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Work-in-Progress: Creating Recycled Products to Incorporate Sustainability Projects in the Undergraduate Chemical Engineering Laboratories

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WIP: Creating Recycled Products to Incorporate Sustainability Projects in the Undergraduate Chemical Engineering Laboratories

Background and Motivation

The core purpose of the University of Texas at Austin is to transform lives for the benefit of society [1]. This purpose entails a commitment to the continuous advancement of our communities through research and innovation. Our research motivation stems from this purpose. We believe this commitment must involve the creation of educational opportunities that promote a better future for our societies through the creation of a sustainable development.

Sustainable development is widely defined as a development that meets the needs of the present without compromising the ability of future generations to meet their own needs [2]–[4]. Its objective is to foster community resilience by promoting the effective use of environmental resources and the invention of processes that facilitate their optimal utilization [2].

Engineering practices that promote a sustainable development are gaining momentum and relevance amongst governments along with corporations as they adapt their policies and business strategies to prepare for the environmental challenges of the future [5], [6]. Within this context, there is a growing interest in the formation of engineers who understand the importance of sustainability and who are capable of driving engineering projects towards sustainable development [7]. Furthermore, multiple industries (e.g., chemical, energy, materials, etc.) will require more engineers who can effectively apply sustainability concepts to the formulation of engineering solutions [8].

The learning of sustainability concepts in the engineering classroom can be facilitated and enhanced by the creation of hands-on opportunities that allow students to propose efficient solutions to environmental problems [9]. Nonetheless, the experiential practice of sustainability can be challenging in the classroom. While the concepts of sustainability, circular economies, and recycling can be taught and incorporated in different courses across the engineering curriculum, the application of these concepts through hands-on experiences can be difficult and often overlooked.

Hence, we propose the utilization of a senior chemical engineering laboratory to incorporate hands-on experiences that allow students to practice sustainability concepts through the study of polymer processing, the economic analysis of circular economies, and the completion of recycling projects. The engineering undergraduate laboratories are the perfect space to learn, develop, and innovate by the application of sustainability practices [7], [9]. The study of experimental practices related to sustainability in the laboratory will be important in three ways: (1) they will provide our students with a better understanding of the role of polymers in our society, (2) they will train our students with new skills to solve and analyze problems (i.e., from a different perspective), and (3) they will encourage innovation and forward-thinking as students apply sustainability concepts in the development of engineering projects. Through this study, we hope to help train a new generation of scientific leaders who are responsible for the sustainability of our communities.

In this work-in-progress, we detail our initial steps towards the utilization of a senior chemical engineering laboratory to incorporate hands-on sustainability experiences in the engineering curriculum. To develop this project, we are using an approach that blends undergraduate research, interdepartmental collaborations, and a focus on experiential learning. We are collaborating with the university Green Fund and the Environmental Health and Safety (EH&S) department to recycle materials, reach the campus community, and understand the environmental and economic impacts of the study. The manuscript describes a summary of the project development, a detail of project goals and current advances, and a summary of our research objectives as we integrate the practice of sustainability into the chemical engineering program.

Motivation and Research Question

The Department of Chemical Engineering at the University of Texas at Austin has invested efforts and resources in the renovation and modernization of the undergraduate teaching laboratories, and our collaborations with industry partners have been at the center of this process [10]. As we have progressed in these efforts, we have identified a clear commitment from our industry partners to the implementation of sustainability practices and the reduction of the environmental impact of their operations within their communities [6]. We believe it is our responsibility to educate our students to be leaders who can contribute to the creation of a sustainable future.

We have recently developed a multi-system experiment station that will serve as a small-scale laboratory to study the potential pathways for recycling the plastic waste produced on our campus. The overall purpose of the project is to serve as a catalyst to incorporate sustainability to the chemical engineering undergraduate laboratories, create campus awareness on the importance of a sustainable future, and, by these efforts, train the sustainability leaders of the future. There are sustainability initiatives in place at other institutions to promote the recycling and reutilization of plastics; however, to the best of our knowledge, this is the first report detailing the integration of sustainability concepts and experiments in a senior year chemical engineering undergraduate laboratory. Our study will answer two main research questions:

1. Can we enhance sustainability learning in chemical engineering by creating laboratory experiments that pursue the application of these concepts?
2. Can hands-on experimental practices be effectively integrated into the chemical engineering curriculum to promote the utilization of sustainability concepts in engineering solutions?

As part of this study, we also aim to collaborate in the implementation of circular economies of plastics on our campus by facilitating the reuse and recycling of plastics produced in research laboratories. We understand this is a small effort within the worldwide plastic crisis; nonetheless, we believe that through this study we will be able to effectively educate our students, promote innovation, stimulate the creation of circular economies, and help create a new engineering student mindset centered around sustainability.

