ENVIHEI

Title of the PBL challenge:
Elective Technical Courses Chemical Engineering

Name of the responsible lecturer

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University / Department / Degree program

Silesian University of Technology / Department of Metallurgy and Recycling / Bachelor's Degree in Management and Production Engineering

Course / Subject in which implemented

4th Course / Projects in Elective Technical Courses Chemical Engineering

Implementation period (dates)

March 1, 2026 – April 30, 2026

Total duration (weeks/hours)

8 weeks / 30 hours

Number of students involved

15 students

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1. Project Design

1.1 Brief description of the project and the challenge proposed

The course is structured as a Project-Based Learning (PBL) experience for students of Management and Production Engineering. Its main objective is to design and manufacture a functional product using waste materials, while applying the principles of sustainable development and the circular economy.

Throughout the course, students engage in the complete product development process, from identifying and analysing available waste materials and resources, through generating and developing a product concept, to manufacturing and evaluating the functionality and performance of the final product. In parallel, students assess the environmental impact of their proposed solutions, the efficiency of resource utilisation, and the possibilities for material recovery, reuse, and application of circular economy principles. The project promotes innovative thinking and the practical application of sustainable production principles in a real-world engineering context.

1.2 Expected learning outcomes (academic and transversal competences)

Upon successful completion of the course, students will have acquired the following competences:

Academic Competences

- Apply principles of sustainable development and circular economy to the design and manufacturing of engineering solutions.
- Identify, analyse, and evaluate the potential and usability of waste materials for reuse in product development and engineering applications.
- Design, prototype, and manufacture functional products using recycled, recovered, or reused materials.

- Apply fundamental engineering, manufacturing, and prototyping techniques throughout the product development and implementation process.
- Evaluate the environmental impact, resource efficiency, and overall sustainability of proposed solutions.
- Prepare professional technical documentation and clearly present project outcomes and results.

Transversal Competences

- Work effectively and collaboratively in multidisciplinary teams to achieve common project goals.
- Apply critical thinking and problem-solving skills to address real-world engineering challenges and project situations.
- Plan, organise, and manage project activities, tasks, resources, and deadlines effectively.
- Communicate technical concepts, design decisions, and project results clearly and professionally, both orally and in writing.
- Demonstrate creativity, innovation, and initiative in the development of sustainable products and solutions.
- Make informed and responsible decisions, taking into account the environmental, economic, and social impacts of proposed solutions

1.3 Targeted sustainability competences

The course contributes to the development of sustainability-related competences and aligns with several United Nations Sustainable Development Goals (SDGs), including:

- **SDG 4 – Quality Education**, by fostering practical, interdisciplinary, and problem-oriented learning through project-based activities focused on sustainability challenges.

- **SDG 9 – Industry, Innovation and Infrastructure**, by promoting innovative product design and sustainable manufacturing practices.
- **SDG 11 – Sustainable Cities and Communities**, by encouraging efficient resource use and environmentally responsible production approaches.
- **SDG 12 – Responsible Consumption and Production**, through the application of circular economy principles, including waste reduction, reuse, recycling, and material recovery.
- **SDG 13 – Climate Action**, by increasing awareness of the environmental impacts of production activities and supporting the development of low-impact and sustainable solutions.

Through the course activities, students will strengthen their competences in:

- Sustainable product design and the implementation of circular economy principles.
- Efficient and responsible resource and waste management.
- Environmental impact assessment and sustainability evaluation.
- Systems thinking and evidence-based decision-making for sustainable development.
- Teamwork, communication, and collaborative problem-solving in sustainability-oriented projects.
- Creativity, innovation, and entrepreneurship in the development of environmentally responsible products and solutions.

1.4 Sustainability approach and how it is integrated into the project

Sustainability constitutes a core dimension of the course and is integrated throughout all stages of the project. The learning activities are grounded in the principles of sustainable development and the circular economy, with particular

emphasis on resource conservation, waste reduction, responsible production, and extending material life cycles through innovative reuse strategies.

Students are required to design, develop, and manufacture a functional product using waste, reclaimed, or recycled materials. Throughout the project, they identify and analyse the origin, characteristics, and potential applications of materials that would otherwise be discarded. The selection of materials and manufacturing methods takes into account their environmental impact, resource efficiency, durability, and potential for future reuse or recycling.

Sustainability considerations are incorporated into both the design and decision-making processes and the final evaluation of the projects. Students assess their solutions not only in terms of technical performance, functionality, aesthetics, and user value, but also with regard to ecological responsibility, material utilisation efficiency, product durability, and opportunities for future reuse, repair, or recycling.

