DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Hybrid Approach to Repurpose Plastics Using Novel Engineered Processes (HARNESS)

04.04.2023

Technical Area 2: Novel Methods for Deconstructing and Upcycling Plastics

Kate H. Kucharzyk, PhD, PI
Jacob Lilly, PhD co-PI
Battelle Memorial Institute

Project Overview

HARNESS strives to develop a proof-of-concept pilot system designed to break down polyether-polyurethane (PE-PU) foams with engineered enzymes, then convert breakdown intermediates to high-value polyols (POs) and diamines.

The primary objective of this project is to develop an innovative platform for waste plastics upcycling to PO and diamines, demonstrated and validated for PE-PU foams, which are abundant materials used in consumer applications, such as packaging, bedding, carpeting, car seats, and apparel.

Project Objectives

Develop an innovative platform for waste plastics upcycling to **PO and diamines**, demonstrated and validated for PE-PU foams, which are abundant materials used in consumer applications, such as packaging, bedding, carpeting, car seats, and apparel.

Specific Objectives:

(Obj.1) Quantitatively benchmark proposed circular technologies relative to incumbent, linear manufacturing by performing TEA and LCA of PE-PU recycling to POs and diamines;

(Obj.2) Apply biological PE-PU processing with enzymatic degradation optimized via in vitro directed evolution approaches for maximal enzymatic rates;

(Obj.3) Apply chemical and mechanical approaches to improve reactive accessible surface areas of the solid PU interface for enzyme action and purify and sort PO and diamine upcycled products;

(Obj.4) Implement market transformation and commercialization plans focused on domestic manufacturing and product distribution.

