TRAINING FOR IMPROVING PLASTICS CIRCULARITY (TIPC): INNOVATIVE APPROACHES TO DEVELOPING A CIRCULAR PLASTICS WORKFORCE

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Abstract

Transforming the plastics industry from a linear model (take-make-use-dispose) into a circular economy is essential for building a safer and more sustainable plastics industry. Achieving circularity in plastics requires a comprehensive approach, including safer material design, improved end-of-life collection and recycling systems, and systemic changes to manufacturing and business practices. As societal and regulatory expectations push companies to adopt these practices, there is a growing need for a workforce equipped with skills to support circular economy initiatives.

In response, the National Institute of Standards and Technology (NIST) awarded grants to 11 universities in 10 states to incorporate circular economy principles into polymer science programs. These grants enable a variety of educational initiatives, including integrating circularity into course and lab curricula, developing case studies, and partnering with local industry. This talk will highlight initial outcomes from activities that engage the local workforce across the plastic value chain. The first, courses for industry professionals, will include projects developing courses for the plastic production and recycling workforces. The second, two summer programs—one for local community college students and the other for plastic industry professionals—will explore the tools and methods for maximizing the impact of one- or two-day trainings.

The Training for Improving Plastics Circularity (TIPC) grants can be a model for further undergraduate and workforce development initiatives, but only once persistent challenges are addressed. These challenges include, but are not limited to, sustaining these programs once initial funding lapses, recruiting workforce participants, and bridging technical gaps. Educational programs like TIPC are key to creating an emerging plastics workforce that understands the problems created by the linear economy and create innovative solutions to support a more circular one.

Introduction and Motivation

For generations, the linear economy has been improving the efficiency by which we extract materials from the earth, produce products out of them, and dispose of the products at the end of their useful life. The workforce of this economy has been trained to improve this efficiency and generate value at every possible step. However, as the world transitions into a circular economy, the workforce will have to re-evaluate the product value chain and value creation opportunities for this new and more regenerative system. Some of the jobs and skills will remain, but others will change. Some of the changes that will have to take place is in line with broader shifts in the workforce, like the need for continuous improvement to maintain an agile workforce (Deloitte, 2020) and integrating upskilling into workforce development plans (Schwartz et al., 2020). But other skills and roles are specific to the circular economy (Beducci et al. 2024). Addressing these needs will require investments into both education and workforce upskilling/training (Burger et al. 2019; Beducci et al. 2024).

The U.S. plastics industry is no exception. Policies like the European Union's "Circular economy action plan" (European Commission, 2015) and extended producer responsibility laws in various U.S. states are pressuring brands to redesign their products to use less plastic, integrate post-consumer material, and be more recyclable. U.S. industries and coalitions like the U.S. Plastics Pact are also pledging to reduce problematic and unnecessary plastics in their products, increase recycled content, and create business models for circular pathways such as reuse. International negotiations, such as the UN Environmental Programme's Intergovernmental Negotiating Committee (INC) on Plastics Pollution (UNEP, 2022), are working to reduce plastic pollution and its impacts, including assessing ways to improve waste management, limit or lower production, and reduce the use of chemicals of concern (Valdivieso, 2024). Despite this evolving landscape, a 2019 Plastics Industry Association report suggested that the U.S. educational curriculum is not keeping up with the trends and evolving technologies in the plastics industry, and this is contributing to the skills gap in the U.S. plastics workforce (Pineda, 2019).

In response to this gap, the National Institute of Standards and Technology (NIST) developed the Training for Improving Plastics Circularity (TIPC) grant program to integrate circularity into undergraduate polymer education

and workforce development. In doing so, then program aims to train the future workforce for a more circular future for the plastics industry and keep the U.S. plastics workforce and companies competitive. This paper introduces the program and the breadth of its projects. It then presents four TIPC projects and their initiatives targeting the existing plastic industry workforce—two that are developing courses and two creating summer programs. Finally, the paper gives a status update on the TIPC projects and suggests dissemination pathways. It should be noted that, while this paper uses four projects as case studies with specific workforce development elements, all 11 TIPC projects are educating the future plastic workforce because many of their undergraduate students enter the plastics industry at some point in their career.

