DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Process Intensified Modular Upcycling of Plastic Films to Monomers by Microwave Catalysis

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Plastics Deconstruction and Redesign

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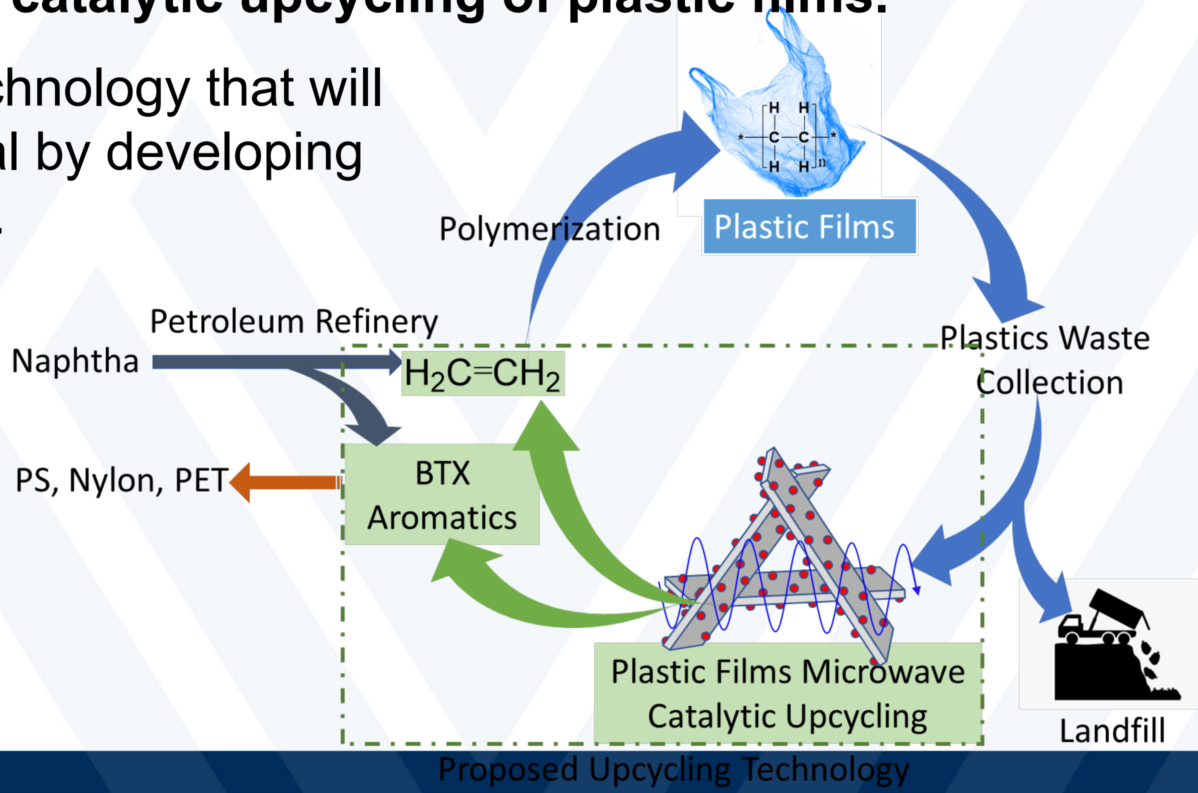
Project Overview

The overall objective of the project is to develop a plastic films upcycling technology that are economically favorable, lower greenhouse gas (GHG) emissions, and efficient conversion of embodied energy of plastics to value added monomer. This will be accomplished through the exploitation of microwave-specific effects on the catalytic upcycling of plastic films.

The project addressed the BETO goal that seeks technology that will make the recycling of polymer films more economical by developing novel degradation, recycling and upcycling methods.

Single-use plastic films, which are primarily made up of ***LDPE (Low Density Polyethylene)*** are the leading contributor of plastic waste at 50%, the vast majority of which is **landfilled** or **leaked into the environment**, harming the natural environment, losing the energy and value embedded in this class of materials.



Project Overview

Single-use films present a particularly difficult circularity challenge.

<u>State of the art technologies</u>

- **Mechanical Recycling:** Very few recyclers include plastic films: jam the rotary sorters; degradation problems
- **Chemical Recycling:**
  - Pyrolysis: 300–900◦C without O_2, liquid or wax products;
  - Gasification: 700–1300◦C with gasifying agent, syngas ($CO+H_2$)
  - Hydrogenolysis: 300◦C,> 3 MPa H_2, alkanes products.