Approach

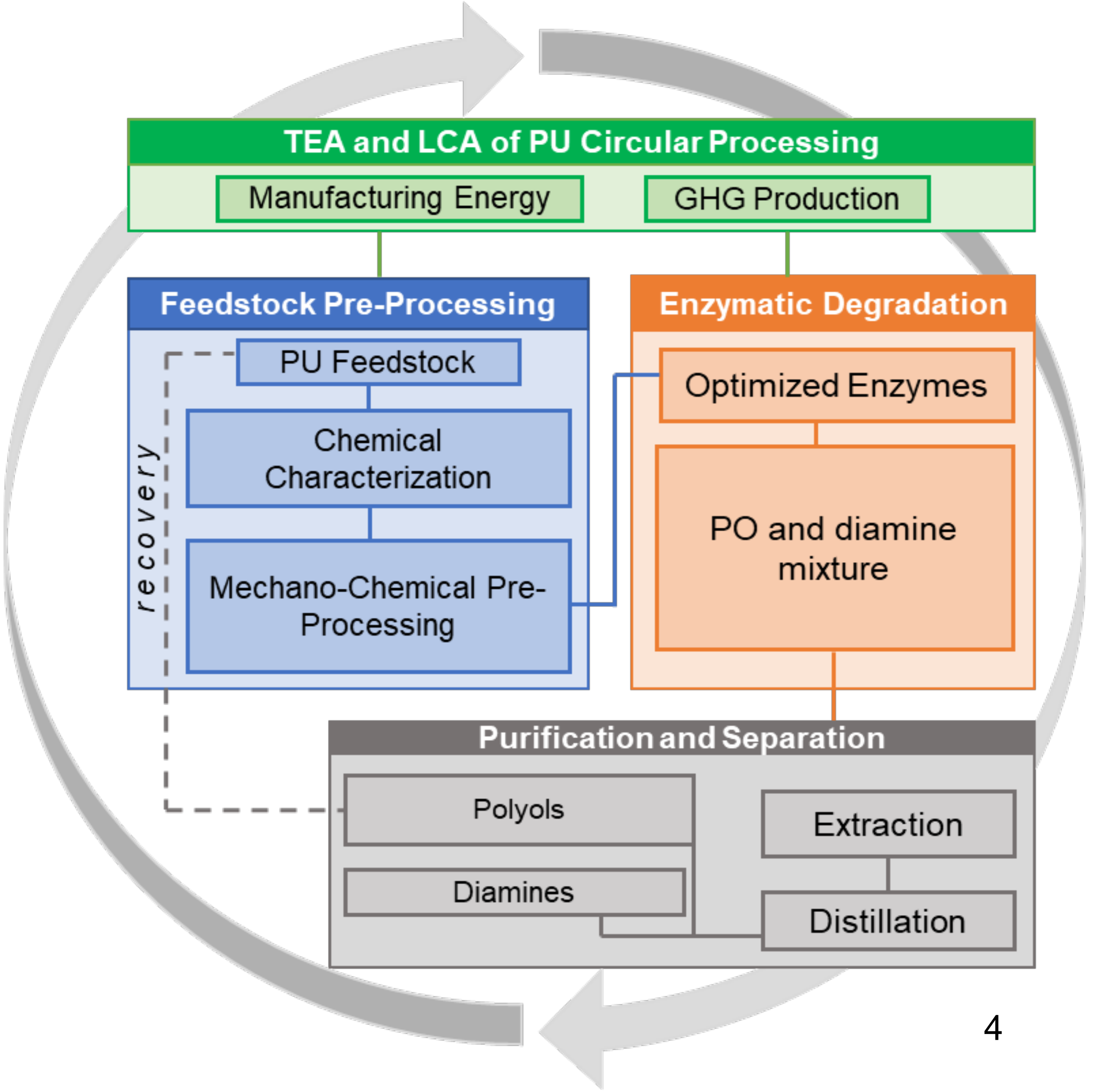
Technical Approach

HARNESS process hybrid technologies for upcycling of polyether-polyurethane (PE-PU) foams to high value polyols and diamines.

Techno-economic and life-cycle assessments mitigates risk of thermodynamic inefficiencies; etching, grinding and mild alkaline hydrolysis coupled with PU degradative enzymes ensure sufficiently rapid biocatalytic breakdown rate and throughput.

Although regenerated polyols and nitrogen-containing compounds are expected to separate well with simple liquid-liquid extraction (continuous gravity decanting), distillation is used as a mitigation approach for low volatility products.

The HARNESS technology will be implemented as a scalable operation with minimal facility footprint requirements, in either existing waste treatment or chemical processing plants, and will establish a new upcycling paradigm for PU materials.