By addressing real-world sustainability challenges, the project enables students to develop systems-thinking skills and gain practical experience in applying sustainable engineering principles. It promotes creativity, innovation, teamwork, and responsible decision-making, while fostering awareness of responsible consumption and production patterns and reinforcing the principles of the circular economy and the United Nations Sustainable Development Goals (SDGs).

1.5 Methodologies and tools used (PBL structure, facilitation techniques, etc.)

The course is delivered through a Project-Based Learning (PBL) methodology, in which students work collaboratively in teams to address an open-ended, real-

world sustainability challenge. Learning is organised around a structured and iterative product development process that integrates problem analysis, creative design, prototype development, testing, evaluation, and critical reflection.

Project Workflow

The project progresses through several interconnected and iterative stages:

- Problem definition and resource assessment: students investigate available waste materials, analyse their origin and properties, and identify potential opportunities for their effective reuse in product development.
- Ideation and concept development: teams generate alternative solutions through brainstorming and design activities, evaluate different options, and develop preliminary product concepts.
- Design and prototyping: selected concepts are developed into functional prototypes using reclaimed or recycled materials and appropriate engineering and manufacturing techniques.
- Testing, evaluation, and iteration: prototypes are assessed against functional, technical, and sustainability criteria, and the results are used to refine and optimise the proposed solutions.
- Final presentation and reflection: teams present their final products, provide the corresponding technical documentation, assess the sustainability and environmental performance of their solutions, and reflect on the project process and outcomes.

Teaching and Facilitation Approach

The instructor acts primarily as a facilitator and project mentor rather than as a traditional lecturer, providing guidance and support throughout the different stages of the project. The learning process is supported through:

- Regular project consultations and milestone reviews.
- Collaborative workshops focused on design, sustainability, and problem-solving.
- Peer-learning activities, feedback sessions, and constructive collaborative critique.
- Coaching to address technical, organisational, and design-related challenges;
- Reflective learning activities that encourage continuous improvement and critical consideration of project decisions.

Methods and Tools

Students apply a range of methods and tools commonly used in sustainable product development, including:

- Human-centered and design thinking approaches, including empathising, defining, ideating, prototyping, and testing.
- Basic engineering design principles and rapid prototyping techniques.
- Materials analysis and selection frameworks to assess waste and recycled resources according to their properties, suitability, and sustainability.
- Visual communication tools, including sketches, technical drawings, diagrams, and CAD or digital modelling where appropriate;
- Project management tools for task planning, timeline development, allocation of team roles and responsibilities, and monitoring of project progress.
- Sustainability assessment approaches based on life-cycle thinking, circularity principles, and consideration of resource efficiency.
- Reporting and presentation tools for documenting project development, communicating results, and presenting the final solution.

Overall, this methodology promotes active learning, interdisciplinary collaboration, problem-solving, and the practical application of sustainability principles, while providing students with hands-on experience in designing and developing innovative products from recovered materials.

1.6 Organization of the project (group formation, timeline, milestones)

The project is organised as a team-based activity within a Project-Based Learning (PBL) framework. Students work in small interdisciplinary groups, allowing them to integrate diverse perspectives and competencies in engineering, design, sustainability, project management, and communication.

Group Formation and Roles

- Students are organised into teams of 3–5 members.
- Teams are formed to ensure a balanced combination of technical, creative, organisational, and communication skills.
- At the beginning of the project, team members allocate responsibilities according to their strengths and interests. Typical roles may include project coordinator, design specialist, materials and sustainability analyst, prototype developer, and documentation or communication coordinator.
- Teams are expected to self-organise, coordinate their activities, and collaborate actively throughout the entire project lifecycle.

Project Phases

The project extends across the duration of the course and follows a structured but flexible phased development process, combining scheduled classroom activities with independent teamwork. The main phases are:

- **Phase 1**: Project initiation and material analysis – identification, collection, and evaluation of waste or recycled materials suitable for product development.
- **Phase 2**: Concept development and selection – generation, comparison, and selection of alternative product concepts and preliminary designs.
- **Phase 3**: Detailed design and prototyping – development of technical designs and construction of functional prototypes using the selected materials.
- **Phase 4**: Testing, iteration, and improvement – assessment of functionality, usability, technical performance, and sustainability, followed by refinement and optimisation of the design.
- **Phase 5**: Final production and presentation – completion of the final product, preparation of supporting technical documentation, and presentation of project outcomes.

Milestones and Monitoring

Project progress is monitored through a series of predefined milestones that provide opportunities for feedback, evaluation, and adjustment:

- **Milestone 1**: Project proposal and analysis of available materials.
- **Milestone 2**: Approval of the selected product concept and preliminary design.
- **Milestone 3**: Completion of the initial prototype.
- **Milestone 4**: Testing results and sustainability assessment.
- **Milestone 5**: Final product, technical documentation, and project presentation.

