SUSTAINABLE ENGINEERING, MINOR

Program Overview

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Learning Outcomes

- Systems Thinking: The engineering classes within the minor comprehensively cover core outcomes across various proficiency levels. Foundational concepts, falling within the "remember and understand" level, are embedded throughout the curriculum. Students explore the interconnectedness among material mining, processing, and recycling (349, 413), as well as delve into stocks-and-flows modeling for regional and global supply chains (335). Additionally, they examine the components and technologies of manufacturing systems (366) in relation to environmental and ecosystem impacts, along with socio-political and economic factors.
  Moving beyond foundational knowledge, classes delve into medium proficiency levels, focusing on analysis and application. Material selection considerations extend beyond emissions and embodied energy to encompass local environmental and socio-political factors (349, 335), shedding light on the local challenges stemming from global solutions. Students explore real manufacturing systems and sustainable solutions from economic and environmental perspectives (366), while also delving into social entrepreneurship to understand how entrepreneurs address social and environmental issues (301). Environmental justice principles are examined through case studies involving marginalized communities worldwide (387).
- Environmental Literacy: Foundational proficiency levels are addressed across several courses within the minor program, encompassing core outcomes essential for building a solid understanding. These include: Exploring the influence of engineering decisions on processes, sourcing, and shipping, and understanding their local and aggregated impacts (335), investigating the limitations of circular economy principles when applied to ecosystem cycles, such as the nitrogen and phosphorus cycles (349), recognizing opportunities to mitigate environmental pollution for social, economic, and environmental benefits, while comprehending concepts like whole lifecycle analysis, cradle-to-gate lifecycle assessment, and closed-loop systems thinking in the context of manufactured products and systems (366), identifying the role of energy, its generation, usage, and environmental impacts, particularly within manufacturing activities and products (366), exploring political innovations at different levels of governance to address climate change (388), and fostering creative solutions through business and social entrepreneurship aligned with the UN Global Goals (301).
  At the medium proficiency level, students engage in: Analyzing embodied energy and emission data associated with material processing and end-of-life considerations (349, 335), examining manufacturing data pertaining to climate change, energy and water use, material depletion, pollution, air quality, waste management, recycling technologies, and chemical toxicity (366), studying case studies on climate change, air quality, and water use, with a focus on local impacts and governance issues (387), conducting in-depth analyses of environmental problems and solutions from various perspectives, such as population growth, climate change, ozone depletion, and fisheries (202).
  Advanced outcomes are achieved through: Developing an understanding of energy and material sources, energy conversion and storage, and thermodynamic energy cycles (349), evaluating tradeoffs in processing choices, such as utilizing alloy chemistry versus heat treatment, with considerations for primary energy costs and recycling feasibility (335), applying environmental justice principles to laws and policies (387), exploring international and global climate change governance, examining relevant laws, ethics, and policies, and considering the normative dimensions of these mechanisms (388).
- Responsible Business and Economy: Foundational concepts, such as business models and their contribution to organizational sustainability, are introduced in course 301. Medium proficiency levels encompass: Direct engagement with companies annually, exploring topics like sourcing, risk management, and corporate recycling commitments, and their impact on decision-making (335), examination of various business models and structures through class lectures and guest speakers, along with discussions on forms of capital related to entrepreneurship and individual team member contributions (301), exploration of circular economy principles and their implications for material and process selection (349), exploration of the ethics, economics, and policy implications of current global environmental problems, considering who, or what, they value and why (202).

  At the high proficiency level, students delve into economic metrics such as net present value, return on investment, and payback analysis, enabling them to conduct near- and long-term cost analyses and informed decision-making (366). Advanced outcomes involve: Introduction to sustainable material and energy usage, as well as end-of-life management technologies for industrial products (366, 349), familiarization with ISO 14000, ISO 14001, ISO 14002 for lifecycle assessment, and ISO 50001 for energy management (366), exploration of alternative business models through lectures and guest speakers (301), consideration of vendor selection and associated supply chain requirements, including case studies and industry-led initiatives such as Solutions for Hope (335).
- Social Responsibility: Foundational proficiency levels are covered through: Introduction to the UN Sustainable Development Goals (SDGs) in courses 301, 349, 387, and 388, with a focus on applying them in group projects, particularly in social entrepreneurship initiatives aimed at achieving specific SDGs (301). Additionally, course 387 emphasizes environmental justice as a core aspect of sustainability. Integration of lectures, class activities, and external projects aimed at fostering critical thinking and encouraging students to reflect on their environmental impact and personal choices (349, 413, 202), exploration of legislative processes and their outcomes using examples such as the Dodd Frank law and the Conflict Minerals clause, traced over a decade through mediums like films (e.g., "When Elephants Fight"), NGO reports, and business press (335), and examination of the environmental impacts of manufacturing and manufactured products across their life cycles, including effects on both the environment and workers in manufacturing plants (366). Advanced outcomes include: Study of material and energy flows at various scales, ranging from local to global, through methods and case studies (349, 366), explicit consideration of competing uses for water, such as process water, agriculture, and residential use, in data analysis and assignments (349, 335), discussion of the social and cultural implications of sustainability choices, including topics like climate justice (387, 388).
- Environmental Impact Assessment: Foundational concepts covered in the minor include: Eco-audits (349), which involve assessing the