Approach

Top Risks

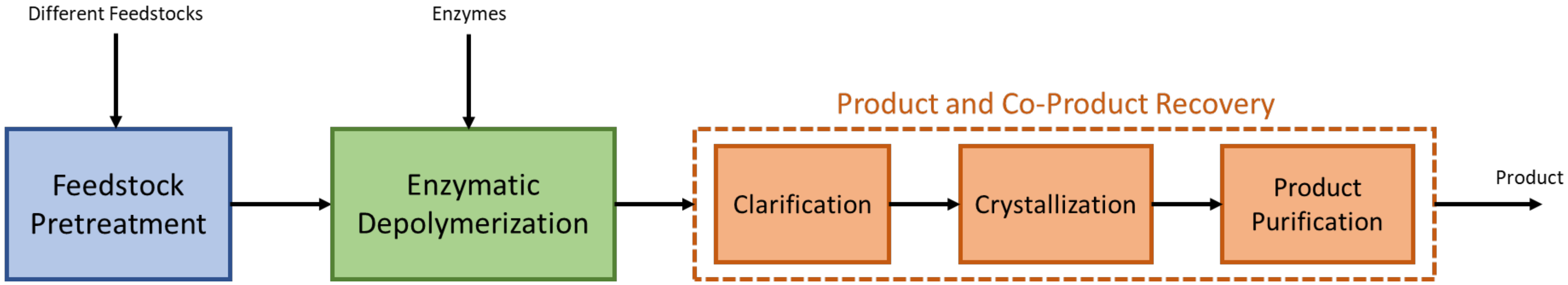
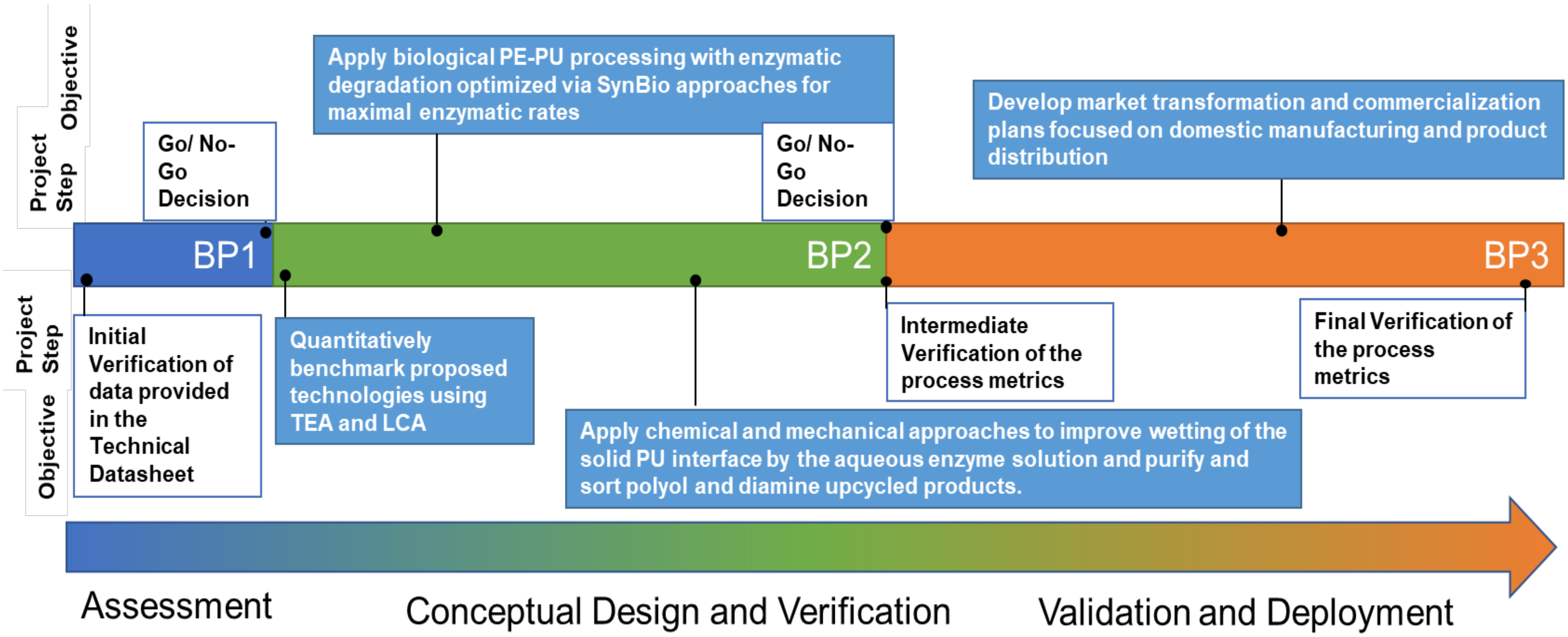


Figure: Process diagram for enzymatic depolymerization of plastics.

Challenges	Risks	Mitigation
Mechano-chem processing uses high energy inputs	Too high energy usage at scale proves not economical	Use of low energy pre-processing coupled with mild acid digestion
Lack of effective PE-PU conversion with available enzymes	Slower progress on enzymatic degradation	Bio sourcing campaign as an alternative source for enzymes with PU degradation capability

Approach
Go-No-Go Decision Points



Approach

Economic and Technical Metrics to Measure Progress

Parameter/Performance	
General Information	
Process Feedstock	*e.g. Unpretreated corn stover, Hydrolysate, Pyrolysis Oils, Biogas*
Mode of Operation	Batch/Continuous
Scale for batch operations or feed rate for continuous operations (1 L, 200 L, 10 g/hr, 5 kg/hr. etc.)	*Provide the scale or feed rate associated with the experiment used to generate benchmark data. For the intermediate and final targets provide envisioned scale or rate.*
Salable Fuel Product	*e.g. butanol, diesel blend stock*

