Waste to Energy: Waste Valorization Towards Energy Generation
WS2022/23

Instructors.
Prof. Dr. Ir. Largus (Lars) Angenent (last 4 weeks)
Department of GeoSciences, Environmental Biotechnology Group
E-mail: l.angenent@uni-tuebingen.de

Dr. Ing. Rodica Zavoianu (first 4 weeks)
Department of Organic Chemistry, Biochemistry, and Catalysis, Catalytic Processes and Catalysts Group
E-mail: rodica.zavoianu@chimie.unibuc.ro

Dr. Marianna Villano (middle 4 weeks)
Department of Chemistry, Chemical and Industrial Processes Group
E-mail: marianna.villano@uniroma1.it

Office hours. Contact the instructor for the specific topic to request a Zoom meeting.

Credits. 6 (10-12 hours per week of work on average)

Start date of course. Monday October 17, 2022

End date of lecturing period. Friday January 16, 2023

Lecture, tutorial, and exam duration: 75 hours

Time of class. Lectures: Video recordings during specific week
Tutorials: To be determined (TBD)

Location of class. Lectures: Video on MOODLE
Tutorials: Zoom link and delayed recording on MOODLE

CIVIS theme. Climate, Environment and Energy

Pre-requisite. B.Sc. students that have at least finished their first year in Natural Sciences and Mathematics or Engineering and Technology. Thus, students with a basic background in Chemistry, Physics, and possibly Biology.

Main course objective. To learn fundamental and practical aspects for the treatment and simultaneous valorization of waste (including wastewater) toward energy generation

Course description and topics. This is a transdisciplinary course where chemistry, unit operations, microbiology, separation technologies, and systems engineering approaches will be taught to understand different options to convert wastes into energy. In particular, the possibility to transform waste materials (including wastewater) into useful and desired products brings the double advantage of treating and stabilizing wastes (thereby reducing their impact on the environment) while simultaneously valorizing them. This perfectly fits with the developing criteria of the circular economy whereby a waste is no longer simply disposed of but is rather

recycled to close the loop. Indeed, the lack of long-term availability as well as the environmental concerns linked to the use of fossil resources for the production of energy and, more in general, chemical platforms, is leading research towards the exploitation of alternative resources.

- Biomass extraction and valorization
- Thermochemical treatment of dry biomass
- Biodiesel production
- Sugar platform to ethanol production from lignocellulosic biomass
- Methods typically used for the analysis and characterization of waste and wastewater
- Fundamental principles of the kinetics of biological reactions
- Commonly used biotechnological processes for waste and wastewater treatment and valorization as both secondary resources and energy carrier
- Combined chemical-biological processes for the conversion of waste biomass resources into biofuels
- Knowledge and understanding of techniques to study the sustainability of the conversion and its economic viability

Goals and Outcomes. This course is intended to give B.Sc. students the capabilities to:

1. Become aware of global energy scenarios
2. Understand actions that can be applied in the context of environmental protection and sustainability
3. Develop skills on main principles of chemical and biotechnological waste-to energy processes
4. Understand the advantages of waste-to-energy conversion and their difficulties to be implemented
5. Known and apply tools for the techno-economic analysis of the studied processes

Course material. Recordings and handouts are provided on MOODL *via* this link:

Quizzes. The quizzes are designed to evaluate the knowledge that you have gained during the lectures and tutorials and by reading the course materials. These quizzes are scheduled after finishing the three different sections. In February, make-up quizzes will be planned.

Grading.	Quiz 1 (first 4 weeks)	30%
	Quiz 2 (second 4 weeks)	30%
	Quiz 3 (last 4 weeks)	30%
	Attendance	10%

Tentative Course Outline (*each lecture and each tutorial lasts 55 minutes***):**