Table 1: The 11 Training for Improving Plastic Circularity (TIPC) grant project universities and their goals.

University	Project Goals
University of Southern California	● Create a multidisciplinary minor in plastics circularity (engineering, chemistry, environmental science, and business). ● Create a summer school targeting community college and primarily undergraduate institutions.
Hawai'i Pacific University	● Create an interdisciplinary minor on polymer circularity with STEM and business courses. ● Create a series of weeklong summer courses for plastic industry professionals.
University of Houston	● Develop workforce training programs on plastic circularity (including circular plastics credential program, and an internship and reverse internship program).
Pennsylvania State University	● Focus on sorting and separating plastics for recycling. ● Create series of modules on polymer chemistry and LCA to add to several courses for students and used to create trainings for workers in the plastics industry across Pennsylvania.
University of Toledo	● Add plastic circularity training into new and existing lab courses in chemical engineering and cosmetic science. ● Integrate technical methods for plastic circularity, including circular product design, material science, and mechanical and chemical recycling. ● Support co-ops and internships with industry partners in the Midwest.
Auburn University	● Create a curriculum on plastic recycling for students and outside professionals in the plastics industry. ● Create a new class on the plastic recycling value chain that emphasizes systems thinking and hands-on training modules that teach metrology and how to use equipment relevant to plastic recycling. ● Create a series of workshops for professionals on polymer recycling and circularity.
University of South Alabama	● Design curriculum around plastic polymer circularity, then integrate it into civil, mechanical, and systems engineering and chemistry courses. ● Make curriculum available to other universities, vocational centers, industry professionals and policymakers. ● Support students entering plastic industries in the Gulf Coast.
University of Massachusetts, Lowell	● Develop case study modules for undergraduate and graduate students in its Plastics Engineering Department and transfer those into parallel curricula in the Mechanical Engineering, Chemical Engineering and Chemistry Departments.

University	Project Goals
Pittsburg State University	● Add lecture and lab modules to plastics engineering technology degree program. Modules will focus on plastics circularity in the materials, design and processing phases of production.
Arizona State University	● Create seven curriculum modules to support a new certificate or degree in sustainable macromolecular materials and manufacturing.
University of Missouri, Kansas City	● Develop interdisciplinary course curricula in plastics circularity, with three different courses in the Division of Energy, Matter and Systems. These will include a critical thinking course, a research skill training course and a polymer characterization lab course.

Training for Improving Plastics Circularity (TIPC)

The TIPC grant program aims to eliminate plastic waste and support the U.S. plastic industry's transition from a linear to a circular economy by funding projects that integrate plastic circularity principles into undergraduate and workforce development curricula across the country. Grants up to $500,000 were awarded to 11 universities (~$5.5 million total) to 1) add polymer circularity into undergraduate and workforce development curricula and 2) prepare the plastics workforce for the circular economy. Over the three-year award period, recipients aim to develop their projects, implement them with undergraduate students or members of the local plastic industry workforce, and create a plan to disseminate project deliverables and/or expand into other regions or universities in the U.S. Although it focuses solely on the plastics industry, the projects aim to cover the industry broadly. Table 1 lists the universities with TIPC projects and their project goals.

While the primary points of contact for the projects are university faculty, projects include direct and indirect involvement from dozens of participants in industry, academia, government, national laboratories, and non-profits across the plastics life cycle. Polymer science evolves rapidly, as does workforce needs and challenges in the industry, the policy landscape, and our understanding of the impacts of plastic pollution and the emissions associated with their production. In addition, transitioning into a circular economy system requires a systems approach (Gazeau et al., 2024; Kirchherr et al., 2017; Zhijun & Nailing, 2007). Therefore, it is important that the plastics workforce understands value-retention and -recovery interventions across the plastics life cycle—from extraction to production, use, and end of use (e.g., recycling)—and is aware of the industries involved in each step of this life cycle.