environmental performance of processes or products, life cycle impact assessment methods and tools (366), discussed within the context of life cycle assessment (LCA), sourcing risks, and business decision-making (335). At the medium-proficiency level, students learn to: calculate embodied energies, carbon footprints, water usage, and other environmental metrics for their designs (349), interpret life cycle impact results related to energy, climate, water/air pollution, and land use (335), explore the social implications of global issues such as food security, agriculture, energy, consumption, and urban development, emphasizing the connections between personal decisions and environmental impact (202). Advanced outcomes are achieved through: Using Iceland as a case study to analyze rising absolute emissions of greenhouse gases (GHGs) alongside relative reductions, while considering the broader implications for energy and water usage (335), examining the Jevons paradox and its potential generalization (335), challenging students to evaluate human responses to improvements and the allocation of saved resources (349), and introducing impact reduction techniques and computational methods for both relative and absolute impact reduction (366).

- Materials Selection: All core topics related to materials selection are comprehensively addressed across courses 349, 335, 413 and 366. In course 335, practical case studies are presented to illustrate the implementation of different materials selection strategies. Additionally, term projects and take-home exam questions in course 349 encourage students to analyze and compare various options in materials selection based on different objectives and constraints. The concept of embodied energy and comparisons among different materials throughout their manufacturing and supply chain are explicitly discussed in both courses 349 and 366. Furthermore, current environmental research literature and identified gaps are introduced to students in course 366. Advanced outcomes include instruction on tools such as EduPack in course 349, as well as other impactful tools like GaBi, Eco-Indicator, and TRACI in course 366 for potential environmental impact assessments throughout the entire life cycle. Real-industrial data from utility bills and sustainability reports of Fortune 500 companies, along with published literature from leading researchers in sustainable manufacturing, are incorporated into course 366. Similarly, utility bills from the university are utilized in course 349. In the context of life cycle assessment (LCA) case studies and tools, students are taught to consider the implications of material consumption impacts at various scales in course 366. Moreover, the role of technological solutions, regulation, and socio-behavioral factors are explored in courses 349 and 335. Research gaps pertaining to material options, alternative manufacturing technologies, and end-of-life management strategies are explored in-depth. Sustainability is approached as a systemic concept, emphasizing interconnectedness and holistic understanding. In-class instruction includes the calculation of embodied energy for materials, enhancing students' understanding of energy consumption throughout the life cycle. Furthermore, the toxicity and environmental impacts of chemicals on both ecosystems and human health are thoroughly covered (349, 366).
- Design: Design fundamentals are instilled through discussions revolving around materials cost, availability, and their environmental impacts as essential design constraints (335). Comparative analyses are presented in 349 to enhance understanding. Students are equipped with analysis methods, tools, and case studies from published literature to foster sustainable design practices for products and manufacturing systems, aiming to minimize adverse environmental and social effects. Concepts such as design for disassembly, energy efficiency, and recycling are explored, with a focus on industrial applications. Incorporating life cycle cost analysis and life cycle assessment, alongside considerations of temporal discounting, provides students with long-term approaches to address environmental challenges (366). Foundational concepts of sustainability and resilience are taught to help students identify opportunities for mitigating climate change and other global environmental issues (202). Advanced proficiency is attained through the presentation and discussion of human-centered design principles, emphasizing the importance of addressing desirability, technical feasibility, and economic viability in business decision-making (349, 335). Additionally, the 366 course delves into: (i) design methodologies integrating whole life-cycle and systems thinking using tools like life cycle assessment, material flow analysis, and energy flow analysis, (ii) a multidisciplinary approach spanning mechanical, materials, environmental, and public health disciplines to tackle industrial sustainability challenges, (iii) systems dynamics concepts encompassing feedback loops, resilience, adaptation, and more, and (iv) sustainability issues and case studies focusing on enhancing emerging manufacturing technologies like additive manufacturing and nano-manufacturing.
- Critical Thinking: Fundamental critical thinking underpins the curriculum in courses 349 and 335. In course 335, students engage in two term papers: one delving into a specific material, exploring its sources, uses, processing requirements, current consumption trends, and future prospects; the other focuses on an engineering device, examining various strategies for its implementation and assessing relative costs. Course 349 tackles material supply, processing, and manufacturing challenges associated with alternative energy conversion and storage systems through comprehensive term projects that consider potential unintended consequences and end-of-life implications. Course 366 provides a comprehensive examination of the sustainability issues surrounding manufactured products and manufacturing technologies, encompassing economic, environmental, and social dimensions. Through a class project of their choosing, students demonstrate their understanding of sustainability analysis methods, values, technologies, and innovations. Additionally, students are educated on the individual roles of people, products, and technologies in sustainability, along with the pertinent information required to assess the sustainability performance of products they produce, purchase, consume, and dispose of. In ENTP 301, students heavily focus on identifying, defining, and validating problems related to creating entrepreneurial ventures. Course 387 delves into ethical consumption and sustainability labels, while course 388 emphasizes normative political thought on climate change and the ethical dimensions of climate change governance, prompting critical self-reflection through a normative and ethical lens. Course 202 serves as a foundational course for undergraduates, fostering critical thinking, written and oral communication skills, information literacy, quantitative reasoning, engagement with ethical issues and diversity, and exposure to experimental and theoretical approaches in various fields. Advanced proficiency entails the integration of diverse sources such as books, scientific articles, business analyses, and current news updates in courses 355 and 349. Students critically evaluate the reliability, accuracy, and trustworthiness of data and news sources in course 349, while also exploring life cycle impact assessment tools in course 366. Furthermore, students in ENTP 301 conduct qualitative and quantitative research to validate identified problems as potential business opportunities by interviewing a social entrepreneur that is working on a social or environmental challenge and building their own entrepreneurial venture where they must not only validate problems,

