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The "Threads" of Biosystems Engineering

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Abstract. *The core concepts, or threads, of Biosystems Engineering (BSEN) are variously understood by those within the discipline, but have never been unequivocally defined due to its early stage of development. This makes communication and teaching difficult compared to other well established engineering subjects.*

Biosystems Engineering is a field of Engineering which integrates engineering science and design with applied biological, environmental and agricultural sciences. It represents an evolution of the Agricultural Engineering discipline applied to all living organisms not including biomedical applications.

The basic key element for the emerging EU Biosystems Engineering program of studies is to ensure that it offers essential minimum fundamental engineering knowledge and competences. A core curriculum developed by Erasmus Thematic Networks is used as benchmark for Agricultural and Biosystems Engineering studies in Europe. The common basis of the core curriculum for the discipline across the Atlantic, including a minimum of competences comprising the Biosystems Engineering core competencies, has been defined by an Atlantis project, but this needs to be taken further by defining the threads linking courses together.

This paper presents a structured approach to define the Threads of BSEN. The definition of the mid-level competences and the associated learning outcomes has been one of the objectives of the Atlantis programme TABE.NET. The mid-level competences and learning outcomes for each of six specializations of BSEN are defined while the domain-specific knowledge to be acquired for each outcome is proposed. Once the proposed definitions are adopted, these threads will be available for global development of the BSEN.

Keywords. Biosystems Engineering, engineering science, applied biological sciences, environmental sciences, agricultural sciences, core curriculum, competences, learning outcomes, knowledge.

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Introduction

The core concepts, or threads, of Biosystems Engineering (BSEN) are variously understood by those within the discipline, but have never been unequivocally defined due to the early stage of development of the discipline. This makes communication and teaching difficult compared to other well established engineering subjects.

Biosystems Engineering is a field of Engineering which integrates engineering science and design with applied biological, environmental and agricultural sciences. It represents an evolution of the Agricultural Engineering discipline applied to all living organisms not including biomedical applications. Therefore, Biosystems Engineering is 'the branch of Engineering that applies Engineering Sciences to solve problems involving biological systems' (ERABEE TN, 2010). Biosystems Engineering excludes Biomedical Engineering[1] (with human biology background prerequisite; also referred to as Bioengineering[2]) and Biotechnology[3].

The very basic key element for the emerging EU Biosystems Engineering program of studies is to ensure that it offers essential minimum fundamental engineering knowledge and competences (POMSEBES, 2008). On this basis, the (USAEE-TN, 2006) core curriculum, approved by FEANI (FEANI-EMC, 2007), has been used as benchmark for both, Agricultural and Biosystems Engineering studies in Europe and has been adopted by ERABEE TN. The core curriculum is available at USAEE Core Curriculum (2007). The Atlantis POMSEBES (2008) project and the Erasmus Network ERABEE) have worked towards defining the common basis of the core curriculum for the discipline across the Atlantic, but this needs to be taken further by defining the threads that link courses together. This would especially help in USA to clearly differentiate Biosystems Engineering programs of studies from others that are really focused on Agricultural Engineering or Biomedical Engineering.

The first structural step in developing compatible programs of the Biosystems Engineering discipline in Europe is the definition of a minimum of desired competences comprising the Biosystems Engineering core competencies. Core competences regard the general competences (i.e. mostly related to math, informatics, sciences like physics, chemistry, etc.), and to generic competencies of the graduate (related to communication, cooperation, design ability, etc.) and the core competences referring to Engineering and Agricultural/Biological Sciences part of the Biosystems Engineering program of studies.

Note that the use of the term Agricultural Sciences part in the core curriculum concerns the corresponding non-engineering part of the traditional programs of studies of Agricultural Engineering. However, Agricultural Engineering is considered a sub-set of the emerging discipline of Biosystems Engineering. Thus, the term Biological Sciences part in the curriculum

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[1] The application of engineering principles and techniques to the medical field. It combines the design and problem solving skills of engineering with the medical and biological science to help improve patient health care and the quality of life of healthy individuals.

[2] Bioengineering (also encompasses Biomedical Engineering and Medical Engineering) is an application of engineering principles and design to challenges in human health and medicine [http://en.wikipedia.org/wiki/Bioengineering].

[3] Techniques that use living organisms or parts of organisms to produce a variety of products (from medicines to industrial enzymes) to improve plants or animals or to develop microorganisms to remove toxics from bodies of water, or act as pesticides or a multidisciplinary field in which biological systems are developed and/or used for the provision of commercial goods or services.

of a modern program of Biosystems Engineering may be interpreted as covering also classical Agricultural Sciences subjects (e.g. soil sciences) or alternatively the term "Agricultural/Biological Sciences part of the Biosystems Engineering program of studies" may be used instead. To avoid confusion during the current transition period from the traditional Agricultural Engineering to the emerging discipline of Biosystems Engineering, and in accordance to the corresponding terminology of the core curriculum of ERABEE, the dual term "Agricultural/Biological Sciences is used in this work.

The core curriculum of Biosystems Engineering studies in Europe (ERABEE TN, 2010) includes core competences, but does not include mid-level competences (specializations dependent competences) related to applied Biosystems Engineering topics, which are defined by the individual programs of studies.

The present paper presents a structured approach to define the Threads of Biosystems Engineering. The definition of the mid-level learning outcomes and the associated competences has been one of the objectives of the Atlantis programme TABE.NET (2012). The mid-level competences and the learning outcomes for each of six selected specializations of BSEN are defined while the domain-specific knowledge to be acquired for each outcome is also proposed. Once the proposed definitions are adopted, these threads will be available for global development of the BSEN.

Core Curricula of Agricultural and Biosystems Engineering - The Europe Approach

The proposed second generation national qualifications framework in Europe define learning outcomes by the knowledge acquired, the skills gained and the competences the students are expected to have when graduating (Gallavara et al., 2008). The learning outcomes in terms of the general competences the students should have following the basic stage of their Agricultural and Biosystems Engineering studies were adopted from the corresponding Thematic Network E4-TN (2003) and incorporated in the core curricula approved by FEANI-EMC (USAAE, 2007). In addition to the general competences, the learning outcomes that compose the fundamental basis of the core curricula of Agricultural and Biosystems Engineering in Europe include two parts of fundamental competences and knowledge associated to the Engineering part and the Biological /Agricultural Sciences part of the core curricula, respectively.

The Fundamental Core Basis of the Core Curricula of Agricultural and Biosystems Engineering in Europe

The minimum set of the fundamental competences and knowledge associated to the learning outcomes of the Engineering part of the core curricula includes the contents of fundamental Engineering subjects mandatory for all specializations of Agricultural/Biosystems Engineering. These contents are expressed in terms of the following well-defined and recognised internationally basic Engineering courses:

(1) Engineering Graphics and Design – CAD, (2) Mechanics – Statics, (3) Strength of Materials, (4) Mechanics-Dynamics, (5) Fluid Mechanics, (6) Applied Thermodynamics, (7) Heat and Mass Transfer, (8) Electricity and Electronics and (9) System Dynamics.

The minimum set of the fundamental competences and knowledge associated to the learning outcomes of the Agricultural/Biological sciences part of the core curricula is designed in such a way that it includes the required fundamental knowledge of Agricultural/Biological sciences subjects mandatory for all specializations of Biosystems Engineering. These subjects represent the Agricultural/Biological sciences related fundamental basic knowledge with a broader biological background for Biosystems Engineering as compared to traditional Agricultural Engineering programs of studies. Based on the core curricula of USAEE (2007), the following courses may be considered as comprising the corresponding Agricultural/Biological core fundamental basis (5 courses may be selected out of six depending on the specializations offered):

1) Plant Biology, (2) Animal Biology, (3) Introduction to Soil Science, (4) Introduction to Agricultural Meteorology and Micro-meteorology, (5) Understanding the Environment and its interaction with Living Organisms and (6) Microbiology.

The Specialization-Specific Mid-Level Learning Outcomes of the Core Curricula of Agricultural and Biosystems Engineering in Europe

According to the design of the core curriculum in the framework of USAEE TN (2007) and ERABEE TN (2010) Thematic Networks and the analysis of POMSEBES (2008), apart from the fundamental core basis learning outcomes and the associated core competencies and basic knowledge, a study program with uniform structure-framework leading to compatible learning outcomes has to incorporate mid-level competences which refer to the optional specializations part of the core curriculum.

The mid-level learning outcomes and the associated mid-level competences and knowledge defined in the core curricula of USAEE (2007) abide to the following typical specializations (or equivalent or combinations of specializations): *Water Resources Engineering, Mechanical Systems and Mechanisms, Structural Systems and Materials, Information Technology and Automation, Bioprocessing, Waste Management, Energy Supply* and *Management*.

Following the corresponding scheme of the fundamental core basis of the core curricula of Agricultural and Biosystems Engineering in Europe, the mid-level learning outcomes of the core curricula of USAEE (2007) were also defined for the two main constituents of the curricula: the Engineering and the Biosystems (Agricultural /Biological Sciences) parts of the core curricula.

The mid-level learning outcomes concern the foundation for the development of advanced level learning outcomes related to various specializations. The associated mid-level competences, knowledge and skills have to be enriched and strengthened through more specialised / advanced level competences and knowledge so as to end up to the specific expertise to be acquired. Thus, the complete program of studies requires that mid-level competences and knowledge are extended and completed with advanced level courses on specialised areas of expertise over the 2^{nd} cycle program of studies (or during the last two years of the integrated two-cycle programs of studies).

The "Threads" of Biosystems Engineering

The mid-level learning outcomes and the associated competences and knowledge, as well as the advanced level knowledge and skills that define the threads of BSEN were defined in a structured way in the framework of the Atlantis programme TABE.NET (2012). The mid-level competences and the learning outcomes for each of six selected specializations of BSEN are defined in the next sections while the domain-specific knowledge to be acquired for each outcome is also proposed.

The six selected specializations of BSEN of interest to EU and USA programs of studies are the following:

Bioprocess engineering, Bioenergy systems, Bio-based materials, Biosystems Informatics and Analysis, Structural systems, materials and environment for biological systems, Water Resources Engineering

Mid-level Competences within a Specific Specialization

Bioprocess engineering

Biosystems mid-level competences for this specialization:

- Understand the biological reactions which govern the life of living organisms and their biological, mechanical and physicochemical characteristics as they are related to production of value added bio-based products
- Understand the biological mechanisms that govern enzymatic reactions
- Understand the biochemical processes that occur in biomass conversion (aerobic digestion, anaerobic digestion, and enzymatic hydrolysis)
- Appreciate matters related to living organisms' interaction with bioprocess systems and the effects of the related physical, chemical and biological factors.
- Understand matters related to environmental impact and sustainability as related to production of various bio-based products and their supply chains.

Engineering mid-level competences for this specialization:

- Understand the mass and energy balance in each step (unit operation) of a process of producing value added bio-based products.
- Understand the effect of process parameters in designing an enzyme reactor for the production of various bio-based products.
- Describe material flow through the processing plant producing valued added bio-based products
- Describe the processes of isolating enzymes from specific microorganisms for the purpose of producing value added bio-based products.
- Understand application of process kinetics principles to design fermenters and bioreactors
- Describe required technologies to separate product from fermentation broths.
- Describe required technologies to effectively utilize genetically engineered microorganisms for bioprocessing.
- Appreciate issues for the techniques and principles and computational methods used to model and simulate bioprocess operations as they are related to value added bio-based product supply chains.

