Allegato **B2**
A.A. 2024-25
Quadro degli obiettivi formativi specifici e delle propedeuticità
Corso di Laurea Magistrale in Industrial Engineering for Sustainable Manufacturing - INTERCLASSE LM 31/LM-33
DM 270/2004, art. 12, comma 2, lettera b

N.	Insegnamento/Course	Settore SSD	Obiettivi formativi specifici/ Specific Educational Objectives	Propedeuticità obbligatorie/ Mandatory prerequisites
1	**Mechatronic Systems**	**ING IND 13**	Study and design of mechatronic systems employed in the industrial environment: kinematic, static and dynamic modelling of mechanical systems, mechanical structure and components, sensors, actuators, data acquisition and control. Implementation of digital twins of mechatronic systems and data acquisition on real mechatronic systems (laboratory).	
2	**Robotics**	**ING IND 13**	Industrial robots, collaborative robots (cobots) and mobile robots: typologies, modelling and control. Applications of robots, cobots and mobile robots in the industrial environment, with a focus on energy saving and sustainability. Implementation of trajectory planning projects in a simulated environment and on real robots, cobots and mobile robots (laboratory).	
3	**Sustainable Manufacturing**	**ING IND 16**	Conceptual basis and environmental analysis of production processes: metal casting, forming and shaping, assembly and joining, machining, finishing, electro-chemical processes. Guidelines for the performance analysis of a manufacturing system. Technologies enabling green manufacturing. Demanufacturing systems. Numerical examples and laboratory demonstrations. Analysis and evaluation of industrial application cases.	

4	**Smart Manufacturing and Process Digitalization**	**ING IND 16**	Innovation of manufacturing processes based on Industry 4.0 principles: Computer-Integrated Manufacturing, Digital Information Technology, networked sensors for data collection and cyber-security, intelligent industrial automation, Multi-scale dynamic modelling and simulation of productive processes, application of machine learning and digital twins in production, advanced industrial robotic applications. Numerical examples and laboratory demonstrations. Analysis and evaluation of industrial application cases	
5	**Green Machine Design**	**ING IND 14**	The module introduces the fundamentals of solid mechanics and concepts of machine design with particular attention to sustainability matters. More in detail, the topics of the module are: the theory of elasticity; the elementary beam theory; the mechanics of notches and fatigue; Design for sustainability: optimal structural design & material selection; Examples of durability analysis of mechanical components (Lab. Activity).	
6	**Digital Modelling for Structural Analysis and Design**	**ING IND 14**	The module provides the future engineer with a solid background regarding numerical approaches for structural analysis of mechanical components and structures, with a focus on the minimisation of primary resources. The key contents of the course are: Fundamentals of structure matrix analysis; Finite element method (FEM); Topology optimisation for green design; Practical use of numerical techniques. Examples of virtual prototyping for durability analysis of machine elements with commercial computer codes (Lab. Activity).	
7	**Cleaner Production Systems**	**ING IND 17**	Lectures take up environmental issues of industrial production systems and train students in systems thinking and life cycle thinking approaches for the	

			assessment and optimization of resource efficiency in industrial pr10ocesses. The course draws on real life case studies from carbon intensive industries such as metalworking and steelmaking, pulp&paper, construction materials, and the food industry. More in detail, the topics include: - Definition and calculation of resource efficiency indicators for production systems (energy footprint, blue water footprint, carbon footprint, material footprint e land footprint); - Characterization of hotspots of carbon emissions (e.g. furnaces, process heating and cooling systems, as well as internal and external logistics systems); - Technology options for the transition to low carbon, circular industrial systems: use of renewable energy sources, energy recovery, industrial symbiosis, revamping and life extension.	
8	**Circular Economy**	**ING IND 35**	Linear economy and circular economy: definitions and principles. Growth and sustainability. Biological cycle, energy flows and industrial ecology. Economic theory and environmental issues. Policies and strategies in a circular economy perspective. Value creation through reducing, reusing and recycling. Agenda 2030.	
9	**Project Management**	**ING IND 35**	Project target and scope. Selecting, planning and managing a project. Time and cost management. Project risk management. Project control and quality management. Stakeholder management. Project management methodologies, techniques, and tools. Project certifications.	
10	**Sustainable Supply Chain Management**	**ING IND35**	Fundamentals of supply chain design and management. Sustainability and product design, procurement, production, packaging, warehousing, transport, delivery. Reverse logistics and	