Along with addressing the entire plastic life cycle, TIPC projects are interdisciplinary to encompass many disciplines involved in the circular economy transition. Courses, trainings, minors, case studies, and summer programs emerging from TIPC target a variety of engineering disciplines, chemistry, physical sciences, economics, business management, and cosmetics.

Finally, the plastics value chain spreads across the entire U.S., so the TIPC program, too, aims to achieve broad geographic coverage. The 10 states the program covers include hotspots of plastic production (e.g., the Gulf Coast and Midwest), manufacturing (e.g., Arizona, Kansas, Missouri), and pollution (Hawai'i). The projects focus on workforce and pollution challenges in their local communities, but the project outcomes aim to have broader implications across the U.S. See Figure 1 for the locations of the TIPC universities.

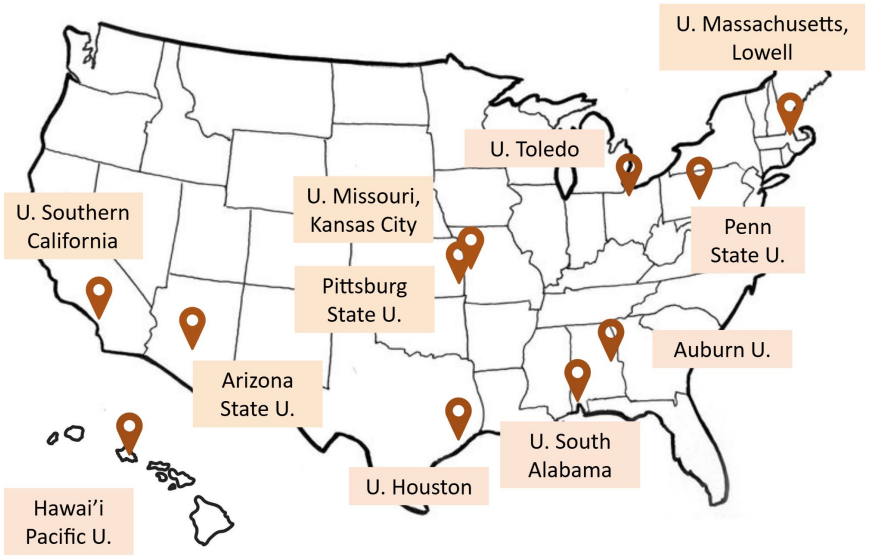

Figure 1: Locations of the 11 universities hosting TIPC projects.

Technology Approach

Courses for industry professionals

Sorting and Recycling (Pennsylvania State University)

The recycling rate for plastics remains low in the U.S. (8.7% in 2018). One challenge to increasing this rate is that it is difficult for MRFs and recyclers to meet input specifications for mechanical and chemical recycling. However, barriers exist to sorting and separating plastic streams to reduce contamination and meet these specifications in a cost effective way. Pennsylvania State University's project "Workforce development in measurement needs for improved sorting efficacy to facilitate recycling of post-consumer plastics" is working to improve plastic sorting and separation by focusing on the measurement challenges. First, it will revise three courses:

1. Polymer laboratory elective: This 400-level course is being redesigned to integrate polymer circularity principles, especially characterization and sortation for recycling.
2. Life cycle analysis elective: This 400-level course on life cycle assessment (based on the ISO 14040 standard) will be revised to incorporate plastic sorting and recycling.
3. Sorting module: A module on plastic sorting will be integrated into this laboratory course that is required for undergraduate students in the polymer track. Circularity principles will also be added to the course.

Once the sorting components are integrated into the courses, the project will work with a Pennsylvania recycling industry non-profit to adapt the components into in-person and virtual training courses for the plastic recycling workforce. In-person courses will first be distributed to recycling professionals in different regions of Pennsylvania during events for the recycling industry hosted by the non-profit. The intended audience is MRF and recycling professionals with anywhere from high school education to a bachelor's degree.

One challenge that the project aims to overcome is to teach the hands-on technique of near-infrared (NIR) sorting in a virtual environment. NIR machines are being used in MRFs to automate sorting, which is traditionally done by hand. Learning how to operate these machines is an important skill for recycling industry employees, and the option of developing the skill asynchronously is attractive to the industry.