Bioenergy systems

Biosystems mid-level competences for this specialization:

- Understand the biological mechanisms which govern the life of living organisms and their biological, mechanical and physicochemical characteristics as they are related to various aspects of energy conversion processes of organic-based materials
- Understand the biochemical energy conversion processes applied to biomass (anaerobic digestion, hydrolysis, esterification and etherification processes, 2nd generation biological conversion processes)
- Appreciate matters related to living organisms interaction with energy systems and the effects of the related physical, chemical and biological factors.

- Understand matters related to environmental protection and sustainability as related to various aspects of energy systems and biomass-to-energy supply chains.

Engineering mid-level competences for this specialization:

- Understand the typologies and quantities of organic by-products available in the agricultural, forestry, zoo technical and agro-industrial sector suitable for energy conversion
- Understand the main physical and chemical characteristics of bio-fuels and existing standards (pellets, wood chips, bio-oils, biogas fuels)
- Understand the biomass harvesting, loading, densification and transport techniques for energy valorization, including in particular agricultural and forestry mechanization processes
- Understand optimization techniques, modeling and planning of biomass supply chains and biomass-based energy production and distribution systems
- Understand the principles of analysis and design of biomass to energy conversion processes (mechanical and thermo-chemical processes) including pre-treatment, drying and storage techniques, bio-oil extraction and refining, air emission abatement systems and related emission level standards
- Appreciate issues for the techniques and principles and computational methods used to model and simulate energy conversion processes as they are related to biomass-to-energy chains.
- Understand mass-energy balances and GHG balances of biomass-to-energy chains during the whole life cycle, in order to proper address sustainability issues of bioenergy
- Understand the energy demand of agricultural, forestry, zoo technical and agro-industrial processes for heat, cool and power
- Understand the main energy efficiency and energy saving measures suitable for the agro-industrial sector
- Understand on site heat/cool and power generation systems for agro-induastruial applications

Bio-based materials

Biosystems mid-level competences for this specialization:

- Understand the science and technology underpinning biomass feedstock production and conversion to bio-based materials.
- Understand the criteria for identification, classification, and description of bio-based material characteristics, and structure-property performance relationships.
- Understand the fundamentals of the biorefinery concept, as applicable to optimal biomass value recovery towards bio-based material production.
- Knowledge of quality assessment attributes and benchmarks for bio-based material, and understanding of how to achieve such in the feedstock-to-product chains.
- Understand the Life Cycle Assessment (LCA) protocol in relation to the optimal coupling biomass feedstock production/recovery, conversion technology/processes, and environmental impact mitigation.

Engineering mid-level competences for this specialization:

- Understand the methods for identification, formulation, analysis, and resolution of engineering technology problems relevant to bio-based material deployment.

- Understanding the basic principles of designing and conducting experiments, and applying a range of standard and specialized research tools and techniques relevant to bio-based material deployment.
- Understand the principles of processing of biomass feedstock (including natural fibres) to bio-polymers or fibre-reinforced polymers.
- Understand the influence of raw material and/or fibre properties on bio-based material characteristics;
- Understand the role of sensors and rapid assessment techniques for in-situ and in-process characterisation of biomass and biomass fractions, towards targeted yield optimisation

Biosystems Informatics and Analysis

Biosystems mid-level competences for this specialization:

- Understand biosystems at the system's level
- Understand critical information needed for biosystem analysis and integration
- Understand methods for deriving quantitative and qualitative conclusions for questions related to biosystems in agriculture, food, energy, and the environment.
- Understand how to provide engineering solutions to biosystem problems at the system's level
- Appreciate recent developments in heuristic and uncertainty analyses
- Understand how to provide support for decision making

Engineering mid-level competences for this specialization:

- Understand how to carry out the 11 tasks of Biosystems Informatics and Analysis:
  1. Define system scope and objectives
  2. Identify system constraints
  3. Establish system performance indicators
  4. Conduct system abstraction (transforming from physical space to information space to facilitate analysis)
  5. Obtain and organize data and information
  6. Handle uncertain and incomplete information
  7. Develop system model to represent a system and its operations
  8. Verify and validate the model
  9. Perform modeling studies including scenario simulation and optimization
  10. Draw conclusions about the system
  11. Communicate outcomes (transforming from information space to physical space to support actions)

Structural systems, materials and environment for biological systems

Biosystems mid-level competences for this specialization:

- Understand the biological mechanisms which govern the life of living organisms and their biological, mechanical and physicochemical characteristics as they are related to various aspects of structural systems and materials (design and analysis of structural systems in support of living organisms, related production, etc.)
- Appreciate matters related to living organisms interaction with controlled or natural micro-environment and the effects of the related physical, chemical and biological factors.

- Understand matters related to environmental protection and sustainability as related to various aspects of structural systems and materials.

Engineering mid-level competences for this specialization:

- Understand the principles of analysis and design and the behaviour of structural systems and components for various conventional and innovative alternative materials designed in support of biosystems related applications and functions
- Understand the mechanical and physicochemical characteristics and behavior of conventional and innovative materials used for the design of structural systems.
- Understand the fundamental mechanical behaviour of soils and their mechanical, hydraulic and physical characteristic with regard to applications in biosystems engineering and as they are related to the design and analysis of structural systems for biosystems related applications.
- Appreciate issues for the techniques and principles and computational methods used to model and simulate structural systems as they are related to biological systems.

Water Resources Engineering

Biosystems mid-level competences for this specialization:

- Understand the biological mechanisms which govern the life of living organisms and their biological and physicochemical characteristics as they are related to various aspects of water resources engineering (design and analysis of hydraulic systems in support of living organisms, related production, etc.)
- Recognise the interactions between water and soils and their effect on the living organisms systems
- Understand matters related to environmental protection and sustainability as related to various aspects of water resources engineering.
- Appreciate the interactions between water and soils and contaminants or pollutants as they are related to soil erosion or nonpoint source pollution.

Engineering mid-level competences for this specialization:

- Understand the principles of analysis and design of water flow in conveyed elements as they are related for the design of Irrigation and Drainage Systems in support of biological systems.
- Understand the principles of analysis that govern the flow of surface-water and groundwater and the hydraulic and physical characteristics of soils as they are related to the design of groundwater systems and hydraulic structures, and the development of nonpoint source pollution models for biosystems related applications.
- Understand the fundamental mechanical behaviour of soils and their mechanical and physical characteristics as they are related to the design of surface-water and groundwater systems and geotechnical structures for biosystems and environment related applications.
- Appreciate issues for the techniques and principles and computational methods used to model and simulate hydrologic and hydraulic systems as they are related to biological systems and production and environmental protection systems.
- Understand the principles of design of instrumentation and equipment in support of water resources engineering systems as they are related to biological, systems and production and environmental protection systems.

Basic-level learning outcomes for all Specializations

The Biosystems Engineering basic-level learning outcomes are to be achieved as a prerequisite for the mid-level learning outcomes of all specializations.

Basic-level learning outcomes for Biosystems Engineering: acquire basic level knowledge and understanding of fundamental principles of Basic Sciences, Engineering Sciences, Biological/Agricultural Sciences and Humanities and Economics

- LOBS (Learning outcome: Basic Sciences). Biosystems Engineering is an engineering programme of studies. Accordingly a major prerequisite is that the students at mid-level must have already acquired a good knowledge in Basic Sciences and the ability to apply this knowledge to various Biosystems Engineering specializations (i.e. mathematics, informatics, physics, chemistry in compliance with the Basic Sciences learning outcomes related to the general competences adopted from the corresponding E4 -TN (E4 2003) and incorporated in the USAEE-TN/ERABEE-TN core curricula approved by FEANI-EMC).
- LOFES (Learning outcome: fundamental Engineering Sciences). As Biosystems Engineering is based on several classical Engineering disciplines, students must have acquired at the basic level a good knowledge and understanding of the fundamental principles of Engineering Sciences and the ability to apply this knowledge for the Biosystems Engineering related problems, in compliance with the core competences and learning outcomes referring to the fundamental Engineering part of the Biosystems Engineering program of studies (refer to learning outcomes of fundamental Engineering part of the USAEE/ERABEE core curricula).
- LOFBS (Learning outcome: fundamental Biological/Agricultural Sciences). The key characteristic of the Biosystems Engineering programmes of studies that distinguishes them from the classical Engineering disciplines is that they are built upon the interaction and integration of knowledge and understanding of basic principles of Engineering Sciences and Technology with the fundamental knowledge about living organisms and systems and the environment. As a result, students must have acquired at the basic level a good knowledge and understanding of the fundamental principles of Biological/Agricultural Sciences and the ability to apply this knowledge for the Biosystems Engineering related problems, in compliance with the core competences and learning outcomes referring to the fundamental Biological/Agricultural part of the Biosystems Engineering program of studies (refer to learning outcomes of fundamental Biological/Agricultural part of the USAEE/ERABEE core curricula).
- LOHE (Learning outcome: Humanities and Economics). As technological advances and biological production and environment are issues of major concern to the society with respect to social, economic, environmental and quality of life aspects, students must have acquired at the basic level a knowledge and understanding of the basic principles of Economy and some elements of Humanities as they apply to Biosystems Engineering related problems (in compliance with the Electives-Humanities learning outcomes related to the general competences adopted from the corresponding E4 -TN (E4 2003) and incorporated in the USAEE-TN/ERABEE-TN core curricula approved by FEANI-EMC).

Basic-level learning outcomes for Biosystems Engineering: acquire basic skills in applying fundamental principles of Basic Sciences, Engineering Sciences, Biological/Agricultural Sciences and Humanities and Economics

- Using the knowledge and understanding acquired at this basic level, the students learn to apply fundamental principles of Basic Sciences, Engineering Sciences, Biological/Agricultural Sciences and Humanities and Economics in various Biosystems Engineering design and analysis problems. This includes learning the basic steps in engineering design following a methodical approach, programming techniques, mathematical and statistical analysis and measurements using sensors and other devices and equipment.

Learning Outcomes to be Achieved in Each Specific Specialization

Bioprocess engineering

Mid-level learning outcomes for specialization “Bioprocess Systems in Biosystems Engineering”: acquire domain specific mid-level knowledge and understanding of Biosystems Sciences and Engineering Sciences necessary for the fields of biomass production, treatment, conversion for production of value added bio-based products.

Biosystems mid-level learning outcomes / knowledge to be achieved for this specialization:

The graduate should be able to:

- LOB1. Describe the physicochemical, mechanical and biological characteristics of living organisms to that affect the design parameters and the process conditions of bioprocessing operations.
- LOB2. Describe types of biochemical reactions (exothermic/endothermic) and reaction kinetics of enzyme mediated reactions in production of value added bio-based products and explain relationships between microorganisms and their products.
- LOB3. Describe the process of isolation of enzymes from specific microorganisms in relation to production of value added bio-based products.
- LOB4. Understand the basics of bio-waste characteristics, thermochemical and the biological treatment alternatives
- LOB5. Explain factors related to environmental impact and sustainability from production of various bio-based products and their supply chains.