but also brainstorm and validate solutions while collaborating with their teammates. In course 388, they explore the implications of political inaction on climate change governance and empower indigenous self-governance and local governance initiatives.

- Communication and teamwork: In the minor, most classes offer ample opportunities for students to enhance their communication and teamwork skills. In course 335, students engage in individual presentations, providing a platform to showcase their understanding of the subject matter. Meanwhile, in course 349, group term projects entail two presentations per group. The second presentation, more advanced, integrates feedback from instructors and peers following the initial mid-semester presentation, fostering iterative improvement and collaborative learning. In course 366, students manage individual projects, honing their ability to balance schedules and allocate time and resources effectively to meet presentation and report deadlines. Course 301 emphasizes interdisciplinary teamwork through two team projects, allowing all participants to develop leadership capabilities as they collaborate on startup ideas. Final presentations serve as pitches for these ventures, providing students with practical experience in project management and presentation skills. In course 202, interactive "What Would You Do" web-based activities facilitate understanding of decision-making processes and their environmental implications. Through role-playing scenarios, students explore various choices and their consequences in a risk-free online environment, fostering collaboration and critical thinking. Their decisions influence subsequent outcomes, reinforcing the connection between choices and their impacts on the environment. Achieving an advanced level of proficiency involves actively developing and utilizing interpersonal skills throughout the semester. Interactions with teammates and guest speakers in courses 349 and 301 provide opportunities for students to refine their communication abilities and collaborative capacities, enhancing their overall learning experience.

Undergraduate Policies

For undergraduate policies and procedures, please review the Undergraduate Academics section of the General Bulletin.

Program Requirements

The Sustainable Engineering minor is accessible to all engineering students. It encompasses courses from different engineering departments and programs such as Materials Science and Engineering (EMSE), Mechanical and Aerospace Engineering (EMAE), Macromolecular Science and Engineering (EMAC), and Applied Data Sciences (DSCI), as well as different departments from other units such as Earth, Environmental and Planetary Sciences (EEPS) and Political Science (POSC) from College of Arts and Science, and Entrepreneurship (ENTP) from the Weatherhead School of Management.

Code	Title	Credit Hours
Foundational Courses		
EMSE 349	Role of Materials in Energy and Sustainability	3
EMAE 366	Sustainable Manufacturing	3
ENTP 301	Entrepreneurial Strategy	3
Technical Elective		
Choose one of the following:		*3*
EMSE 335	Strategic Metals and Materials for the 21st Century	
EMAC 413	Polymers Plus Green Chemistry and Engineering	
DSCI 351	Exploratory Data Science	
Non-Technical Elective		
Choose one of the following:		*3*
EEPS 202	Global Environmental Problems	
POSC 387	Environmental Justice	
POSC 388	Global Politics of the Climate Crisis	
Total Credit Hours		**15**