Date	What?	Instructor	Topic
17.10.2022	4 lectures	Zavoianu	**Introduction to biofuels:** Definition of fuels and biofuels; Emission factors, Comparative analysis of the chemical composition of the raw biomass materials; Evolution of the production of biofuels – (from I generation to IV generation); Carbon emission trading systems and markets; Total primary energy supply by fuel; Growth in CO_2 emissions by energy sub-sector from 2010 to 2021; and Life cycle assessment and sustainability.
17.10.2022	2 tutorials	Zavoianu	**Questions from the lectures and exercises** – how to calculate the heat of combustion using thermodynamical data – basic calculations for life cycle assessment.
24.10.2022	4 lectures	Zavoianu	**Hydrogen production through thermochemical conversion of dry biomass** – including: Pyrolysis of biomass; Gasification; Supercritical water (fluid-gas) gasification; Steam and other reforming; Sequential cracking method.
24.10.2022	2 tutorials	Zavoianu	**Questions from the lectures and exercises.**
31.10.2022	4 lectures	Zavoianu	**Bioethanol production from biomass and biomass waste** – Chemical/enzymatic pretreatment of the lignocellulosic biomass and its conversion to fermentable glucides; Bioethanol drying; Gazol fuel; Application of life cycle assessment for bioethanol production from different biomass sources.
31.10.2022	2 tutorials	Zavoianu	**Questions and virtual laboratory** – Hydrolysis of starch extracts – identification of starch, glucose, calculation of the mass balance, yield to the target product, Virtual laboratory – Fermentation, determination of bioethanol concentration in the liquid product.
07.11.2022	4 lectures	Zavoianu	**Biodiesel production from biomass waste and vegetable oil** – Transesterification of triglycerides; Types of enzymes and its activity; The influence of the type of alcohol used for the transesterification; Comparative analysis of diesel and biodiesel properties; An integrated process combining ethanol dehydration by absorption and biodiesel production by reactive distillation; Life cycle assessment for each type of biodiesel manufacture procedure.
07.11.2022	2 tutorials	Zavoianu	**Questions and virtual laboratory** – Biodiesel manufacture from sunflower spent oil in base catalysis – determination of the total content of fatty acids, free acidity, iodine number and saponification number in the raw material, mass balance, yield to target product, determination of biodiesel viscosity and flammability point.
14.11.2022	4 lectures	Villano	**Methods used for the analysis of the organic and inorganic carbon content in waste and wastewater:**

			Definition of biochemical and chemical oxygen demand (BOD and COD, respectively); Definition of total inorganic and organic carbon content (TIC and TOC, respectively); Methods typically used for the analytical determination of BOD and COD, as well as TIC and TOC; How to theoretically determine BOD and COD, as well as TIC and TOC.
14.11.2022	2 tutorials	Villano	**Question and discussion on the recorded classes and theoretical exercises.**
21.11.2022	4 lectures	Villano	**Biotechnological process - fundamental and principles of the kinetics of biological reactions:** -Enzymatic reactions: Description and Kinetics (eq. of Michaelis-Menten); Determination of kinetic parameters; Effect of inhibitory compounds on reaction kinetics; -Microbial reactions: Description and Kinetics (Monod Model); Effect of cellular decay and cellular maintenance on the reaction kinetics; Yield of microbial growth (thermodynamic and observed).
21.11.2022	2 tutorials	Villano	**Question and discussion on the recorded classes and theoretical exercises.**
28.11.2022	4 lectures	Villano	**Biotechnological processes – Design of biological reactors:** General introduction to the study of reactors; Specific characteristics of biological reactors; Difference between batch and continuous-flow reactors; Definition of characteristic parameters (*e.g.*, hydraulic and sludge retention time); Examples of reactors configurations.
28.11.2022	2 tutorials	Villano	**Question and discussion on the recorded classes and theoretical exercises.**
05.12.2022	4 lectures	Villano	**Biotechnological processes – Design of biological reactors:** Mass balances in biological reactors (examples: chemostat; activated sludge system); Oxygen mass transfer in biological aerobic reactors; Main differences between aerobic and anaerobic reactors
05.12.2022	2 tutorials	Villano	**Question and discussion on the recorded classes and theoretical exercises.**
12.12.2022	4 lectures	Angenent	**Anaerobic Digestion (for biogas generation):** Anaerobic food web; Bioreactor configurations; Examples of wastewaters and wastes; Experiences in different countries; Fundamentals behind anaerobic digestion; Thermophilic anaerobic digestion
12.12.2022	2 tutorials	Angenent	**Question and discussion on the recorded classes and theoretical exercises.**
19.12.2022	4 lectures	Angenent	**The coupling of thermochemical systems with anaerobic digestion and Physical and chemical removal of CO_2 from biogas to produce renewable natural gas:** Thermal hydrolysis; Hydrothermal liquefaction; Hydrothermal carbonization; Physical absorption by water scrubbing; Chemical absorption with amines; Pressure-swing adsorption.

19.12.2022	2 tutorials	Angenent	**Question and discussion on the recorded classes and theoretical exercises.**
23.12.2022-06.01.2023	**Public holiday**	**No lecture/no tutorial**	**-**
9.01.2022	4 lectures	Angenent	**Biogas upgrading to biomethane: power-to-gas with ex-situ biomethanation:** Power-to-gas concept to store electric power in the natural gas grid; Electrolysis; Biomethanation at thermophilic conditions; Microbial electrochemical systems; Bioreactor configurations.
9.01.2023	2 tutorials	Angenent	**Question and discussion on the recorded classes and theoretical exercises.**
16.01.2023	4 lectures	Angenent	**Microbial chain elongation and syngas fermentation after gasification of biomass:** Ethanol as an electron donor; Lactate as an electron donor; Product separation (distillation and pertraction); Scale-up perspectives and commercialization; Syngas fermentation.
16.01.2023	2 tutorials	Angenent	**Question and discussion on the recorded classes and theoretical exercises.**