Regular checkpoint and review sessions with the instructor support timely project progression, provide constructive feedback, monitor team performance, and ensure that sustainability objectives remain integrated throughout the

development process. This structured approach promotes accountability, effective teamwork, and continuous improvement while maintaining alignment with the course learning outcomes.

1.7 Deliverables requested from students (type, format, deadlines)

Throughout the course, student teams are required to produce and submit a series of structured project deliverables. These deliverables document the development process, demonstrate achievement of the learning outcomes, and provide opportunities to assess the technical, functional, and sustainability performance of the proposed solutions.

Deliverable 1: Project Proposal and Concept Definition

- **Type**: Team report and short presentation
- **Format**: PDF report (approximately 2–3 pages), with a 5-minute presentation
- **Content**: Identification and analysis of the selected waste or recycled materials; proposed product concept and intended functionality; preliminary sustainability considerations; and an outline of the planned manufacturing approach.
- **Submission**: End of Week 2

Deliverable 2: Design Documentation and Prototype Progress Review

- **Type**: Technical design report and prototype progress review
- **Format**: PDF report (approximately 4–6 pages), supported by sketches, technical drawings, CAD models where applicable, photographs, and an in-class prototype demonstration
- **Content**: Development of the selected concept, including product design specifications, material selection and justification, manufacturing

methods, prototype development progress, and an initial assessment of functionality and technical feasibility.

- **Submission**: End of Week 5

Deliverable 3: Final Product and Sustainability Assessment

- **Type**: Functional prototype or product and final project report
- **Format**: Physical product/prototype accompanied by a PDF report (approximately 3–4 pages)
- **Content**: Description of the final product and its design and manufacturing process; evaluation of functionality and technical performance; assessment of environmental impact and resource efficiency; analysis of circular economy principles and potential for future reuse or recycling; and conclusions and lessons learned.
- **Submission**: End of Week 8

Deliverable 4: Final Presentation and Prototype Demonstration

- **Type**: Oral presentation and live demonstration
- **Format**: Presentation slides (PowerPoint or PDF) and a 10-minute presentation
- **Content**: Overview of the project and final solution; key design, engineering, and sustainability decisions; presentation and demonstration of the final product; discussion of results and challenges encountered during development; and reflection on possible improvements and future developments.
- **Submission**: Final project session (Week 8)

Together, these deliverables support continuous project monitoring, encourage reflective learning, and provide multiple opportunities for feedback and improvement throughout the project lifecycle. They also enable the assessment

of both the technical quality of the developed solutions and their integration of sustainability and circular economy principles.

1.8 External collaborators involved (mentors, companies, experts...) and their role

No external collaborators were involved in this implementation.

2. Project Evaluation

2.1 Assessment criteria and methods used

Student performance was assessed based on both their engagement and progress throughout the project and the quality of the final product and project outcomes. The assessment emphasised the practical application of engineering principles, creativity and innovation, effective teamwork, project planning and execution, and the integration of sustainability considerations throughout the design and development process.

Table 1. Assessment components, criteria, weighting, and methods used to evaluate student performance during the pilot implementation.

Component	Criteria	Weight	Assessment Method
Project proposal and concept	clarity of objectives, originality of idea, feasibility, identification of waste materials, sustainability considerations	15%	evaluation of written proposal and short presentation
Design and prototype development	quality of design process, technical documentation, material selection, engineering approach, prototype progress	30%	review of design documentation, consultations, prototype inspection
Final product / prototype	functionality, durability, innovation, quality of manufacturing, effective use of waste materials	30%	demonstration and practical evaluation of the final product
Sustainability assessment	environmental impact analysis, resource efficiency,	15%	evaluation of final report and sustainability analysis

	circular economy integration, reuse potential		
Final presentation and teamwork	communication skills, clarity of presentation, ability to justify decisions, collaboration within team	10%	oral presentation

The following assessment methods were used throughout the course:

- Evaluation of written technical reports and project documentation
- Observation of project progress during workshops and consultations
- Assessment of the physical prototype and its functionality
- Oral presentations and product demonstrations
- Feedback sessions with instructors and peers

The assessment process supported continuous improvement, encouraged innovation, and promoted sustainable engineering practices.

2.2 Evidence of student learning (examples, outputs, results)

The project outcomes demonstrated students' ability to integrate engineering design methodologies with sustainability and circular economy principles when addressing practical production and environmental challenges. Throughout the project, students progressed from identifying opportunities for the reuse of waste or recycled materials to designing, developing, and manufacturing functional products. The completed solutions incorporated considerations of resource efficiency, material recovery and reuse, and environmentally responsible production practices.