			recycling. Life Cycle Assessment and certifications.	
11	**Fundamentals of Control Systems and Optimal Control**	**ING INF 04**	The course will provide a reasoned overview of the most important notions and results concerning system dynamics, control theory and optimal control. Lectures will be devoted both to the theoretical results and to their implementation.	
12	**Advanced Technologies for Green Manufacturing**	**ING IND 16**	New technologies, advanced methodologies and best practices for green innovation of production systems. Additive manufacturing: general principles and applications such as energy production, mobility, aerospace and biomedical; innovative materials and processes; process monitoring and control. Remanufacturing and hybrid manufacturing. Environmental advances in casting, forming, machining and joining processes. Zero-defect manufacturing: advanced techniques for inspection and quality, statistical process control, design of experiments. Numerical examples and laboratory demonstrations. Analysis and evaluation of industrial application cases.	
13	**Fundamentals of Metallurgy**	**ING IND 21**	Fundamentals of physical metallurgy: crystallography, reinforcing mechanisms for metals, phase diagrams (Fe-C diagram). Fundamentals of solidification and diffusion: thermodynamics and kinetics. The shrinkage and segregations. Practical examples of solidification: solidification in ingot. Massive and surface heat treatments: solid state transformations. Thermodynamics and kinetics of solid reactions. Steel heat treatments: annealing, quenching, tempering and aging. Surface treatments: surface hardening, carburizing, nitriding, boriding and anti-wear coatings. Designation of steel, Characterization and testing of	

			metals. Introduction to non-ferrous metals and alloys.	
14	**Environmentally Friendly Plants for Steelmaking and Metallurgy**	**ING IND 21**	Introduction to physics and chemistry in steel/metal making, Fe-extractive metallurgy. Production of steel from iron ore: blast furnace process, steel treatment of iron, conversion process of iron,. Direct Reduction of iron ore. Energy and environmental aspects of the steel making processes from iron ore. Production of steel from scrap: electric furnace metallurgy, Secondary metallurgy, Secondary metallurgy. Energy and environmental aspects of the steel making processes from scrap. The production of stainless steel. Static and continuous casting. Remelting processes of steel. Introduction to plastic deformation of metals: rolling and forging. Energy and environmental aspects of plastic deformation processes.	
15	**Materials for Sustainable Industrial Manufacturing Processes**	**ING IND 22**	A detailed knowledge of the manufacturing processes, which lead to the fabrication of technological products, and the correct selection at the design stage of the best-suited materials to the specific applications, can be key elements for a more sustainable industrial production. The course, after a review of some specific basics of materials science and technology, aims to provide new methodologies to approach the materials selection and their design, combining in operation performances and cost containment with the requirement to minimize the environmental impact of product manufacturing, use, and disposal.	
16	**Industrial eco-efficiency**	**ING IND 17**	The course aims to provide eco-efficiency assessment tools for analysing the environmental impact of industrial operations, logistics systems and service facilities. Technology system and alternative sources integrations in service facilities and logistics are	

			analysed to achieve sustainability goals. Tools for planning and evaluating eco-efficiency strategies at the industry system level and under conditions of uncertainty are also studied (DSS, MCDM, MCDA). Real case studies are examined and discussed	
17	**Sustainable Energy Conversion Systems**	**ING IND 9**	The course focuses on innovative technologies for energy conversion, providing students with knowledge of the configurations and the energy performance of thermal power plants of various sizes (from distributed micro-generation to large scale), driven by different fuels (fossil fuels, biofuels, and e-fuels) or by external heat sources (such as waste heat, geothermal heat, solar heat).Technology options (e.g. flue gas treatment, carbon capture and storage) and operations modes (e.g. polygeneration) aimed at minimizing the environmental impact of power generation will be covered. Student will gain insights into performance trade-offs, as well as into the challenges and opportunities of integrating advanced power plants within smart energy grids.	
18	**Decarbonization of Processing Industry**	**ING IND 27**	Analyze the most relevant low-carbon technologies currently being proposed in the framework of policies aimed at reducing carbon emissions and mitigating climate changes. Principles and applications of CO2 capture, separation, sequestration technologies (Carbon Capture and Storage - CCS, geological storage, exhaust gas separation, Direct Air Capture – DAC). CO2 valorization technologies to added-value products such as fuels/e-fuels, polymers, chemicals. Reminders of core concepts of catalysis, ab- and ad-sorption.. Examples of thermocatalytic CO2 conversion (Sabatier reaction, Reverse Water Gas Shift Reaction – RWGS, Dry	

			Reforming of Methane – DRM). Examples of carbon intensive sectors (steel, chemical, cement, power) and strategies for their decarbonization. Laboratory practice in a few selected examples will be carried out.	
19	**Hydrogen Technologies**	**ING IND 27**	The course aims to describe the properties of hydrogen as an energy carrier and its role in the energy transition and the circular economy both as a means of decarbonisation and energy storage from renewable sources. It will be divided into the following topics: Hydrogen identity card: Hydrogen chemical and physical properties, abundance, reactivity. Safety and standards. Technologies for the production (thermocatalysis, electrocatalysis, photocatalysis) transport and storage (compression, liquefaction, hydrides) of hydrogen. Uses of hydrogen in energy and transport sectors: H2 combustion engine, and fuel cells. Applications in heavy transport (ships, trucks, trains). Fundamentals and applications of fuel cells with lab activity to consolidate theoretical aspects. H2 versus batteries in the circular economy (energy storage chains from renewable sources, decarbonisation processes).	