Experimental Laboratory Implementation

To develop our educational study, we first developed our experimental study. Our main in-laboratory experimental goal has been to create a sustainable plastic recycling process. Polymeric materials have been highlighted by their detrimental environmental impacts, as such, these materials represent a risk to the future sustainability of our society [4]. Our experimental project objective is to implement this process as a circular economy of plastics, typically defined as a production model that keeps materials, products, and services for as long as possible [11]. Through this project, we envision generating a small-scale, long-term solution that ensures the efficient recycling of a portion of the plastic waste produced on our campus and the creation of continuous value from them [6], [11].

To create value, we are focusing on plastic waste streams not currently recycled on our campus because they are too small (i.e., size) for large-scale processing (e.g., pipette tips, syringes, and boxes). Our final products will balance the needs of our campus, the capabilities of our laboratories, and the sustainability of the recycling process. However, we envision a portion of this continued value creation will be intangible (i.e., creation of awareness, education on sustainability, accomplishment of campus environmental goals, etc.). Three elements are typically identified in the creation of a circular economy of plastics using recycling processes [12]: (1) designing or redesigning recyclable plastic products; (2) utilizing systems to recover end-of-life plastics; (3) reusing plastics by recycling them into new products that generate value. Our experimental work focuses on the third element of this circular process, the utilization of mechanical recycling methods for reuse and the creation of new products.

The experimental research team is composed of a faculty member, a master's student, and four undergraduate chemical engineering students (i.e., the "sustainability team"). The project is funded by the university Green Fund. The sustainability team has focused on four sequential objectives as we develop the research in the laboratory and as we expand this research to the engineering classroom:

1. Leveraging chemical engineering knowledge and utilizing polymer chemistry, polymer processing technologies (e.g., single screw extrusion, injection molding, 3D printing, etc.), and polymer characterization techniques (i.e., morphology, rheology, tensile testing, etc.) to develop standard procedures to process and characterize plastic samples produced by research laboratories in our campus.
2. Upscaling recycling processes to diminish the volume of plastic waste streams generated that are not currently processed.
3. Developing projects that promote the application of sustainability concepts in the laboratory by integrating plastic processing projects utilizing real campus samples.
4. Creating campus awareness about the importance of sustainability in our communities.

Experimental Development

At the time of this work in progress, the team has worked on objectives 1 and 2 listed above, in particular. Figure 1 depicts an overview of the steps followed from team assembly to the generation of results.

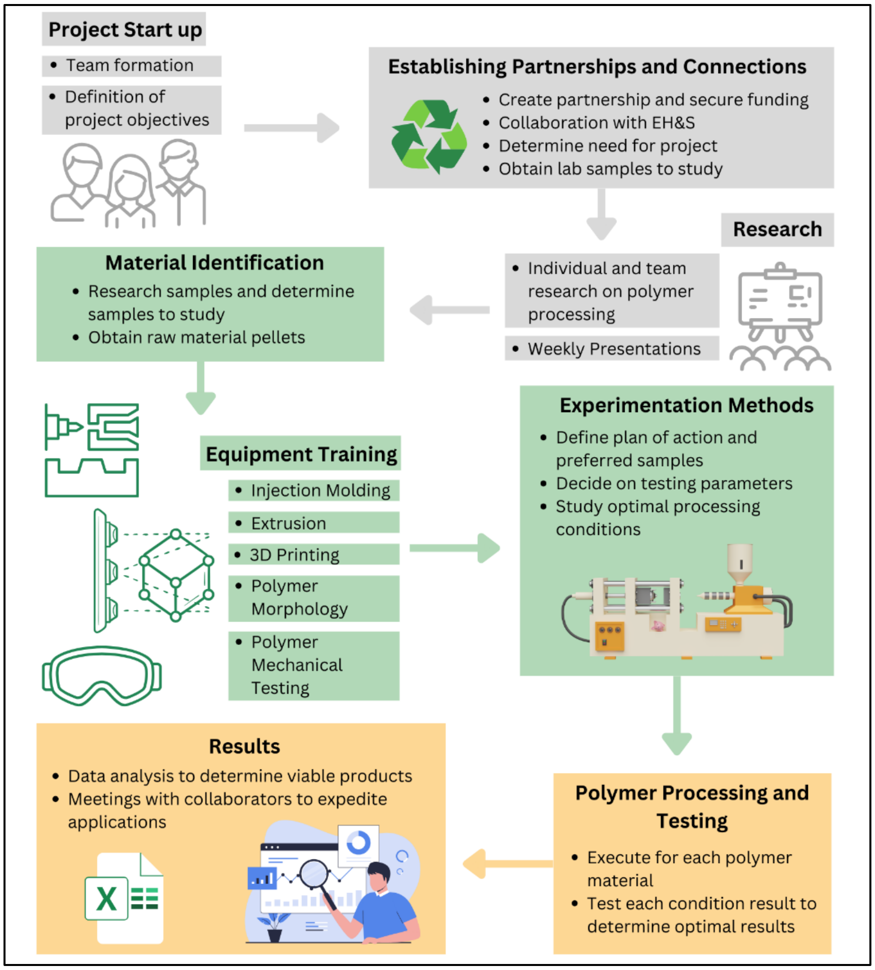

Figure 1. Typical experimental sequence to identify, recycle, and create plastic products.