Approach
Team Communication

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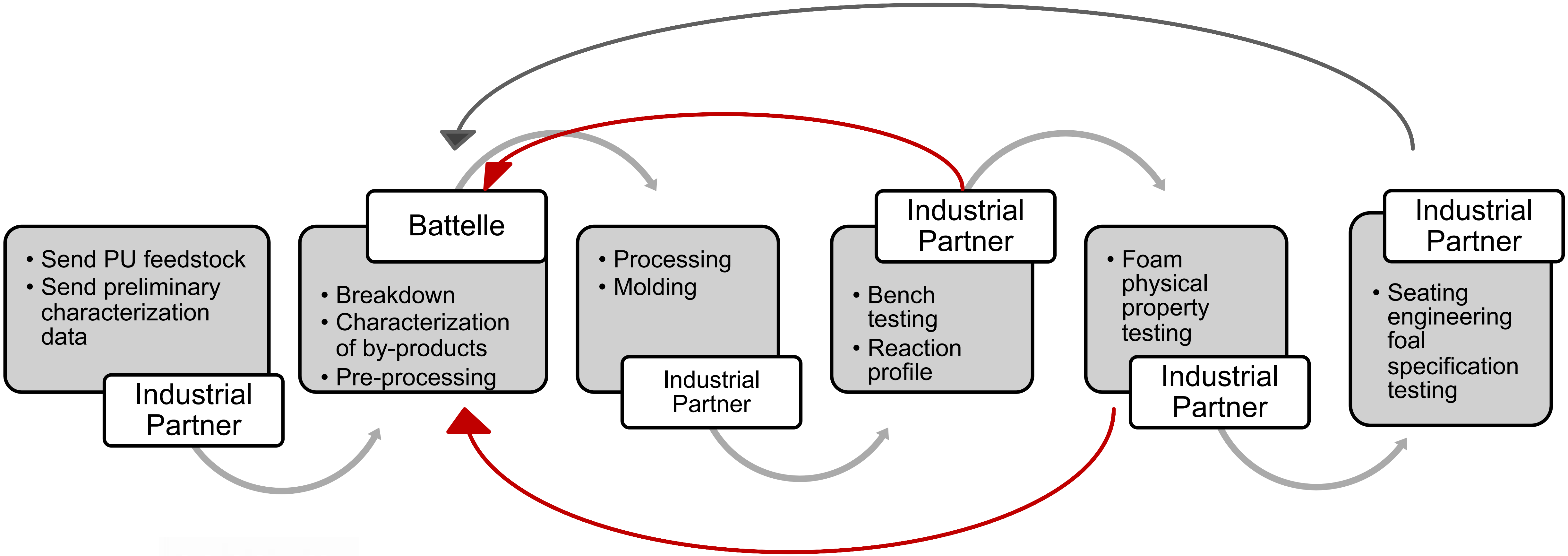
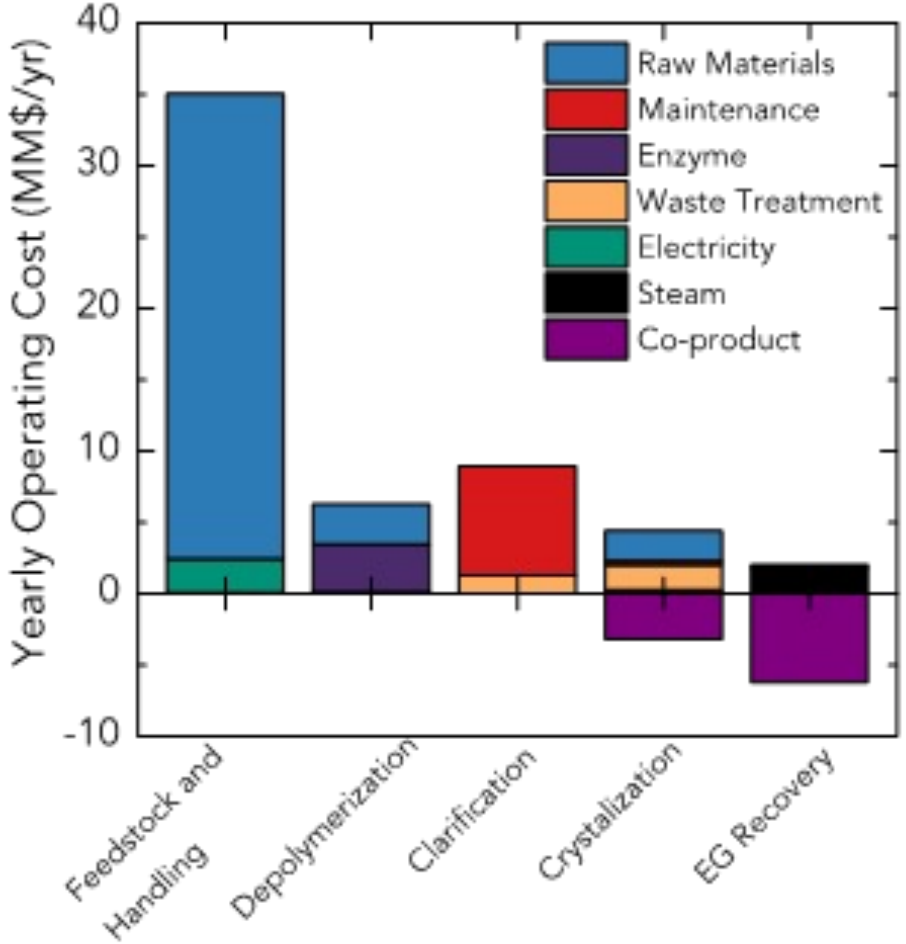


