of a Li-ion battery, incl. redox reactions
- Calculate the open circuit voltage (VOC) of battery cell from the chemical potentials of the negative and the positive electrode
- Explain why the charge/discharge potentials differ from VOC
- Describe different ways to improve the energy density of a lithium-based battery
- Explain the concept of C-rates in batteries
- Discuss advantages and disadvantages of redox flow batteries relative to Li-ion batteries
- Assess and discuss the scalability of different battery chemistries

11. Power-to-X

- Explain the main principles of an electrolyzer
- Outline the characteristics of the most common types of electrolyzers (AEC, PEMEC and SOEC)
- Explain the function of the components in a stack
- Explain the shape of a polarization curve
- Calculate the voltage efficiency and the heat evolved at a given cell voltage
- Calculate the total current, voltage and electrical power of an electrolyzer stack if given dimensions (electrode area add number of cells) and working point (cell voltage and current density)
- Explain the concept of power-to-X
- Explain the main synthesis paths to synthetic fuels from hydrogen (Sabatier, Fischer-Tropsch, Methanol and Haber-Bosch)
- Explain the advantages and disadvantages of powering vehicles with hydrogen instead of batteries
- Explain the advantages and disadvantages of converting hydrogen into carbon based synthetic fuels
- Explain CCS and CCU
- Discuss the challenges with carbon capture (CCS and CCU)

12. Infrastructure and Cost

- Fermi estimation
- OPEX and CAPEX
- Capital structure and WACC
- Present value calculation and NPV

- IRR
- LCOE
- What "objective" LCOE comparisons are missing

13. Wrap-up

- N/A