Experimentally, we have developed two consecutive stages to process and test recycled plastic products:

- **Stage 1:** During the first stage of this study, we worked with equipment available in our laboratories - acquired for this purpose - to identify ways to reuse plastic waste typically produced on our campus but not processed. We worked with EH&S to identify material streams produced by research labs that are not currently recycled. We ordered commercial samples of these plastics, and the sustainability team utilized polymer processing equipment to determine methods and process conditions to recycle them.

- **Stage 2:** Subsequently, we switched our focus to the reutilization of the selected plastic sources that show the highest potential for reuse. Students worked with real samples obtained from research laboratories; samples are provided by EH&S. The typical processing sequence is depicted in Figure 2.

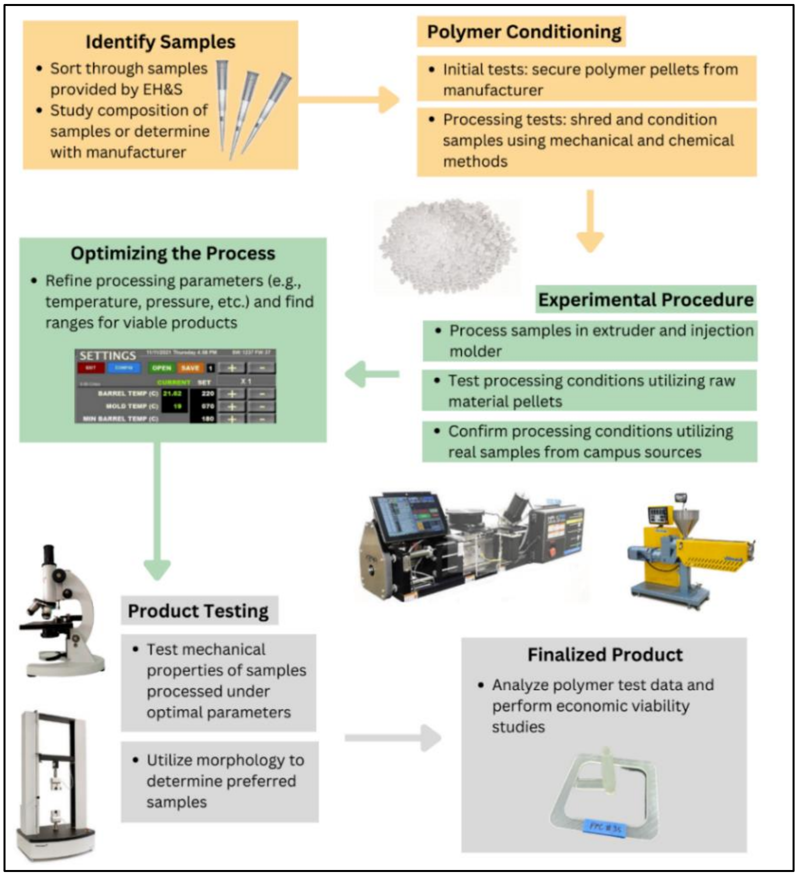

Figure 2. Research sequence to develop viable plastic products.

Table 1 details some of the materials studied, the resulting processing conditions, and the number of trials applying the procedures depicted in Figure 2 and utilizing an injection molding machine.

Table 1. Optimal injection molding processing conditions for selected polymer samples.

Material	Barrel Temperature[a] (°C)	Mold Temperature[b] (°C)	Injected Amount[c] (cm^3)	Trials[d] Completed
Polypropylene Copolymer	145	75	6.19	39
High-Density Polyethylene	172	70	6.33	19
Polypropylene Homopolymer	180	55	6.2	25
High-Impact Polystyrene	250	75	6.09	41

[a] Defined as the current and the set temperatures of the injection molding machine barrel.
[b] Defined as the current and the set temperatures of the injection molding machine mold.
[c] Defined as the volume of plastic injected into the mold cavity.
[d] A run-through of the injection molding machine at various barrel and mold temperatures to find optimal processing conditions.

It is important to note that the team has not completed an economic analysis at this point; in addition, the team has restricted the polymer recycling process to that of a linear recycling process. Nonetheless, these aspects will be studied in future developments of the project. Figure 3 describes the sequential 7-step procedure to produce viable recycled products.