Progress and Outcomes

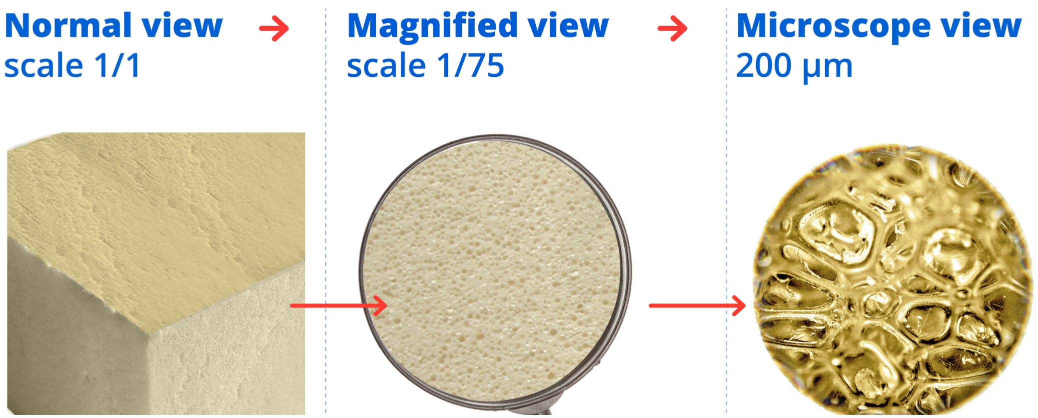
TEA/LCA Analysis

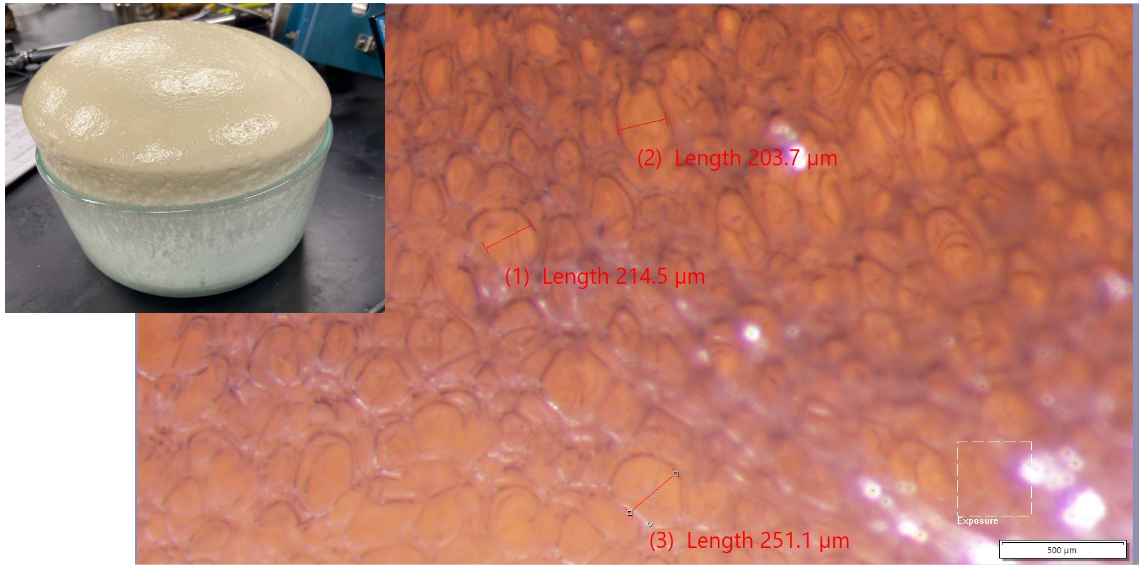
- The detailed cost breakdown that combines the capital and operating contributions from each process step for PET enzymatic depolymerization.
- Highest contribution (29%) to the total capital investment is from product recovery steps followed by feedstock pretreatment and the depolymerization section at 20% each.
- Feedstock cost is the largest contributor to the operating expenses.
- Due to the variable nature of post-consumer waste composition, and the lack of uniformity in sorting schemes, the