The final deliverables provided concrete evidence of the achievement of the intended learning outcomes. Students demonstrated practical problem-solving skills, sustainable product design, technical and creative development, prototype manufacturing, project planning, teamwork, and professional

technical documentation. The completed projects also showed their ability to apply engineering knowledge in real-world contexts while considering both technical performance and environmental aspects.

Examples of the products developed by the students included:

- **Project 1**: A clock made from an old aluminium wheel rim.
- **Project 2**: A seat made from an old bicycle.
- **Project 3**: A lamp made from plastic bottles in the shape of a lotus flower.
- **Project 4**: A bench welded from reclaimed steel elements.
- **Project 5**: A wine rack made from used chains using welding techniques

3. Reflections and Recommendations

3.1 Main achievements and strengths of the project

The project combined the principles of sustainable development and circular economy with hands-on experience in product design and manufacturing using waste, reclaimed, and recycled materials. Through participation in the project, students engaged in the complete product development process, from concept generation and design through prototype construction, testing, and final evaluation, gaining practical experience across the different stages of the product lifecycle.

The project supported the development of a broad range of competences, including technical and engineering skills, project planning and management, organisation, and effective teamwork. It also encouraged creativity, critical thinking, and innovation by challenging students to identify valuable applications for secondary raw materials and develop functional, resource-efficient solutions.

An important component of the project was the development of environmental awareness and responsible production attitudes. By applying circular economy principles and considering the environmental implications of their material and design choices, students strengthened their understanding of the role of sustainability in modern engineering and manufacturing.

Overall, the project provided students with practical knowledge, skills, and attitudes relevant to contemporary industrial environments, where sustainable development, resource efficiency, innovation, and responsible production practices play an increasingly important role.

3.2 Challenges faced and how they were addressed

Several challenges were encountered during the project. One of the main difficulties was the variability and limited quality of the available waste materials, which required careful selection, pre-assessment, testing, and adaptation of the design solutions. This was addressed through early material assessment and an iterative prototyping process before final design decisions were made.

Another challenge involved balancing product functionality and technical requirements with sustainability constraints. This was managed by applying circular economy principles and prioritising design simplicity, material efficiency, and responsible resource use.

Students also experienced some difficulties with teamwork, task distribution, and coordination, particularly when aligning responsibilities and schedules. These challenges were mitigated through clear role allocation and the use of basic project management tools. Limited previous experience in prototyping was

addressed through instructor guidance, practical workshops, and peer-learning activities.

Finally, time constraints were managed through structured project milestones and regular progress reviews, which helped teams maintain steady progress, identify potential delays, and make timely adjustments throughout the project.

3.3 Lessons learned for future implementations

The project findings indicated that early-stage analysis of waste-based materials was essential for improving design feasibility and reducing the need for later iterations. Clearly defined milestones and intermediate deliverables also supported more effective workload management and helped students maintain steady progress throughout the course.

The implementation showed that strengthening initial prototyping skills through practical, hands-on workshops could reduce technical barriers and improve the quality of the final products. Structured support for teamwork, including clear role allocation and appropriate coordination tools, also contributed to more efficient collaboration.

Regular feedback sessions proved particularly valuable and should be maintained or further developed in future iterations. Finally, involving external partners at an earlier stage could further enhance the real-world relevance and innovative potential of the projects by strengthening the connection between classroom activities and practical industrial challenges.

4. Supporting Material

4.1 Lecturers' materials and project documentation

Lecturers' materials and project documentation are available in the following link:

https://drive.google.com/drive/folders/1xi02l2nejwO6WKY98oE0fgrS4KO8A9qR?usp=drive_link

4.2 Deliverables produced by students, final presentations or pitch materials

An example of deliverables produced by students is available in the following link:

https://drive.google.com/drive/folders/1U_FY5_izY1VyUkhGJjVpQmQC6aI3iOWE?usp=drive_link

Students' final presentations are available in the following link:

https://drive.google.com/drive/folders/1vFrSOGir_zIpJJqmIcDUBDJVgljO9xE8?usp=drive_link

4.3 Images/videos (with consent)

Photographic and video records were captured with the explicit consent of the participating students, and are available in the following link:

https://drive.google.com/drive/folders/1emQ-DKWTIOaZeWauajZ_ImAgByhJPnIJ?usp=drive_link

4.4 Any other relevant material

All the materials, including this report, are available in the following link:

https://drive.google.com/drive/folders/1jZ9PkMWKJumrBjG-CvLINA4s5iuo0ncM?usp=drive_link