Engineering mid-level learning outcomes / knowledge to be achieved for this specialization:

The graduate should be able to:

- LOE1: Draw and analyze process flow diagrams, define a system and draw the system boundaries for mass and energy balance
- LOE2: Apply the knowledge gained from thermodynamics and transport phenomena to design various unit operations technologies in processing biological materials.
- LOE3: Design unit operation steps to achieve a given task in the process of producing value added bio-based materials.
- LOE4: Understand the effect of process parameters in designing an enzyme reactor for the production of various bio-based products.
- LOE5: Apply process kinetics principles to design fermenters and bioreactors
- LOE6: Utilize computational models to simulate bioprocess operations as they are related to value added bio-based product supply chains.

Bioenergy systems

Mid-level learning outcomes for specialization “Bioenergy systems in Biosystems Engineering”: acquire domain specific mid-level knowledge and understanding of Biosystems Sciences and Engineering Sciences necessary for the fields of (i) biomass production, treatment, conversion for energy production; (ii) energy efficiency and rationale use of energy in the agricultural, forestry and agro-industrial sectors; (iii) use of renewable energy sources in agricultural, agro-industrial and in various Biosystems Engineering applications.

Biosystems mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOB1. Describe the physicochemical, mechanical and biological characteristics of living organisms to that affect the design parameters and the microenvironment and operation of energy systems.
- LOB2. Recognize the main environmental issues for selecting and using biomass sources for energy production and main environmental impact of biomass based energy generation plants
- LOB3. Understand the basics of bio-waste characteristics, thermochemical and the biological treatment alternatives for energy generation

Engineering mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOE1. Understand the composition, physical and chemical characteristics of organic-based materials suitable for energy production, especially wood, agricultural and forestry residues, agro-industrial by-products, energy crops.
- LOE2. Know and distinguish the biological and thermochemical energy conversion processes and the main thermodynamic energy cycles for energy conversion of biomasses into heat, cool, power and fuels for transport.
- LOE3. Know and distinguish the fundamental principles of operation and efficiencies of boilers, heat exchangers, engines, turbines, compressors, electrical machines, adsorption chillers
- LOE4. Understand the main biomass harvesting, loading, transport, drying, storage, densification and upgrading techniques required in bioenergy chains.
- LOE5. Understand the techniques to estimate the biomass energy potentials of a given territory, as regards both dedicated energy crops and residual biomass.
- LOE6. Deal with biomass standards, specifications and classifications, power plants emission standards and regulations, codes and specifications of energy conversion devices (boilers, turbines, engines, fuel cells)
- LOE5. Understand the behavior of various structural components and systems, identify their main elements, and develop numerical models to simulate energy conversion processes
- LOE6. understand the main typologies of energy consumption (heat, electricity) in the agricultural and agro industrial processes, the techniques to carry out energy audits in these sectors and the measures to increase the energy efficiency.

Mid-level skills for specialization “Bioenergy Systems in Biosystems Engineering”: acquire domain specific mid-level skills in integrating and applying principles of Biosystems Sciences and Engineering Sciences in various biomass to energy conversion routes, including biomass production, treatment, transport and energy conversion.

- LOBE1. Design and optimize the main elements of energy conversion systems fired by biomass fuels for heat, power and transport fuels.

- LOBE2. Design and optimize the biomass production, harvesting, transport, handling, treatment and storage steps in order to fulfill the technological, environmental and economic requirements of bioenergy chains.
- LOBE3. Design the basic components of energy conversion systems related to the air emissions abatement and waste management.
- LOBE4. design and optimize the use of renewable energy sources in agricultural and agro-industrial sectors (wind power, solar thermal, photovoltaic, small hydro, greenhouses integrated and rural buildings integrated renewable energy plants, heat pumps)

Bio-based materials

Mid-level learning outcomes for specialization “Bio-based materials”: acquire domain specific mid-level knowledge and understanding of Biosystems Sciences and Engineering Sciences necessary for the field of (i) biomass resource production (including extraction from biological waste streams); (ii) the associated conversion/refining processes and technologies; the Life Cycle environmental impacts of bio-based materials and composites, and; (iii) the synergistically coupled by-products and co-products, geared to enhancement of entire value chains, in a biorefinery concept.

Bio-based material refers to organic material in which carbon is derived from contemporary biological sources (plant, animal and aquatic matter). Bio-based products in this context are commercial or industrial products (other than food or feed), that are composed of bio-based material, in whole or significant part.

Biosystems mid-level learning outcomes / knowledge to be achieved for this specialization:

The graduate should be able to:

- LOB1. Understand the concepts of bio-based products and insights at the forefront of bio-based materials production and use, including end-of-life disposal/recycling.
- LOB2. Articulate the importance of the biorefinery concept and pertinent extractive steps, as applicable to the processing of various biomass classes into a spectrum of marketable bio-products and fuel.
- LOB3. Describe factors related to environmental impact and sustainability from production of various bio-based products and their supply chains.

Engineering mid-level learning outcomes / knowledge to be achieved for this specialization:

The graduate should be able to:

- LOE1. Understand basic principles of materials science and engineering properties of biological materials.
- LOE2. Describe the measurement of mechanical, physical, chemical, thermal and electromagnetic properties of biomaterials and the significance of these properties in pertinent engineering applications.
- LOE3. Describe resource constraints, health and safety issues, and risk assessment issues associated with feedstock production, and processing/conversion/refining of bio-based materials.
- LOE4. Design and conduct experiments pertaining to, identification, classification, characterisation and correlation of structure-property performance, through the use of analytical methods, tools, and modelling techniques.
- LOE5. Design and optimize biomaterial recovery process yield, and enhance products quality and performance in use.

Mid-level skills for specialization "Bio-based materials": acquire domain specific mid-level skills in integrating and applying principles of Biosystems Sciences and Engineering Sciences for this specialization.

The graduate should be able to:

- LOBE1. Integrate knowledge, including *Biosystems* interaction with technologies associated with other disciplines and professions, based on the principles of sustainability, eco-efficiency, industrial ecology, and green chemistry.
- LOBE2. Understand the economic, financial, institutional and commercial considerations related to innovation and marketing of bio-based materials and products.

Biosystems Informatics and Analysis

Mid-level learning outcomes for specialization "Biosystems Informatics and Analysis in Biosystems Engineering": acquire domain specific mid-level knowledge and understanding of Biosystems Sciences and Engineering Sciences necessary for the topics of (i) systems level thinking and understanding; (ii) procedural methods for deriving solutions for problems in systems of agriculture, food, energy, and the environment; (iii) concepts and numerical techniques of engineering economics and systems modeling/simulation/optimization; (iv) recent developments in heuristic and uncertainty analyses; and (v) formulation and provision of decision support .

Biosystems mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOB1. Describe the scope of systems, subsystems, and components of bio-based production and processing systems.
- LOB2. Recognize the systems level issues and problems to be addressed and solved. Examples include managing and utilizing resources to produce food, feed, fiber, and fuel while ensuring a sustainable natural environment; laborious operations under conditions not conducive to human productivity; advancement of technologies in other industries inevitably increase the threat of attracting labor forces away from agriculture; market demand for product quality is increasing; modernization of agriculture (using information and technologies) is necessary; employing human intelligence and machine power in a sustainable and economically viable manner (i.e. sustainability and competitiveness) is highly desirable.
- LOB3. Explain the unique challenges in integration of biosystems including systems informatics, modeling, analysis, decision support, design and specification, logistics, model-based control, and concurrent science, engineering, and technology (ConSEnT).

Engineering mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOE1. Understand systems approach for conducting quantitative analysis and providing engineering solutions for problems in agriculture, food, energy, and the environment.
- LOE2. Know how to organize and execute systems analyses that require strong engineering and computational methods including informatics (concept diagrams, database design, application programmers interface, etc.), modeling and analysis (simulation and optimization models, agent-based models, and model application and analysis, etc.), and decision support system (web-based decision support system, integration with models, databases, and user interfaces, etc.).

- LOE3. Employ mathematical, logical, and heuristic reasoning algorithms to derive computational solutions for complex systems level problems.

Mid-level skills for specialization "Biosystems Informatics and Analysis in Biosystems Engineering": acquire domain specific mid-level skills in integrating and applying principles of Biosystems Sciences and Engineering Sciences in analyzing, optimizing, planning, design, management, and operating various biosystems.

- LOBE1. Apply engineering economics principles to evaluate economic viability of the biosystems under consideration and conduct what-if type of trade studies for various design scenarios.
- LOBE2. Identify key parameters and variables and evaluate the extent of their influence on the overall performance of biosystems under consideration.
- LOBE3. Illustrate the utility and effectiveness of systems informatics and analysis methodology through case studies on contemporary biosystems.
- LOBE4. Formulate and present outcomes and conclusions of systems analysis, as well as feasible engineering solutions, in appropriate forms for targeted audiences.

Structural systems, materials and environment for biological systems

Mid-level learning outcomes for specialization "Structural Systems, Materials and Environment in Biosystems Engineering": acquire domain specific mid-level knowledge and understanding of Biosystems Sciences and Engineering Sciences necessary for the fileds of structural systems, materials and environment in various Biosystems Engineering applications.

Biosystems mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOB1. Describe the physicochemical, mechanical and biological characteristics of living organisms to that affect the design parameters and the microenvironment and operation of structural systems.
- LOB2. Recognize the main environmental issues for selecting and using materials and creating sustainable structural systems.
- LOB3. Understand the basics of waste characteristics, biological reactions and the biological treatment alternatives

Engineering mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOE1. Understand the composition, atomic and crystal structure and chemical bond types of structural materials, especially concrete, wood, ceramics, polymers and metallic materials.
- LOE2. Know and distinguish the mechanical and physicochemical characteristics of conventional and innovative alternative materials used in structural systems.
- LOE4. Understand the actions in structures and the associated loads.
- LOE3. Understand the soil mechanics related design aspects of the structural systems
- LOE6. Deal with structural and materials related codes and specifications
- LOE5. Understand the behaviour of various structural components and systems, identify their main elements, and develop numerical models to simulate structural systems

Mid-level skills for specialization "Structural Systems, Materials and Environment for Biological systems in Biosystems Engineering": acquire domain specific mid-level skills in integrating and applying principles of Biosystems Sciences and Engineering Sciences in various Biosystems

Engineering analysis and design applications and projects related to the specialization of structural systems, materials and environment.

- LOBE1. Design and optimize the main elements of structural systems, by applying the specifications contained in standards
- LOBE2. Design and optimize the micro-environment of the structural system
- LOBE3. Design the basic components of the structural system related to the waste management system

Water Resources Engineering

Mid-level learning outcomes for specialization “Water Resources Engineering”: acquire domain specific mid-level knowledge and understanding of Biosystems Sciences and Engineering Sciences necessary for the field of Water Resources Engineering in various Biosystems Engineering applications.