purity grade and relative contaminant percentages of plastics feedstock vary between material recovery facilities which, in turn, will affect the quality and price of the feedstock.
- Additional sensitivity cases were explored where depolymerization-related sensitivities such as solids loading, enzyme loading, residence time and the extent of conversion stand out as the dominant factors to the overall cost of the process.



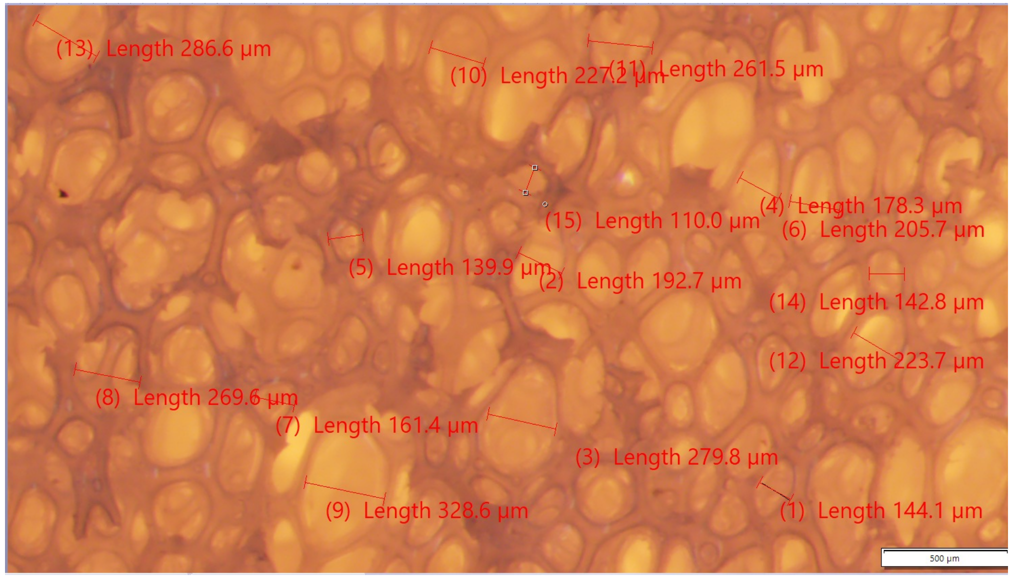
Progress and Outcomes
Material Characterization

- Collaborators from Faurecia, Steelcase and BASF provided industrial feedstock for work in the program