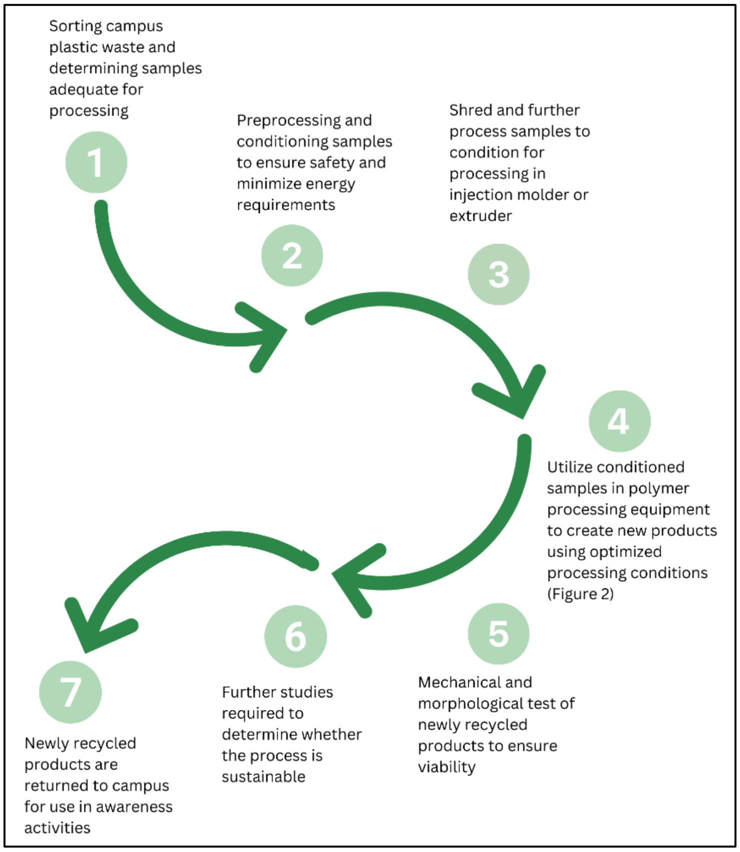

Figure 3. Visual representation of the 6-step sequence to create viable recycled products.

In a typical sequence, students prepare, condition, and shred the samples as a pre-processing step. Then, they apply methods investigated in stage 1 to find optimal conditions. Consequently, final products are tested and characterized to understand whether our solutions are viable. Once effective processing methods are identified and developed, the research team will do a financial analysis to study the economic feasibility of the products. The team will also further study the durability and mechanical properties of the products to determine whether these recycling processes contribute to the creation of a circular economy for plastics on our campus. Initially, we envision creating recycled products that will help us with our outreach, education, and awareness efforts (e.g., promotional university products such as keychains, chess pieces, glasses, or the production of recycled pellets to use in outreach demonstrations), and that will create mostly intangible value. In the long term, we will work with EH&S to determine products that may be more appropriate for reuse in research labs and that are of tangible value.

Educational Development and Future Work Directions

In future stages of the project, we will continue working with EH&S to find new possible samples to process. We want this collaboration and plastic recycling process to become a project that can be completed by student teams in our senior-level unit operations laboratory course (referred to as "the projects laboratory"). This laboratory course is a core course in the chemical engineering program. The class must be taken by all students who intend to obtain an undergraduate chemical engineering degree. Registration in the course can fluctuate slightly every term; nonetheless, it is approximately 70 to 90 students per semester. The course is offered twice a year. We expect 15 to 20 students to participate in this project every semester.

In our program, this laboratory course pursues the fulfillment of learning objectives that aid students in the acquisition of the skills necessary for the professional practice of chemical engineering, this includes learning and practicing new concepts of relevance to chemical engineering research. One of the main learning experiences offered by the course is the development of class projects. The details of the course and the class projects have been described elsewhere [10]. During the completion of class projects, students propose their own research, create individual and group proposals, build their own theory, and complete their experiments in their proposed schedule. The project's final report is a poster session where students present and discuss their experimental results. The sustainability research will be integrated into the class projects as we believe this section of the course offers more flexibility to create innovative approaches to engineering solutions.

Once we integrate this experience, we expect laboratory teams to work closely with EH&S in the determination of plastic samples that need to be recycled. Student teams will use the laboratory to propose solutions to recycle plastic and to create value-added products. As the project is developed, we will perform student surveys to understand how their perception of sustainability progresses through the increased exposure to these practices. We will also ask student teams to create their own project objectives, summarize their accomplishments, and detail their learning at the end of the course as a result of participating in these projects.

The main educational benefits produced by this project will be the opportunities students will have to work on projects directly related to sustainability, the incorporation of sustainability practices in our program, and the dissemination of results within our campus as well as to the engineering education community. We believe this will also be a great opportunity to showcase how our efforts converge with our campus commitment to a sustainable future.

Acknowledgments

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