Biosystems mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOB1. Describe the physicochemical and biological characteristics of living organisms and the micro-meteorological and micro-environmental parameters that affect the design parameters, simulation and operation of hydraulic systems such as irrigation and drainage systems.
- LOB2. Understand the relations between soil, water, contaminants or pollutants and living organisms for the design of hydraulic and hydrological systems.
- LOB3. Recognize the main environmental issues for selecting and using materials and creating sustainable hydraulic systems.
- LOB4. Know the fundamentals of nonpoint source pollution and understand the basics of waste characteristics, biological reactions and the biological treatment alternatives

Engineering mid-level learning outcomes to be achieved for this specialization:

The graduate should be able to:

- LOE1. Understand the soil physics and soil mechanics and know their physical and hydraulic characteristics related to the design aspects of hydraulic and hydrological systems.
- LOE2. Understand the principles of water movement in porous media and conveyed elements.
- LOE3. Know and distinguish the mechanical and physicochemical characteristics of conventional materials used in hydraulic systems.
- LOE4. Know the design and technical characteristics of the different irrigation systems, and the related equipment such as pumps, valves, or flow measuring devices.
- LOE5. Distinguish the characteristics and design principles related to water facilities.
- LOE6. Develop numerical models to simulate hydraulic and hydrological systems.
- LOE7. Identify the main elements of structural and geotechnical systems used to design water facilities and deal with structural, materials related codes and specifications

Mid-level learning outcomes for specialization “Water Resources Engineering”: acquire domain specific mid-level skills in integrating and applying principles of Biosystems Sciences and Engineering Sciences in various Biosystems Engineering analysis and design applications and projects related to the field of Water Resources Engineering.

- LOBE1. Apply geographical information system techniques and numerical modeling to assess environmental risks associated to hydraulic works and diffusion of contaminants and pollution.
- LOBE2. Understand the principles of water and environmental laws and apply them for the planning, design and management of water resources.
- LOBE3. Design elements and systems to prevent soil erosion and to restore stream and riparian areas.
- LOBE4. Design the basic components of the hydraulic system related to the waste management system.

Knowledge Associated with the Learning Outcomes for Each Specific Specialization

The tables in the Appendix contain the knowledge associated to the learning mid-level outcomes defined in the previous section. Three different levels have been identified for each specialization: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements (refer to the core curriculum of USAEE (2007)).

Conclusion

The core concepts, or threads, of Biosystems Engineering (BSEN) have never been unequivocally defined due to the early stage of development of the discipline. This makes communication and teaching difficult compared to other well established engineering subjects.

Biosystems Engineering is a field of Engineering which integrates engineering science and design with applied biological, environmental and agricultural sciences. It represents an evolution of the Agricultural Engineering discipline applied to all living organisms not including biomedical applications. Therefore, Biosystems Engineering is 'the branch of Engineering that applies Engineering Sciences to solve problems involving biological systems' (ERABEE TN). Biosystems Engineering excludes Biomedical Engineering (with human biology background prerequisite; also referred to as Bioengineering[4]) and Biotechnology.

The very basic key element for the emerging EU Biosystems Engineering program of studies is to ensure that it offers essential minimum fundamental engineering knowledge and competences (POMSEBES, 2008). On this basis, the (USAEE-TN, 2007) core curriculum, approved by FEANI (FEANI-EMC, 2007), has been used as benchmark for both, Agricultural and Biosystems Engineering studies in Europe and has been adopted by ERABEE TN. The core curriculum is available at the site of USAEE 2007. The Atlantis POMSEBES project and Erasmus Network ERABEE) have worked towards defining the common basis of the core curriculum for the discipline across the Atlantic, but this needs to be taken further by defining the threads that link courses together. This would especially help in USA to clearly differentiate Biosystems Engineering programs of studies from others that are really focused on Agricultural Engineering or Biomedical Engineering.

The first structural step in developing compatible programs of the Biosystems Engineering discipline in Europe is the definition of a minimum of desired competences comprising the Biosystems Engineering core competencies. Core competences regard the general

[4] Bioengineering (also encompasses Biomedical Engineering and Medical Engineering) is an application of engineering principles and design to challenges in human health and medicine [http://en.wikipedia.org/wiki/Bioengineering].

competences (i.e. mostly related to basic sciences, and to generic competencies of the graduate related to communication, cooperation, design ability, etc.) and the core competences referring to Engineering and Agricultural/Biological Sciences part of the Biosystems Engineering program of studies.

The core curriculum of Biosystems Engineering studies in Europe (ERABEE TN) includes core competences, but does not include mid-level competences (specialisations dependent) related to applied Biosystems Engineering topics, which are defined by the individual programs of studies.

The present paper presents a structured approach to define the Threads of Biosystems Engineering. The definition of the mid-level competences and the associated learning outcomes has been one of the objectives of the Atlantis programme TABE.NET. The mid-level competences and the learning outcomes for each of six selected specializations of BSEN are defined while the domain-specific knowledge to be acquired for each outcome is also proposed. Once the proposed definitions are adopted, these threads will be available for global development of the BSEN.

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References

E4-TN SOCRATES/Erasmus Thematic Network. 2004 E4 Thematic Network: Enhancing Engineering Education in Europe edited by Claudio Borri and Francesco Maffioli,Firenze University Press, 2003, Available at: http://www.unifi.it/tree/dl/cd/E4_Index.pdf Accessed 1 June 2012

ERABEE TN 2007-2010 Education & Research in Biosystems Engineering in Europe; a Thematic Network; funded by the European Programme The Lifelong Learning Programme (LLP). Available at: http://www.erabee.aua.gr/ Accessed 1 June 2012

FEANI, Fédération Européenne d'Associations Nationales d'Ingénieurs ;European Federation of National Engineering Associations ; European Monitoring Committee (EMC) ; Available at: http://www.feani.org/webfeani/ Accessed 1 June 2012

Gallavara, G. Hreinsson, E. Kajaste, M. Lindesjöö, E. Sølvhjelm, C. Sørskår, A. K. Sedigh Zadeh M., 2008 Learning outcomes: Common framework – different approaches to evaluation learning outcomes in the Nordic countries Joint Nordic project 2007–2008, by the Nordic Quality Assurance Network for Higher Education (NOQA), European Association for Quality Assurance in Higher Education 2008, Helsinki

POMSEBES 2006-2008 Policy Oriented Measures in Support of the Evolving Biosystems Engineering Studies in USA-EU, POMSEBES: Project No. 2006-4563/003-001-CPT-CPTUSA co-funded by the European Commission and the US Department of Education, Fund for the Improvement of Post Secondary education (FIPSE), under the ATLANTIS programme (Actions for Transatlantic Links and Academic Networks for Training and Integrated Studies). Available at: http://www.pomsebes.aua.gr/ Accessed 1 June 2012

TANE.NET, Trans-Atlantic Biosystems Engineering Curriculum and Mobility; co-funded by the European Commission and the US Department of Education, Fund for the Improvement of Post Secondary education (FIPSE), under the ATLANTIS programme (Actions for

Transatlantic Links and Academic Networks for Training and Integrated Studies). Available at: http://www.ucd.ie/tabe/ Accessed 1 June 2012

USAEE TN 2002-2006 University Studies of Agricultural Engineering in Europe: funded by the European Programme The Lifelong Learning Programme (LLP). Available at: http://www.hostforce.co.uk/nondrup/usaee/usaee-tn.htm Accessed 1 June 2012

USAEE Core Curriculum; 2007 University Studies of Agricultural Engineering in Europe: funded by the European Programme The Lifelong Learning Programme (LLP). Available at: http://www.hostforce.co.uk/nondrup/usaee/files/USAEE%20Core%20Curricula%20Pivot%20FEANI_final%20version.pdf Accessed 1 June 2012

Appendix. Knowledge associated with the learning outcomes defined for each specialization

Knowledge for the specializations under consideration: the following tables contain the knowledge associated to the learning outcomes defined in this paper. Three different levels have been identified for each specialization: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements

Specialization: Bioprocess engineering

Knowledge for specialization "Bioprocess engineering": *the following tables contain the knowledge associated to the previously defined learning outcomes. Three different levels have been identified: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements.*

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Biosystems	- LOB1. **Describe** the physicochemical, mechanical and biological characteristics of living organisms to that affect the design parameters and the process conditions of bioprocessing operations.	-	1. Describe biological growth characteristics, specifically on microorganisms 2. Describe role of enzymes in a reaction 3. Describe ways to inhibit/control enzyme in a reaction	1. Explain the metabolic pathways in living organisms, specifically on microorganisms 2. Explain the characteristics of enzymes and microorganisms 3. Describe the process of isolation of enzymes from specific microorganisms
	- LOB2. **Describe** types of biochemical reactions (exothermic/endothermic) and reaction kinetics of enzyme mediated reactions in production of value added bio-based products and **explain** relationships between microorganisms and their products.	-	1. Describe chemical reactions and explain reaction rate theory 2. Describe enzyme catalysis reactions 3. Explain the role of enzymes in biochemical reactions	1. Explain relationships between microorganisms and their products 2. Describe the biochemical reactions in living systems 3. Identify of the products from biochemical reactions in living systems.
	- LOB3. **Describe** the process of isolation of enzymes from specific microorganisms in relation to production of value added bio-based products.	-	1. Explain relationships between enzymes and their products 2. Describe the biochemical processes involving enzymes in living systems	1. Explain relationships between microorganisms and their products 2. Describe the processes of extraction and isolation of enzymes from living systems (microorganisms, fungi and plant and animal tissues
	- LOB4. Understand the basics of bio-waste characteristics, thermochemical and the biological treatment alternatives	-	1. Characterize various by-products from biochemical reactions 2. Describe biological methods to treat wastes from bioprocess operations	1. Describe biochemical reactions in biological systems to treat biowaste 2. Design biological treatment systems to convert biowaste into alternate value products
	- LOB5. Explain factors related to environmental impact and sustainability from production of various bio-based products and their supply chains.		1. Understand the environmental implications from biobased industries 2. Describe economic issues related to environmental impact from bio-waste management	1. Explain regulatory (e.g. OSHA, GMP, HACCP), environmental and ethical issues and considerations 2. Conduct life cycle analysis on bio-based products 3. Identify sustainable solutions for value added bioproducts and their supply chains

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
	- LOE1: **Draw and analyze** process flow diagrams, define a system and draw the system boundaries for mass and energy balance	-	1. Define what a process is; 2. Draw simple process flow sheets; 3. Differentiate between a unit operation and a	1. Draw block diagrams for a processing plant 2. Design a plant layout for processing 3. Identify major process units in a processing

			process; 4. Identify the building blocks (unit operations) of a process;	plant 4. Describe material flow through the processing plant 5. Perform advanced mass balance for unit operations; 6. optimize the flow of the material through the plant
Engineering	- LOE2: **Apply** the knowledge gained from thermodynamics and transport phenomena to design various unit operations technologies in processing biological materials.	-	1. Identify the components and modes of operation of a bioreactor 2. Describe the functions of a bioreactor 3. Perform mass and energy balance for unit operations; 4.	1. Perform advanced mass balance for unit operations 2. Perform energy balance for unit operations
	- LOE3: **Design** unit operation steps to achieve a given task in the process of producing value added bio-based materials.	-	1. Understand the principles and applications of various unit operations; 2. Perform mass and energy balance for unit operations; 3. Evaluate the economics of unit operations 4.	1. Design a complete process; 2. Identify appropriate unit operations for a given task; 3. Design a unit operation step to achieve a given task; 4. Perform economic analysis for processes
	- LOE4: Understand the effect of process parameters in designing an enzyme reactor for the production of various bio-based products.	-	1. List the process parameters in bioreactors 2. Describe the effect of process parameters on bioreactor output 3. Explain the role of process parameters on production of selected bio-products	1. Optimize the bioreactor for maximum performance 2. Optimize the bioreactor for maximum production of bio-based products 3. Select the process parameters for process optimization 4. Analyse the effect of process parameters on bioreactor performance
	- LOE5: **Apply** process kinetics principles to design fermenters and bioreactors	-	1. Describe various types of reactions and reaction rate 2. Describe role of enzymes in a reaction	1. Describe modes of bio-reactor operation 2. Describe the impact of reaction parameters on microbial systems 3. Monitor reaction parameters effectively
	- LOE6: **Utilize** computational models to simulate bioprocess operations as they are related to value added bio-based product supply chains.	-	1. Utilize simulation tools to simulate simple bioprocess operations 2. Conduct what-if scenarios using simulation models	1. Simulate the processes and process control using software such as SuperPro

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Integration Biosystems - Engineering	- LOBE1. Integrate knowledge, including *Biosystems* interaction with technologies associated with other disciplines, based on the principles of sustainability, ecological impacts, toward developing a biorefinery.	-	1. Sustainability fundamentals. 2. Bioremediation, biodegradation, and biological waste management fundamentals. 3. Roles of microorganisms and plants in bioprocessing. 4. Strategies and technologies for waste minimisation.	1. Bioprocessing case studies e.g., biopolymers, biochemicals, biofuel, pharmaceuticals, food and feed supplements, etc. 2. Metabolic engineering applications for improved bioprocessing operations.