Plastic Production (University of Houston)

Whereas Pennsylvania State University is targeting the downstream workforce, the project "Workforce Training in the Circular Plastics Economy at the University of Houston" is integrating polymer circularity into plastic production. The metro Houston area hosts >40% of the U.S.'s petrochemical capacity (Colliers, 2024) and the Houston Ship Channel—part of the Port of Houston—was recognized in 2019 as the largest petrochemical complex in the U.S.

(Bridges, 2019). As the petrochemical industry transitions into a circular economy, the thousands of workers who work in plastic production in the Houston area will need to reskill to remain competitive. The TIPC project "Workforce Training in the Circular Plastics Economy at the University of Houston" is helping to do this by integrating polymer circularity principles into the plastic production workforce through a micro-credential program.

The program will be divided into five mostly virtual courses, or "badges", the completion of which will result in a certificate:

1. Polymer Taxonomy, Waste Identification, and Use
2. Measurements and Characterization Tools for Circular Plastics
3. Handling Plastic Waste
4. Advanced Recycling Methods
5. Valuation, Life Cycle Analysis, and Technoeconomic Analysis

Classes will take place in the evening to support participation by the full-time workforce and include lectures by University of Houston faculty, industry professionals, and subject-matter experts from U.S. national laboratories. Along with lectures, there will also be hands-on and virtual demonstrations of testing methods and Q&A opportunities for students. The intended audience is plastic industry employees (e.g., holding bachelor's degrees in chemistry and engineering) and managers and strategists looking to incorporate plastic circularity into product development. Once the classes are created and recorded, the badges can be delivered asynchronously with real-time Q&A sessions.

The University of Houston is hosting a plastics circularity workshop in spring 2025 to garner participation from industry and local governments on what to include in the trainings training. Badge 1 (Polymer Taxonomy, Waste Identification, and Use) is expected to be offered in summer 2025 as a 1-credit hour (15 hours of training) continuing education course.

Summer programs

Community College and Undergraduate Institutions (University of Southern California)

In response to demands from students, colleagues, industry partners, and the local community, the University of Southern California's (USC's) TIPC project ("Enabling Innovation in Plastics Circularity through Interdisciplinary Education") is creating an interdisciplinary minor on plastic circularity it will pilot at USC then disseminate to the greater Los Angeles area and beyond. The minor targets undergraduates in chemistry, engineering, environmental science, and business/entrepreneurship majors and includes the development of two new courses.

Part of the project's outreach to the larger Los Angeles community is a one-week summer program. The audience is students in community colleges and primarily undergraduate-serving institutions in the Los Angeles area who have taken at least one general chemistry course. The summer program aims to teach the future workforce about the plastics problem and relevant educational and career opportunities in plastic circularity by 1) facilitating the transition of community college students into 4-year STEM programs relevant to plastics circularity and 2) engage students with plastics businesses and industries.

- Pollution: collect ocean plastics and learn about the plastic pollution problem
- Recycling: tour a recycling facility and learn about the life cycle of polymers, including their end of life
- Laboratory methods: learn about polymer characterization and degradation challenges
- Career pathways: learn about plastic production and entrepreneurship opportunities

The first summer course was taught in the summer of 2023 and had six students. The project team is working to increase its capabilities to host more students in future years.

Plastic Pollution for Industry Professionals (Hawai'i Pacific University)

The state of Hawai'i is heavily impacted by plastic waste. In addition to the waste it produces and processes, it is affected by ocean plastic pollution from the nearby Pacific Garbage Patch (Brignac et al., 2019; Currie et al., 2019) and derelict fishing gear. Despite this confluence of plastic waste, there is no plastic waste conversion facilities in Hawai'i; instead, plastic waste is sorted, baled, and shipped to Southeast Asia for processing. Hawai'i Pacific University's (HPU's) TIPC project, "Achieving a Circular Economy in Hawaii: Creating Plastic Circularity

Curriculum to Bridge Industry Professionals and Undergraduates," aims to build out the state's plastic recycling sector and connect the existing plastic industry workforce with HPU undergraduates.