Battelle's standard foam formulation for BOTTLE BP2

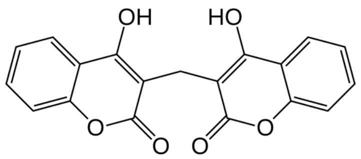


Commercial foam

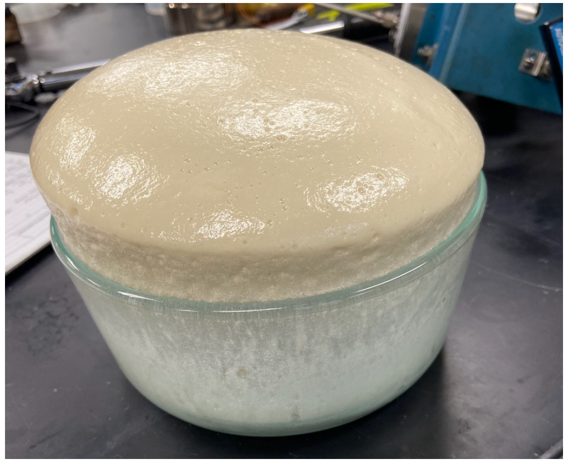
Progress and Outcomes

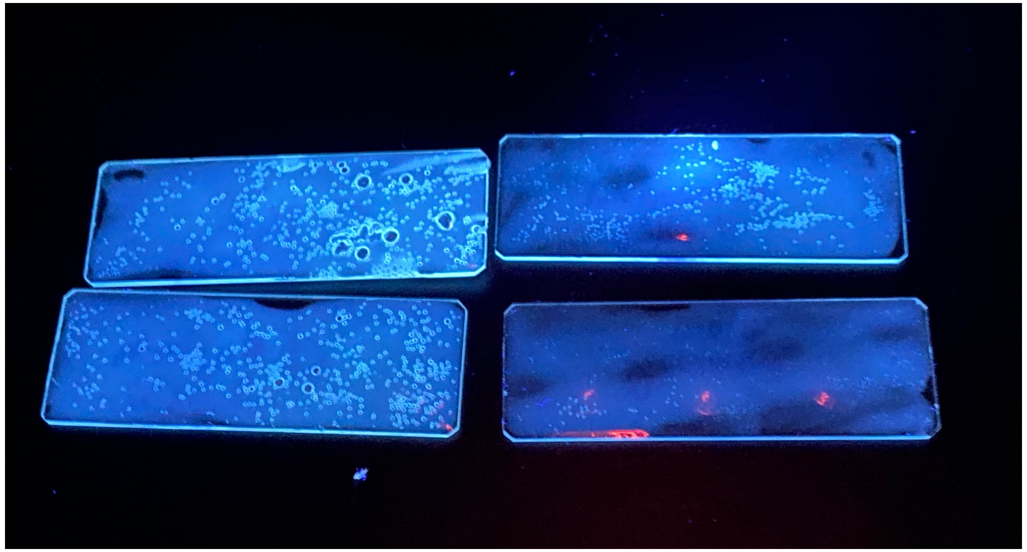
Development of Analytical Methods for Degradation Detection

Battelle's standard foam formulation for BOTTLE BP2 translated to film, with fluorescent crosslinker included



Fluorescence tracking in the process of degradation. Excitation light wavelengths of 395 nm (blue), 450 nm (green), and 525 nm (red).





Progress and Outcomes

Status of Key Milestones

Milestone Summary Table								
Budget Period	**Task No**	**Subtask**	**Milestone Type**	**Milestone No**	**Milestone Description**	**Milestone Deliverables**	**Anticipated Date**	**Anticipated Quarter**
1	1	1	Go/No-Go	1.1-1.3	PMP2 in the DOE Data Management Plan Technical Data Sheets	Send to DOE for approval Send to DOE for approval Send to DOE for approval	3 MAA3	Q1Y1