	- LOBE2. Knowledge and understanding of the economic, financial, commercial considerations related to innovation and marketing of bio-based value added products.	-	1. Marketing functions related to innovative/emerging bioprocessing industries. 2. Lead market initiatives in sustainable production of bio-products. 3. Product validation, quality management and regulatory issues. 4. Fundamentals of cross-functional team based approach to problem solving.	1. Strategic process planning, and environmental and marketing management. 2. Design of planning tools for bio-product supply chain management, optimization of manufacturing processes, and general process modelling for continuous improvement. 3. Quantitative methods for decision making based on current market situation and future demand forecasts.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Specialization: Bioenergy systems

Knowledge for specialization "Bioenergy systems": *the following tables contain the knowledge associated to the previously defined learning outcomes. Three different levels have been identified: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements.*

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Biosystems	- LOB1. **Describe** the physicochemical, mechanical and biological characteristics of living organisms to that affect the design parameters and the microenvironment and operation of energy systems.	-	1. Identify and describe the principles for animal physiology and nutrition. 2. Describe the systems for animal husbandry and fish farming, identifying their main constraints and requirements. 3. Identify and quantify the micro-environmental parameters to be met by various animal and fish production and housing systems. 4. Describe the main physiological functions of the different crops and other plants and biological systems (e.g. mushrooms, algae and other micro-organisms) in protected production systems. 5. Introduce the management principles and micro-environmental requirements in relation to protected crop and other biosystems production. 6. Identify and describe the principles for biosystems nutrition.	1. Types of animal production, components, inputs and organisation of enterprises for cattle, sheep, pigs, poultry, rabbits etc. 2. Analyse and quantify the sources of losses and quality and productivity problems arisen with the management of animals and measures to overcome them. 3. Identify and describe the main components, inputs and organisation of protected crop production systems. 4. Identify and describe the main algae, and other microorganisms and biosystems production systems. 5. Analyse and quantify the sources of damages, quality and productivity losses and problems arisen with the management of crops, fruits, or horticultural products and other bisosystems and measures to overcome them.
	- LOB2. **Recognize** the main environmental issues for selecting and using biomass sources for energy production and main environmental impact of biomass based energy generation plants	-	1. Identify and describe the main characteristics of environmental components (air, soil, water, cultural or socioeconomic) in relation to the impacts derived from activities related to energy conversion of biomass. 3. Introduce the environmental impact assessment process and explain the main evaluation methods. 4. Introduce the life cycle assessment method of bioenergy supply chains and energy conversion systems 5. Describe the fundamentals of the main impacts: noise, water, air pollution, biological, cultural and land-use and landscape.	1. Design an impact assessment technique 2. Calculate and assess pollutant loading on the environment 3. Evaluate the socioeconomic impact on the environment of energy generation systems and energy demand in agro-industrial and agricultural sectors 4. Design bioenergy pre-treatment, processing and conversion plans to minimize the environmental impacts and propose measures in order to correct the impacts generated.
	- LOB3. Understand the basics of bio-waste characteristics, thermochemical and the biological treatment alternatives for energy generation	-	1. Description of the main characteristics associated to waste materials derived from animal and plant management and from agro-industrial sector. 2. Identify the sources and categories of waste materials.	1. Introduction to microbiology and biochemistry of liquid wastes. 2. Contamination of soil and water due to residues: processes, consequences and strategies to be adopted.

			3. Describe the legal framework of environmental issues, including general laws and major legislation related to waste management. 4. Identify and describe the characteristics of the main waste management technology options, e.g., biological treatment, composting, recycling or energy recovery. 5. Introduction to the main physicochemical processes associated to the management of waste materials and the associated biological reactions.	3. Design a waste management plan in the framework of a project or activity. 4. Analysis of energy conversion options of biodegradable wastes from agricultural, agro-industrial and zootechnical sectors
Component	**Learning Outcome**	**Knowledge for each learning outcome**		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
	- LOE1. Understand the composition, physical and chemical characteristics of organic-based materials suitable for energy production, especially wood, agricultural and forestry residues, agro-industrial by-products, energy crops.	-	1. Low heating values of various typologies of biomasses. 2. Bulk density, energy density 3. Ash contents 4. Influence of biomass physical and chemical parameters in storage 5. Metals in biomass: typologies and influence in energy conversion processes 6. BOD and COD of fermentable biomasses 7. Chemical and physical parameters of biofuels from biomass processing 8. Bioliquids: viscosity, oleic acid contents, chemical and physical parameters	1. Techniques to measure the ashes melting point. 2. Fouling and slugging problems in boilers due to low melting point of biomass ashes. 3. Bonding processes in pelletization, effect of naturar binders, lignin behaviour at various temperatures and moisture contents in pelletization 4. Techniques to measure biogas yield in anaerobic digestion processes: batch tests 5. Acidity of bio-oils and effects of storage on bio-oil quality.
	- LOE2. Know and distinguish the biological and thermochemical energy conversion processes and the main thermodynamic energy cycles for energy conversion of biomasses into heat, cool, power and fuels for transport.	-	1. Basic principles of thermodynamics 2. Basics of thermal cycles 3. Basic principles of combustion, gasification, pyrolysis processes, 4. Basic principles of anaerobic digestion 5. Basic principles of hydrolysis, esterification, distillation	1. Use of biofuels in transport: technologies and biofuel upgrading processes 2. Use of biogas in transport: upgrading technologies, environmental balances 3. Enzimatic hydrolisys of lignocellulosic biomass 4. 2nd generation processes for lignocellulosic biomass: FT processes 5. 2nd generation processes for bioliquids: hydrogenation of bio-oils 6. Dark fermentation and anaerobic fuel cells 7. Biorefinery concept and: biochemical and thermochemical bioenergy pathways
	- LOE3. Know and distinguish the fundamental principles of operation and efficiencies of boilers, heat exchangers, engines, turbines, compressors, electrical machines, adsorption chillers	-	1. Basic principles of boilers, heat exchangers, heat distribution systems and district heating 2. Adsorption chillers technologies 3. Basic principles of thermal machines, internal combustion engines, gas turbines 4. Basic principles of electrical machines.	1. Joule cycles: small and large scale turbines, typology of biofuels suitable, dual-fuelling and cofiring options, cogeneration options, externally fired gas turbines, environmental impacts 2. Rankine cycles: efficiencies and technologies with steam and organic fluids, environmental impacts 3. Internal combustion engines: spark ignition and diesel cycles, dual fuelling options, air emission

Engineering				levels, noise and other environmental impacts, efficiencies vs size vs fuel options, cogeneration configurations 4. Fuel cells for biofuels and biological fuel cells
	- LOE4. Understand the main biomass harvesting, loading, transport, drying, storage, densification and upgrading techniques required in bioenergy chains.	-	1. Basic principles of biomass drying processes 2. Biomass harvesting, loading and transport techniques. 3. Biomass storage techniques as a function of biomass typology 4. Biomass chipping and grinding modes 5. Biomass densification techniques	1. Costs assessment and environmental assessment of biomass logistics: transport and storage 2. Costs and environmental impact of biomass chipping and drying: on site vs centralized options 3. Biomass torrefaction 4. Hydrotreatment processes 5. Biomass mechanical and chemical pre-treatments for anaerobic digestion processes
	- LOE5. Understand the techniques to estimate the biomass energy potentials of a given territory, as regards both dedicated energy crops and residual biomass.	-	1. Energy crops yield and influencing factors 2. Biomass energy potentials estimates: techniques and classifications 3. Seasonality of biomass availability and influence on bioenergy routes 4. GIS aided tools for potentials estimates 5. Alternative uses of biomass and cost supply curves	1. Energy crops potential estimates: short rotation forestry 2. Energy crops potential estimates: annual herbaceous crops 3. Energy crops potential estimates: silage crops 4. Energy crops potential estimates: oleagineous crops 5. Case studies of agricultural residues estimates 6. Case studies of forestry residues estimates 7. Case studies of agro-industrial residues estimates.
	- LOE6. Deal with biomass standards, specifications and classifications, power plants emission standards and regulations, codes and specifications of energy conversion devices (boilers, turbines, engines, fuel cells)	-	1. Introduction to the technical standards for biomass classification 2. Introduction to the standards for biomass physical and chemical measurements . 3. Standards for energy conversion processes.	1. Specific standards for biogas: threads and trends 2. Specific standards for bio-liquids: sustainability issues and LCA implication at global level 3. Specific standards for solid biomass.: standardization of pellets, torrefied pellet and wood chips

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Integration Biosystems - Engineering	- LOBE1. Design and optimize the main elements of energy conversion systems fired by biomass fuels for heat, power and transport fuels.	-	1. Design thermal biomass plants components according to the corresponding design codes. 2. Design digestor and biogas treatment and upgrading according to the corresponding design codes 3. Design electrical machines for biomass power plants and basic elements of grid connection rules	1. Optimise the design of storage, boiler size, heat exchanger size on the basis of the energy demand 2. Optimize diameters, insulation level, temperature and pressure of district heating networks on the basis of length, energy demand and techno-economic parameters 3. Optimize the moisture content of biomasss for energy conversion under various constraints and techno-economic parameters 4. Optimize the size of biomass CHP plants and boilers on the basis of techno-economic parametrrs and energy demand. 5. Operational issues of CHP plants: baseload vs peak

				vs on-off operations
	- LOBE2. Design and optimize the biomass production, harvesting, transport, handling, treatment and storage steps in order to fulfill the technological, environmental and economic requirements of bioenergy chains.	-	1. Optimal sizing of biomass conversion plants on the basis of supply chain transport costs, economies of scale, efficiency dynamics, end uses. 2. Decoupling of biomass processing and biofuel energy conversion: opportunities and case studies	1. MILP tools for optimal location and sizing of bioenergy conversion plants 2. Optimal selection of biomass transport and storage modes by MILP tools.
	- LOBE3. Design the basic components of energy conversion systems related to the air emissions abatement and waste management.	-	1. Air emission abatement systems for biomass boilers 2. Air emission abatement systems for engines and turbines	1. Air emission regulations and costs assessment of optimal air emission abatement levels
	- LOBE4. design and optimize the use of renewable energy sources in agricultural and agro-industrial sectors (wind power, solar thermal, photovoltaic, small hydro, greenhouses integrated and rural buildings integrated renewable energy plants, heat pumps)	-	1. Basics of wind energy 2. Basics of solar thermal 3. Basics of photovoltaics 4. Basics of small hydro plants 5. Elements of energy efficiency in rural buildings 6. Energy efficiency in agro-industrial sector	1. Integration of solar thermal and biomass boilers 2. Integration of bioenergy systems and heat pumps 3. Energy efficiency and bioenergy routes