One way it is making this connection is through a series of one-week summer courses for plastic industry professionals. The target audience is plastic industry professionals interested in better understanding plastic pollution, microplastics, and plastic circularity. Three courses are slated, each yielding a certificate:

- Plastics in the Environment
- Quantification Methods for Microplastics
- Towards Polymer Circularity

Hands-on learning will be prioritized through field activities such as recovering and measuring microplastics and touring waste management facilities on Oahu. Industry professionals will also perform environmental sample processing, characterizations, and micro- and nanoplastic detection using instruments in the Center for Marine Debris Research. Along with showing industry professionals the impacts of plastic pollution in a U.S. state and methods being developed to measure the impact of that pollution, the summer courses aim to connect workers with HPU undergraduates—e.g., through identifying internship opportunities. The three courses will be offered starting summer of 2025.

Discussion

Transitioning into a circular economy CE will require adaptations and changes to current curricula. There is also the need to educate the current and upcoming U.S. workforce for multi-faceted and multidisciplinary challenges to keep the country and its employees competitive. The TIPC grant program is one of many efforts to adapt to these changes, and it has resulted in a wide array of innovative labs, courses, internships, and pedagogy across the plastics value chain.

There are two cohorts of recipients: one that started in 2022 and the other in 2024; this means that cohort one's grant period ends in 2025 while cohort two is just beginning. Projects tend to spend the first part of their three-year grant period developing the curricula and building capacity and the second part implementing and disseminating. Capacity building involves working with groups of faculty, regional industry partners and non-profits, and national labs to develop the curricula. Much of the TIPC funds from some projects also went into capacity building through purchasing new equipment needed to conduct measurements to teach plastic circularity—e.g., extruders, pelletizers, injection and blow molding equipment, melt flow indexers, and CAD software; this equipment is giving students the ability to measure thermal and mechanical properties of plastics, including virgin, post-consumer, and post-industrial, and molecular weight. The 2022 cohort is in the implementation and dissemination stage, with each teaching their new course content and measuring its impact in different ways, from student evaluations to recording courses and analyzing progress towards learning outcomes.

A number of challenges have emerged and been discussed during biannual TIPC cohort meetings (which began in 2024).

Recruitment: Because many of these courses are new, most are offered as electives and few are currently required for majors. Even though polymer circularity topics are very compelling to undergraduates, work is needed to communicate the availability of new courses—and the new minors. However, one interdisciplinary 100-level course had to expand its 100-student cap after the first year it was taught.

Sustaining the programs after funding lapses: While this was not a pressing problem in any of the meetings, PIs were working with their departments and universities to keep the courses, minors, and workforce development mechanisms in place after the three years of TIPC funding expired. One immediate problem those who purchased equipment faced is paying for maintenance, as maintenance plans can be impractical and lab fees may be insufficient to cover repairs. Some universities were exploring finding donors and private partnerships to maintain the equipment and others suggested consolidating equipment into one lab and finding a sponsor for that lab.

Co-teaching interdisciplinary courses: Inconsistent teaching styles and conflicting content objectives across disciplines made it difficult at times to develop interdisciplinary course content. Getting courses approved by multiple colleges or departments could also prove challenging. For interdisciplinary minors, determining which department will sponsor and assess the minor, especially for small schools with fewer faculty. At least one TIPC project also suggested that getting approval from national and regional education and accreditation bodies was proving a challenge.

Finally, determining prerequisite courses could be a challenge, as foundational polymer chemistry is important for all of these courses but may be challenge for students to learn in a short time.

Conclusions & Recommendations

The TIPC grant program is one example of how multidisciplinary circular economy principles can be integrated into undergraduate and workforce development curricula. The program and many innovative curriculum development techniques that come out of it may act as a model for training other parts of the circular economy. This could include for other materials like the electronics sector (e.g., electrical engineering disciplines) or product design. In addition, while this paper highlighted projects working on plastic production and recycling, there is an acute need to train other the workforce for other value-retention and -recovery methods, like repair and refurbishing. Finally, lessons learned from TIPC cohorts one and two may also justify future TIPC funding rounds.

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