Milestone Completed

Progress and Outcomes

Status of Key Milestones

Milestone Summary Table

Budget Period	Task No	Subtask	Milestone Type	Milestone No	Milestone Description	Milestone Deliverables	Anticipated Date	Anticipated Quarter
	2	2.1		2	TR4 Initial TEA, LCA results	Send preliminary report of data modeling for energy inputs and greenhouse gas emission for PE-PU foams	6 MAA	Q2Y1
	3	3.1 &3.2		3.1	TR - PU material characterization data and pre-processing methods and data	Send 3-5 slides for commercial PU characterization and pre-processing developed methods	12 MAA	Q4Y1
		3.3 & 3.4		3.2	TR- Industrial PU characterization data and pre-processing data	Send 3-5 slides for commercial PU characterization and pre-processing developed methods	15 MAA	Q1Y2
2	4	4.1 & 4.2	Milestone	4.1	TR - Optimization of enzymes and degradation efficiency data	Send data report and 3-5 slides for enzyme efficiency and commercial PU degradation. Degradation must meet at least 60% efficiency	15 MAA	Q1Y2
	5	5.1		5.1	TR – Upcycling of PU degradation products	Send 3-5 slides for separation and purification methods of PU materials for upcycling into secondary products	18 MAA	Q2Y2
	6	6	Go/No-Go	6	TR - Intermediate Verification Data	Provide data sheets and demonstrate process efficiency to the DOE reviewers. Meet at least 60% energy reduction and 60% recycling goals	18 MAA	Q2Y2
	7	7.1	Milestone	7.1	RPPR in the DOE requested format	Send to DOE for approval	every 3 mo	Q1-Q4

Milestone Completed

Impact

- PE-PU flexible foam is used in a wide range of durable applications (mattresses, upholstered furniture, and vehicles). In 2016, 18 million tons (MT) of PU were produced worldwide, representing 5.3% of global plastic production, and ranking as the 7th most produced synthetic polymer.

DOE

- The end-of-life stage is more challenging and only 10% of total PU waste being recycled.
- Efficient upconversion processes are critically needed to divert more PE-PU foam material from landfills and establish at least 40% energy savings.
- DOE support benefits the domestic economy by integrating local manufacturing facilities into the scaleup steps which align with the BOTTLE Consortium’s mission to improve energy productivity across the manufacturing/industrial sector.

Environmental

- The product verification and analysis will document the economic benefits and the decrease in greenhouse gas (GHG) emission.
- The HARNESS process will be easily adaptable and reconfigurable to other plastics to the benefit of the circular economy.

Path to Commercialization

- The target market for the HARNESS degradation products represents producers being Dow/Sadara, Covestro, Shell, BASF, and Huntsman.
- HARNESS project integrates key industrial PU formulators and manufacturers such as BASF, Faurecia and Steelcase that participate in technology development strategy and are vested in terms of transition of HARNESS technology into the market space.

Summary

- HARNESS strives to develop a proof-of-concept pilot system designed to break down polyether-polyurethane (PE-PU) foams with engineered enzymes, then convert breakdown intermediates to high-value polyols (POs) and diamines.

- HARNESS team has developed a pipeline of methods to characterize waste PU material, produce industrially relevant PU material for testing and is screening for enzymes with ability to degrade PE-PU

- Program has a clear commercialization plan with multiple industrial partners to transition the developed technology into operations.

Quad Chart Overview

Timeline

09/30/21 – 08/30/25

DEFOA-0002245	FY22 Costed	$1,299,778
DOE Funding	*(10/01/2021 – 9/30/2022)*	
Project Cost Share *		$502,400

TRL at Project Start: TRL0
TRL at Project End: TRL6

Project Goal

HARNESS strives to develop a proof-of-concept pilot system designed to break down polyether-polyurethane (PE-PU) foams with engineered enzymes, then convert breakdown intermediates to high-value polyols (POs) and diamines.

End of Project Milestone

RPPR in the DOE requested format
Send to DOE for approval

Funding Mechanism

DEFOA-0002245

Project Partners*

- NREL
- Allonia

*Only fill out if applicable.

Additional Slides

Responses to Previous Reviewers' Comments

- If your project has been peer reviewed previously, address 1-3 significant questions/criticisms from the previous reviewers' comments which you have since addressed
- Also provide highlights from any Go/No-Go Reviews

Note: This slide is for the use of the Peer Reviewers only – it is not to be presented as part of your oral presentation. These Additional Slides will be included in the copy of your presentation that will be made available to the Reviewers.

Publications, Patents, Presentations, Awards, and Commercialization

- List any publications, patents, awards, and presentations that have resulted from work on this project
- Use at least 12 point font
- Describe the status of any technology transfer or commercialization efforts

Note: This slide is for the use of the Peer Reviewers only – it is not to be presented as part of your oral presentation. These Additional Slides will be included in the copy of your presentation that will be made available to the Reviewers.