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Specialization: Bio-based materials

Knowledge for specialization "Bio-based materials": *the following tables contain the knowledge associated to the previously defined learning outcomes. Three different levels have been identified: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements.*

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Biosystems	- LOB1. Understand the concepts of bio-based products and insights at the forefront of bio-based materials production and use, including end-of-life disposal/recycling.	-	1. Definition and classifications of bio-based material. 2. Technologies for primary feedstock processing, feedstock physical properties influencing biomaterial production processes. 3. Process monitoring, control and biomaterial yield optimisation. 4. Biomaterial co-products and byproducts of primary biomass processing to biofuel and biochemicals. 5. Commercial bio-based and part bio-based material formulations.	1. Biomaterial physiochemical processes and interaction with living organisms. 2. Enzyme-catalysed oxidation reactions and biodegradation rates. 3. Understanding of biodegradability characteristic of substances, including system conditions for biodegradation. 4. Standardized Tests for biodegradability; readily biodegradable, inherently biodegradable and non-biodegradable. 5. Standards for sustainable bio-based materials and products.
	- LOB2. Articulate the importance of the biorefinery concept and pertinent extractive steps, as applicable to the processing of various biomass classes into a spectrum of marketable bio-products and biofuels.	-	1. Selective separation processes for the isolation of useful fractions from primary feedstock. 2. Processing water footprint, energy efficiency, environmental impacts (health/toxicity, safety and risk issues). 3. Energy recovery from unit processes and material process waste stream, hence; minimisation of the consumption of non-renewable energy resources.	1. Process optimisation for multiple product recovery from biomass at reduced environmental burden, hence achieving sustainability of the bio-based economy (*viz.*, biopolymer, biopolymer fractions, lipids, phytochemical extraction etc). 2. Process chain integration to include carbon capture and storage, and phycoremediation of process wastewaters.
	- LOB3. Describe factors related to environmental impact and sustainability from production of various bio-based products and their supply chains.	-	1. Life Cycle Assessment fundamentals. 2. Environmental regulations and guidelines governing to life cycle process emissions. 3. Green chemistry concept for environmentally friendly design of chemical processes and products.	1. Life Cycle Assessment (LCA) of bio-based materials production process pathways—bioresource, material production, manufacturing, and use to end-of-life treatment. 2. Identification and evaluation of latent environmental impact factors— e.g., global warming, ozone depletion, acidification, eutrophication, resource depletion, toxicity, smog formation, etc. 3. Benchmarking of product/process performance to limit shift of environmental burdens between unit operations in the processing steps.
Component	**Learning Outcome**	**Knowledge for each learning outcome**		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)

Engineering	- LOE1. Understand basic principles of materials science and engineering properties of biological material.	-	1. Relationships between composition, structure, and properties of biomaterials, including food plant and animal tissues. 2. In situ and non-destructive material characterization techniques. 3. Properties of biomaterials, smart materials and eco-materials, including unique attributes and performance characteristics.	1. Modelling of properties and applications of biomaterials and composites. 2. Design, development and maintenance of knowledge base pertaining to new and improved biomaterial.
	- LOE2. Describe the measurement of mechanical, physical, chemical, thermal and electromagnetic properties of biomaterials and the significance of these properties in pertinent engineering applications.	-	1. Composition, structure and properties of industrial, biological and environmental materials and processes. 2. Range, significance and limitations of material variability. 3. Use of sensors and rapid assessment techniques for resource characterization and yield optimization.	1. Develop tools and reference measurement procedures, reference materials, critically evaluated data, and best practice guides for measurement quality assurance. 2. Design and development of sensors and rapid assessment techniques for in-situ characterization of biomass resource and useful byproducts for optimization of desirable characteristics. 3. Biomaterial composites property optimisation.
	- LOE3. Describe resource constraints, health and safety issues, and risk assessment issues associated with feedstock production, and processing/conversion/refining of bio-based materials.	-	1. Environmental and sustainability limitations. 2. Chemical reactions and exposure limits of humans and other organisms to toxicity process materials and emissions. 3. Knowledge and understanding of active codes of practice and industry standards, and the need for their application to bio-based materials.	1. Bioresource mapping for quantity and utilisation options. 2. Industrial chemical reactions in biomaterials processing and by-products extraction. 3. Design of material resource conversion process monitoring and control.
	- LOE4. Design and conduct experiments pertaining to, identification, classification, characterisation and correlation of structure-property performance, through the use of analytical methods, tools, and modelling techniques.	-	1. Bio-based content verification. 2. Biodegradability. 3. Environmental performance criteria. 4. Identification and evaluation of ethical issues and concerns.	1. Unit operations of biomaterial and bio-products engineering and manufacture. 2. Heat and mass transfer as applying to biomaterial processing 3. Industrial research with biomaterials and composites.
	- LOE5. Design and optimize biomaterial recovery process yield, and enhance products quality and performance in use.	-	1. Needs and range of applications of biomaterials in packaging, structural material, energy, etc. 2. Evaluation of quality and performance of bio-materials based products 3. Fundamentals of Nanotechnology & Nanomanufacture as applying to biomaterials.	1. Purification, modification and performance enhancement of biomaterials; 2. Development of technologies for enhancing biodegradability, and for eco-efficient recycling and/or disposal. 3. Design of molecular and *nano*-scale manipulation technologies of biopolymer structures; 4. Nanotechnology standards for bio-material characterization for health (occupational exposure), safety (toxicity/hazard potential) and the environmental performance (toxicological screening).

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Integration Biosystems - Engineering	- LOBE1. Integrate knowledge, including *Biosystems* interaction with technologies associated with other disciplines and professions, based on the principles of sustainability, eco-efficiency, industrial ecology, and green chemistry.	-	5. Sustainability fundamentals. 6. Bioremediation, biodegradation, biotransformations, and biological waste treatment. 7. Roles of tissue culture and genetic engineering in biomaterial synthesis. 8. Strategies and technologies for waste prevention and minimisation of process energy requirement.	3. Environmental biotechnology research. 4. Biomaterial production case studies e.g., biodegradable polymer, biopesticide, biofuel generation, and biosyntheses of enzymatic detergents, surfactants, biological dyes, food and feed supplements etc. 5. Synthesis methods and applications for designer biomaterials with unique physical properties.
	- LOBE2. Knowledge and understanding of the economic, financial, institutional and commercial considerations related to innovation and marketing of bio-based materials and products.	-	5. Marketing functions related to innovative/emerging biomaterials and bio-based products industries. 6. Lead market initiatives in sustainable construction, protective textiles, mulch for agriculture, recycling (waste bags + shopping bags), and renewable energy etc. 7. Product validation, quality management and regulatory issues. 8. Fundamentals of cross-functional team based approach to problem solving.	4. Strategic product planning and environmental marketing management. 5. Design of planning tools for biomaterial supply chain management, optimization of manufacturing processes, and general process modelling for continuous improvement. 6. Quantitative methods for decision making based on current market situation and future demand forecasts.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Specialization: Biosystems Informatics and Analysis

Knowledge for specialization "Biosystems Informatics and Analysis": *the following tables contain the knowledge associated to the previously defined learning outcomes. Three different levels have been identified: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements.*

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Biosystems	- LOB1. Describe the scope of systems, subsystems, and components of bio-based production and processing systems.	-	1. Boundaries and components of a system. 2. Underlying concept of system abstraction. 3. Tasks, processes, and operations within bio-based production systems. 4. External factors influencing bio-based systems.	1. Develop graphical representations of systems 2. Apply object oriented approach to system abstraction. 3. Formulate quantitative and qualitative descriptions of tasks, processes, and operations. 4. Describe interfaces of the system with its external environment.
	- LOB2. Recognize the systems level issues and problems to be addressed and solved. Examples include managing and utilizing resources to produce food, feed, fiber, and fuel while ensuring a sustainable natural environment; laborious operations under conditions not conducive to human productivity; advancement of technologies in other industries inevitably increase the threat of attracting labor forces away from agriculture; market demand for product quality is increasing; modernization of agriculture (using information and technologies) is necessary; employing human intelligence and machine power in a sustainable and economically viable manner (i.e. sustainability and competitiveness) is highly desirable.	-	1. The concept of local versus global system issues. 2. Objectives of the bio-based system under study. 3. Measurement of system's performance towards achieving its goals. 4. Data and information required for system analysis. 5. Methods for data and information processing.	1. Determine the criticality of each system objective. 2. Identify system constraints. 3. Understand the reliability of data and information. 4. Understand the limitation of data and information processing algorithms and methods. 5. Understand the unique characteristics and practical expectations of bio-based systems.
	- LOB3. Explain the unique challenges in integration of biosystems including systems informatics, modeling, analysis, decision support, design and specification, logistics, model-based control, and concurrent science, engineering, and technology (ConSEnT).	-	1. System descriptors in a form useful for its analysis, design, integration, and operation. 2. Interrelationships of tasks, processes, and operations. 3. Analysis in physical space versus informational space. 4. Models that represent the real bio-based systems. 5. Mathematical models versus physical models.	1. Understand the concept of sufficient and complete set of system descriptors. 2. Establish correlation of component interactions using mathematical, logical, relational, and heuristic methods. 3. Identify parameters and variables, as well as their relationships (e.g. equations and formulas). 4. Understand and emphasize concurrency of bio-based systems in their analyses and operations. 5. Implement information environment for decision support .

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Engineering	- LOE1. Understand systems approach for conducting quantitative analysis and providing engineering solutions for problems in agriculture, food, energy, and the environment.	-	1. Critical problems in the systems of agriculture, food, energy, and the environment. 2. Steps involved in systems analysis. 3. Concepts and principles of problem solving.	1. Recognize typical cases that are representatives of current systems of agriculture, food, energy, and the environment. 2. Apply computational methods to carry out systems analysis steps. 3. Apply engineering analysis and design methods to solving system level problems.
	- LOE2. Know how to organize and execute systems analyses that require strong engineering and computational methods including informatics (concept diagrams, database design, application programmers interface, etc.), modeling and analysis (simulation and optimization models, agent-based models, and model application and analysis, etc.), and decision support system (web-based decision support system, integration with models, databases, and user interfaces, etc.).	-	1. Mathematical models that contains descriptors and their relationships of systems. 2. Digital computing techniques for solving equations. 3. Concept of decision support and its theoretical foundations.	1. Develop computerized mathematical models. 2. Apply computer models to simulate system's performance and, possibly carry out optimization algorithms. 3. Develop decision support tools and contents for use by decision makers.
	- LOE3. Employ mathematical, logical, and heuristic reasoning algorithms to derive computational solutions for complex systems level problems.	-	1. Numerical methods for solving equations. 2. Methods for handling incomplete and uncertain data and information 3. The concept of conducting "experiments" using computer models.	1. Conduct stochastic simulation. 2. Develop artificial neural networks. 3. Perform fuzzy reasoning. 4. Perform optimization using genetic algorithms.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
	- LOBE1. Apply engineering economics principles to evaluate economic viability of the biosystems under consideration and conduct what-if type of trade studies for various design scenarios.	-	1. Critical problems in the systems of agriculture, food, energy, and the environment. 2. Steps involved in systems analysis. 3. Concepts and principles of problem solving.	1. Recognize typical cases that are representatives of current systems of agriculture, food, energy, and the environment. 2. Apply computational methods to carry out systems analysis steps. 3. Apply engineering analysis and design methods to solving system level problems.

Integration Biosystems - Engineering	- LOBE2. Identify key parameters and variables and evaluate the extent of their influence on the overall performance of biosystems under consideration.	-	1. Mathematical models that contains descriptors and their relationships of systems. 2. Digital computing techniques for solving equations. 3. Concept of decision support and its theoretical foundations.	1. Develop computerized mathematical models. 2. Apply computer models to simulate system's performance and, possibly carry out optimization algorithms. 3. Develop decision support tools and contents for use by decision makers.
	- LOBE3. Illustrate the utility and effectiveness of systems informatics and analysis methodology through case studies on contemporary biosystems.	-	1. Numerical methods for solving equations. 2. Methods for handling incomplete and uncertain data and information 3. The concept of conducting "experiments" using computer models.	1. Conduct stochastic simulation. 2. Develop artificial neural networks. 3. Perform fuzzy reasoning. 4. Perform optimization using genetic algorithms.
	- LOBE4. Formulate and present outcomes and conclusions of systems analysis, as well as feasible engineering solutions, in appropriate forms for targeted audiences.	-	1. Principles for communicating outcomes of systems analysis.	1. Prepare technical reports that clearly state the scope and objectives of the system analysed, the critical problems addressed, the methods used in the analysis, and the results of the analysis.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Specialization: Structural systems, materials and environment for biological systems

***Knowledge for specialization "structural systems, materials and environment for biological systems Biosystems Engineering":** the following tables contain the knowledge associated to the previously defined learning outcomes. Three different levels have been identified: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements.*

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Biosystems	LOB1. **Describe** the physicochemical, mechanical and biological characteristics of living organisms that affect the design parameters and the microenvironment and operation of structural systems.	-	1. Identify and describe the principles for animal physiology and nutrition. 2. Describe the systems for animal husbandry and fish farming, identifying their main constraints and requirements. 3. Identify and quantify the micro-environmental parameters to be met by various animal and fish production and housing systems. 4. Describe the main physiological functions of the different crops and other plants and biological systems (e.g. mushrooms, algae and other micro-organisms) in protected production systems. 5. Introduce the management principles and micro-environmental requirements in relation to protected crop and other biosystems production. 6. Identify and describe the principles for biosystems nutrition.	1. Types of animal production, components, inputs and organisation of enterprises for cattle, sheep, pigs, poultry, rabbits etc. 2. Analyse and quantify the sources of losses and quality and productivity problems arisen with the management of animals and measures to overcome them. 3. Identify and describe the main components, inputs and organisation of protected crop production systems. 4. Identify and describe the main algae, and other microorganisms and biosystems production systems. 5. Analyse and quantify the sources of damages, quality and productivity losses and problems arisen with the management of crops, fruits, or horticultural products and other bisosystems and measures to overcome them.
	LOB2. **Recognize** the main environmental issues for selecting and using materials and **creating** sustainable structural systems.	-	1. Identify and describe the main characteristics of environmental components (air, soil, water, cultural or socioeconomic) in relation to the impacts derived from activities related to materials selection and use and structural design. 2. Introduce the environmental impact assessment process and explain the main evaluation methods. 3. Introduce the life cycle assessment method of analysis of materials 4. Describe the fundamentals of the main impacts: noise, water, air pollution, biological, cultural and land-use and landscape.	1. Design an impact assessment technique 2. Calculate and assess pollutant loading on the environment 3. Evaluate the socioeconomic impact on the environment of structural systems and materials 4. Design plans to minimize the impacts derived from structural systems and materials and propose measures in order to correct the impacts generated.
	LOB3. Understand the basics of waste characteristics, biological reactions and the biological treatment alternatives	-	1. Description of the main characteristics associated to waste materials derived from animal and plant management and that of other biosystems.	1. Introduction to microbiology and biochemistry of liquid wastes. 2. Contamination of soil and water due to residues:

			2. Identify the sources and categories of waste materials. 3. Describe the legal framework of environmental issues, including general laws and major legislation related to waste management. 4. Identify and describe the characteristics of the main waste management technology options, e.g., biological treatment, composting, recycling or energy recovery. 5. Introduction to the main physicochemical processes associated to the management of waste materials and the associated biological reactions.	processes, consequences and strategies to be adopted. 3. Design a waste management plan in the framework of a project or activity.
Component	**Learning Outcome**	**Knowledge for each learning outcome**		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Engineering	LOE1. **Understand** the composition, atomic and crystal structure and chemical bond types of structural materials, especially concrete, wood, ceramics, polymers and metallic materials.	-	1. Atomic structure and bonding in solids. 2. Crystal structures 3. Ceramics: structure, properties and processing 4. Polymers: structure, characteristics and processing 5. Metals: phase diagrams and phase transformations, thermal processing 6. Imperfections in solids	1. Composite materials: composition, moulding methods, mechanical properties, applications. 2. Corrosion and degradation of materials. 3. Fatigue of materials, especially in concrete and metallic materials. 4. Thermal, magnetic, electric and optical properties of materials. 5. Material selection and design considerations.
	LOE2. **Know** and **distinguish** the mechanical and physicochemical characteristics of conventional and innovative alternative materials used in structural systems.	-	1. Basic principles of constitutive equations for solids: classical elasticity, plasticity. 2. Fluids: idealized fluids, Newtonian fluids, laminar and turbulent fluid. 3. Stress-strain diagrams of wood, steel, concrete, polymers and other structural materials. 4. Basic mechanical properties and behaviour of wood, steel, concrete and polymers.	1. Mechanics of solids: Viscoelasticity, hypoelasticity, and advanced concepts of plastiticity (hypoplasticity, hardening and softening, deformation theory). 2. Properties and behaviour of innovative or alternative materials: composite materials, bio-based materials, glass or aluminium.
	LOE3. **Understand** the soil mechanics related design aspects of the structural systems	-	5. Characteristics of granular materials behaviour: softening/hardening, permanent deformations, influence of path loads or load rates. 6. Determine properties of soils through specific laboratory tests and site examinations 7. Understand the practical significance of different soil behaviour for the problems of design foundation and construction 8. Calculate basic shallow foundations and earth-retaining walls.	5. Understand the different soil mechanics theories and the basic mechanic parameters applied to soils. 6. Calculate slab-on-grade, and deep foundations 7. Know the different pathologies associated to foundations due to construction. 8. Understand the principles of slope stability and its applicability for calculating dams and embankments.

	LOE4. **Understand** the actions in structures and the associated loads.	-	1. Design philosophies: Load and Resistance Factor Design (LRFD) and Allowable Strength Design (ASD). 2. Safety factors for materials and loads. 3. Concepts of stability and deformation. 4. Identify and determine static and pseudostatic loads (live loads, use, snow and wind) and apply them in structures.	1. Calculate and apply dynamic loads (earthquake, cyclic loads) 2. Principles and consequences of second order analysis due to applied loads. 3. Calculation and effects of thermal loads in structures. Particular case for fire in steel, concrete and wood materials (influence on loads and material properties).
	LOE5. **Understand** the behaviour of various structural components and systems, **identify** their main elements, and **develop** numerical models to simulate structural systems	-	1. Concepts of numerical solution techniques 2. Basic analysis techniques used to discretize continuous systems 3. Common methods for solving equations, both linear and non-linear. 4. Fundamentals of computer-based analysis: matrix equation solution techniques, least-square, numerical integration, finite difference, time integration. 5. Introduction to computational mechanics: static and dynamic finite element analysis; control volume in fluid flow. 6. Types and behaviour of main structural elements: beams, shells and solids. Principles for Finite Element formulation.	1. Fundamentals of Discrete Element Method. 2. Development of a complete Finite Element Model for a complex system with dynamic analysis. 3. Development of a complete CFD model for a complex system. 4. Parametric analyses of mechanical or geometric parameters of the model.
	LOE6. **Deal** with structural and materials related codes and specifications	-	1. Introduction to the structural Eurocodes system 2. Introduction to the EN standards for materials. 3. Specify the constraints and limitations imposed by the standard applied to the problem in question.	1. Propose design changes to optimize the structural design in agreements to the requirements of the structural Eurocodes. 2. Identify alternative and simplified methods for designing structural components meeting the standard requirements.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Integration Biosystems - Engineering	LOBE1. **Design** and **optimize** the main elements of structural systems, by applying the specifications contained in standards	-	1. Design structural components according to the corresponding design codes. 2. Apply design procedure for a specific design project 3. Identify and apply landscape impact criteria in the design using GIS based modelling	1. Optimise the design of structural components according to the corresponding design codes. 2. Apply the design optimisation procedure for a specific design project
	LOBE2. **Design** and **optimize** the micro-environment of the structural system	-	1. Understand the fundamentals of achieving the micro-environment requirements of various biosystems (as defined in LOB1) by proper design of the structural system and materials selection. 2. Design structural systems and materials adapted to	1. Analyze the influence of biological and environmental factors in the development of structural systems in order to improve the designs 2. Optimise the design of structural systems and materials selection to best meet the biological

			the biological micro-environment requirements	micro-environment requirements.
	LOBE3. **Design** the basic components of the structural system related to the waste management system	-	1. Specify the requirements of designed structural systems according to the type of the biosystems waste managed. 2. Identify and design the structural system elements related to alternative waste disposal management systems for various biosystems 3. Provide the basis to estimate waste disposal costs as affected by the structural design and materials	1. Provide the fundamentals for planning site investigations 2. Provide the basis for planning research in order to analyze the effect of new uses or treatments of residues on the structural design and the selection of materials.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Specialization: Water Resources Engineering

Knowledge for specialization "Water Resources Engineering": *the following tables contain the knowledge associated to the previously defined learning outcomes. Three different levels have been identified: Basic, Intermediate and Advanced. The knowledge associated to level 1 (Basic) is supposed to have been achieved through the core curriculum requirements.*

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Biosystems	LOB1. **Describe** the physicochemical and biological characteristics of living organisms and the micro-meteorological and micro-environmental parameters that affect the design parameters, simulation and operation of hydraulic systems such as irrigation and drainage systems.	-	1. Identify and describe the principles of the biosystems physiology and nutrition 2. Describe the main physiological functions of the different crops and other plants and biological systems (e.g. mushrooms, algae and other micro-organisms) in relation to micro-meteorological and micro-environmental parameters. 3. . Introduce the management principles and micro-environmental requirements in relation to protected crop and other biosystems production. 4. Identify and describe the principles for animal physiology and nutrition. 5. Describe the systems for animal husbandry and fish farming, identifying their main constraints and requirements especially with respect to waste management issues. 6. Identify and quantify the micro-environmental parameters to be met by various animal and fish production and housing systems.	1. Analyse and quantify the water needs of plants (crops, tress, vegetables, vines) and other bisosystems under various micro-meteorological and micro-environmental conditions 2. Analyse and quantify the sources of damages, quality and productivity losses and problems arisen with the management of crops, trees, or vegetables and other bisosystems and measures to overcome them. 3. Identify and describe the main components, inputs and organisation of protected crop production systems. 4. Identify and describe the main algae, and other microorganisms and biosystems production systems. 5. Types of animal production, components, inputs and organisation of enterprises for cattle, sheep, pigs, poultry, rabbits etc and waste management solutions.
	LOB2. **Understand** the relations between soil, water, contaminants or pollutants and living organisms for the design of hydraulic and hydrological systems.	-	1. Identify and describe the plant nutrients contained in soils. 2. Distinguish the major groups of microorganisms in soil and water, their interrelationships and responses to environmental changes, and their interaction with plants and livestock. 3. Describe the effects of fertilizers, cover crops, compost and other soil improvement supplements on plant productivity and soil quality. 4. Identify the plant principles of plant interactions with soil and water environments (nutrient and water uptake, transport or transpiration) and apply them in crop and environmental management. 5. Identify and classify the sources and types of soil and water contaminants and pollutants. 6. Describe the chemical and physical mechanisms for	1. Identify the soil fertility assays and procedures to prevent soil from erosion and loss of fertility. 2. Describe the requirements of water quality for plant and animal consumption. 3. Describe the techniques used to prevent plants from water stress. 4. Describe the interactions existing between contaminants and pollutants with biosystems. 5. Identify the main consequences of contaminants and pollutants in biosystems.

Component	Learning Outcome	Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
			the diffusion of contaminants in soils and water.	
	LOB3. **Recognize** the main environmental issues for selecting and using materials and creating sustainable hydraulic systems.	-	1. Identify and describe the main characteristics of environmental components (air, soil, water, cultural or socioeconomic) in relation to the impacts derived from activities related to materials selection and use in hydraulic systems. 2. Introduce the environmental impact assessment process and explain the main evaluation methods. 3. Introduce the life cycle assessment method of analysis of materials 4. Describe the fundamentals of the main impacts: noise, water, air pollution, biological, cultural and land-use and landscape.	1. Design an impact assessment technique 2. Calculate and assess pollutant loading on the environment 3. Evaluate the socioeconomic impact on the environment of hydraulic systems and construction materials used in them. 4. Design plans to minimize the impacts derived from hydraulic systems and construction materials and propose measures in order to correct the impacts generated.
	LOB4. **Know** the fundamentals of nonpoint source pollution and **understand** the basics of waste characteristics, biological reactions and the biological treatment alternatives	-	1. Identify the sources and categories of waste materials. 2. Identify the main causes of Nonpoint Source Pollution (NPS) and their transport mechanisms. 3. Description of the main characteristics associated to waste materials and pollutants derived from agricultural activities and that of other biosystems. 4. Describe the legal framework of environmental issues, including general laws and major legislation related to waste management. 5. Identify and describe the characteristics of the main waste management technology options, e.g., biological treatment, composting, recycling or energy recovery. 6. Introduction to the main physicochemical processes associated to the management of waste materials and the associated biological reactions.	1. Introduction to microbiology and biochemistry of liquid wastes. 2. Contamination of soil and water due to residues: processes, consequences and strategies to be adopted. 3. Design a waste management plan in the framework of a project or activity. 4. Evaluate and quantify the existence of NPS in the framework of an agricultural activity. 5. Describe the main practices and techniques used to minimize NPS in plant and animal management.
Component	**Learning Outcome**	**Knowledge for each learning outcome**		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
	LOE1. **Understand** the soil physics and soil mechanics and **know** their physical and hydraulic characteristics related to the design aspects of hydraulic and hydrological systems.	-	1. Distinguish the characteristics of granular materials behaviour: softening/hardening, permanent deformations, influence of path loads or load rates. 2. Know and understand the main hydraulic properties of soil: permeability, electrical conductivity, diffusivity, velocity gradient and dispersion. 3. Know the basic theory of soil mechanics. 4. Understand the principles of slope stability and its applicability for calculating dams and	1. Determine properties of soils through specific laboratory tests and site examination 2. Understand the different soil mechanics theories and the main parameters involved in each one. 3. Understand the practical significance of different soil behaviour for the problems of design foundation and construction of water facilities. 4. Calculate basic shallow foundations and earth-retaining walls.

			embankments.	
Engineering	LOE2. **Understand** the principles of water movement in porous media and conveyed elements.	-	1. Describe the principles of water flow and chemical transport in the vadose zone, including hydraulic properties, diffusive and convective transport. 2. Distinguish the principles used for the design of pipe systems and open channels. 3. Know and apply energy and momentum principles to fluid flow situations, and be able to solve problems for forces in static and moving fluids. This includes the different flow regimes (laminar and turbulent), the concepts of energy loss in pipe systems and open channels. 4. Know the principles that govern the geomorphology of estuaries and deltas, with special attention to sediment deposition and erosion phenomena.	1. Understand and make calculations related to drainage of saturated soils. 2. Apply standard energy approaches and formulas, and be able to solve for and design pressure pipe systems 3. Apply standard approaches and formulas, and be able to solve for and design open-channel flow systems
	LOE3. **Know** and **distinguish** the mechanical and physicochemical characteristics of conventional materials used in hydraulic systems.	-	1. Basic principles of constitutive equations for solids: classical elasticity, plasticity. 2. Fluids: idealized fluids, Newtonian fluids, laminar and turbulent fluid. 3. Stress-strain diagrams of wood, steel, concrete, polymers and other structural materials. 4. Basic mechanical properties and behaviour of wood, steel and concrete.	1. Mechanics of solids: Viscoelasticity, hypoelasticity, and advanced concepts of plastiticity (hypoplasticity, hardening and softening, deformation theory).
	LOE4. **Know** the design and technical characteristics of the different irrigation systems, and the related equipment such as pumps, valves, or flow measuring devices.	-	1. Distinguish the design characteristics and components of the main irrigation systems: surface, sprinkler or drip-irrigation. 2. Apply the principles of irrigation systems in the design of networks. 3. Understand the basic elements of pump and turbine flow, and be able to analyze and select the pump needed for pressurizing situations. 4. Understand the principles used to measure flow in conveyed pipes and open channels. 5. Understand how to collect and interpret information about the earth´s surface through non contact methods.	1. Distinguish the interactions existing between irrigation and drainage. 2. Apply mathematical models for the management of vast irrigation areas. 3. Know the fundamentals of measurement systems, including signal conditioning, systems response, and data acquisition or interfacing microcomputers. 4. Know the electrotechnics principles used in pumps, valves or electrical equipment used in hydraulic systems.
	LOE5. **Distinguish** the characteristics and design principles related to water facilities.	-	1. Know the constrains and studies required to design water facilities, including climatologic data, hydrological data, soil properties, land uses and morphology, water requirements. 2. Distinguish the design requirements of usual water facilities such as dams, spillways, pipe networks, sewer systems, ground-water dams, or canals. 3. Apply the analytical and hydraulic design	1. Know fundamentals of statistical treatment of spatial data applied to hydrologic problems. 2. Distinguish the principles used in the analysis of spatial processes. 3. Know the main groundwater exploration techniques and apply them to assess water quality.

			approaches to common water facilities such as culverts, spillways, pipe networks, sewer systems, canals, and scour and sediment transport.	
	LOE6. **Develop** numerical models to **simulate** hydraulic processes and hydrological systems.	-	1. Know the principles and concepts associated to surface hydrology: hydrographs, precipitation and runoff 2. Know the fundamentals for developing models to simulate groundwater flow and transport and calibrating them. 3. Principles for modelling watersheds related to the design of water facilities: damns, spillways, culverts or ditches. 4. Know and use empirical stream flow models for simulating processes in surface hydrology.	1. Modelling of water flow in the vadose zone by applying numerical methods, such as finite element or finite differences, in unsaturated soils 2. Apply the principles of surface hydrology for the calculation of peak flows in storms or calculation of reservoir storage. 3. Apply watershed models to analyse the influence of irrigation in aquifers, draw-wells or the groundwater transport of contaminants and pollutants.
	LOE7. **Identify** the main elements of structural and geotechnical systems used to **design** water facilities and **deal** with structural, materials related codes and specifications	-	1. Concepts of numerical solution techniques 2. Introduction to the structural Eurocode system 3. Specify the constraints and limitations imposed by the standard applied to the problem in question. 4. Fundamentals of computer-based analysis: matrix equation solution techniques, least-square, numerical integration, finite difference, time integration, finite element analysis, control volume in fluid flow. 5. Types and behaviour of main structural elements: beams, shells and solids. Principles for Finite Element formulation. 6. Basic analysis techniques used to discretize continuous systems	1. Fundamentals of Discrete Element Method. 2. Development of a complete Finite Element Model for a complex system with dynamic analysis. 4. Development of a complete CFD model for a complex system. 5. Propose design changes to optimize the structural design in agreements to the requirements of the structural Eurocodes.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements

Component	Learning Outcome	Knowledge for each learning outcome		
		Level 1*	Level 2 (Intermediate)	Level 3 (Advanced)
Integration Biosystems - Engineering	LOBE1. **Apply** geographical information system techniques and numerical modeling to **assess** environmental risks associated to hydraulic works and diffusion of contaminants and pollution.	-	1. Know the fundamentals of Geographical Information Systems, including spatial database structures, scripting, data models and errors. 2. Conduct in depth investigation of advanced topics in remote sensing applications, measurements and theory. 3. Develop basic GIS models to study runoff, erosion	1. Apply GIS and numerical models to assess risks associated to failures in water facilities, e.g., damns, main pipes or ground-water damns. 2. Apply GIS and numerical models to study groundwater flow and contaminant transport.

			or contaminant transport.	
	LOBE2. **Understand** the principles of water and environmental laws and **apply** them for the planning, design and management of water resources.	-	1. Understand the principles and issues contained in water laws. 2. Describe the types of water rights, groundwater rights and management and protection of instream uses. 3. Describe maximum limits for pollutants and contaminants in water. 4. Know the principles used for planning irrigation and controlling irrigation operation in vast areas.	1. Apply GIS models for planning water resources in a vast area. 2. Apply mathematical programming techniques to solve specific items of water resources planning, such as water allocation, capacity expansion or reservoir operation. 3. Develop plans to guarantee water quality.
	LOBE3. **Design** elements and systems to prevent soil erosion and to restore stream and riparian areas.	-	1. Know theoretical and empirical foundations of sediment production on hill slopes using computer models and field experiments. 2. Distinguish the fundamentals and main techniques used to prevent erosion caused by precipitation runoff 3. Know the influence of crop and irrigation management practices in soil erosion.	1. Develop restoration strategies of eroded riparian areas. 2. Development of hillslope and riparian restoration concepts. 3. Apply geomorphic principles to coastal management.
	LOBE4. **Design** the basic components of the hydraulic system related to the waste management system	-	1. Specify the requirements of designed hydraulic systems according to the type of the biosystems waste managed. 2. Identify and design the elements related to alternative waste disposal management systems for various biosystems 4. Provide the basis to estimate waste disposal costs as affected by the hydraulic design and materials used	1. Provide the fundamentals for planning site investigations 2. Provide the basis for planning research in order to analyze the effect of new uses or treatments of residues on the structural components of hydraulic systems.

* Knowledge corresponding to Level 1 (Basic) has been achieved through the core curriculum requirements