Energy intensive and higher GHG emission; Low control over product selectivity; Low value of products

<u>Proposed technology</u>

Microwave catalytic plastic upcycling

(1) **High energy efficiency** (< 300 ◦C and ambient pressure);

(2) **High conversion**;

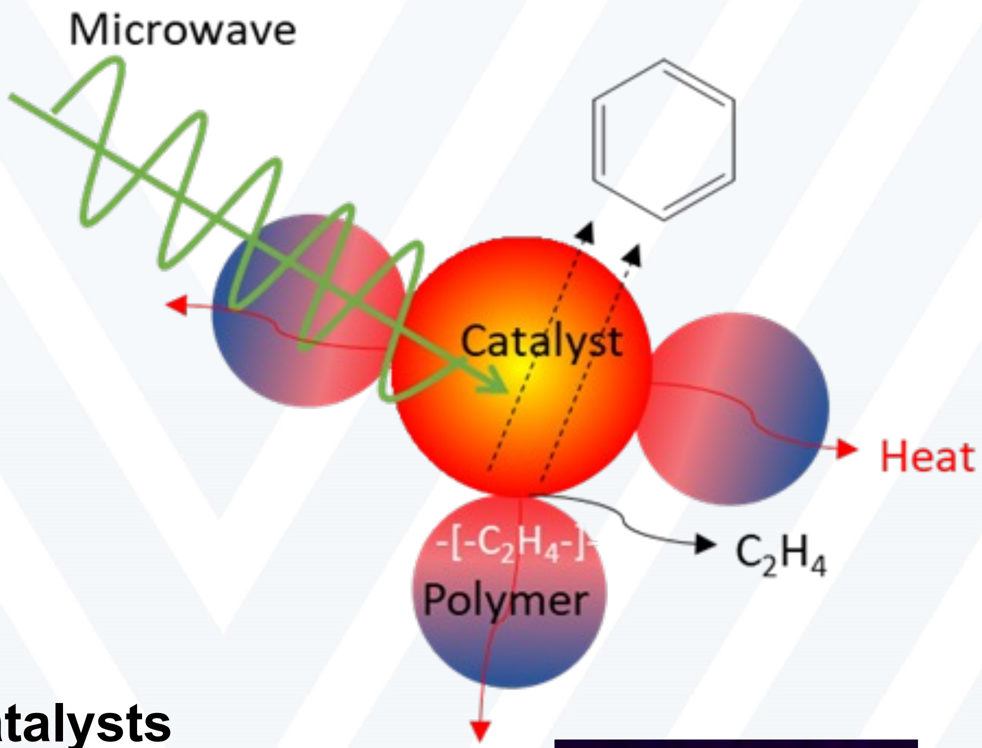
(3) **High value of product**- Olefins and BTX

The project will address microwave sensitive **catalysts development and process optimization**, **Continue Feeding Microwave Reactor (CFMR)** development for process scaleup, as well as develop **TEA and LCA** to evaluate economic, energy, and environmental benefits.

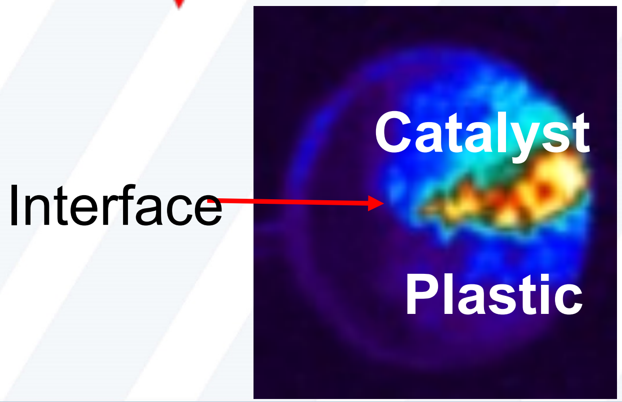
1 – Approach

In the proposed upcycling process, the catalyst particles play two roles simultaneously.

- One is the efficient transfer of microwave electromagnetic energy into thermal heat.
- The other is the catalytic function that enables reactions to occur when the particle reaches the necessary temperature.



The project will address microwave sensitive catalysts development, microwave catalytic upcycling system scalability investigation, as well as the economic, energy, and environmental benefits evaluation.



1 – Approach

Technical Scope

In BP I,

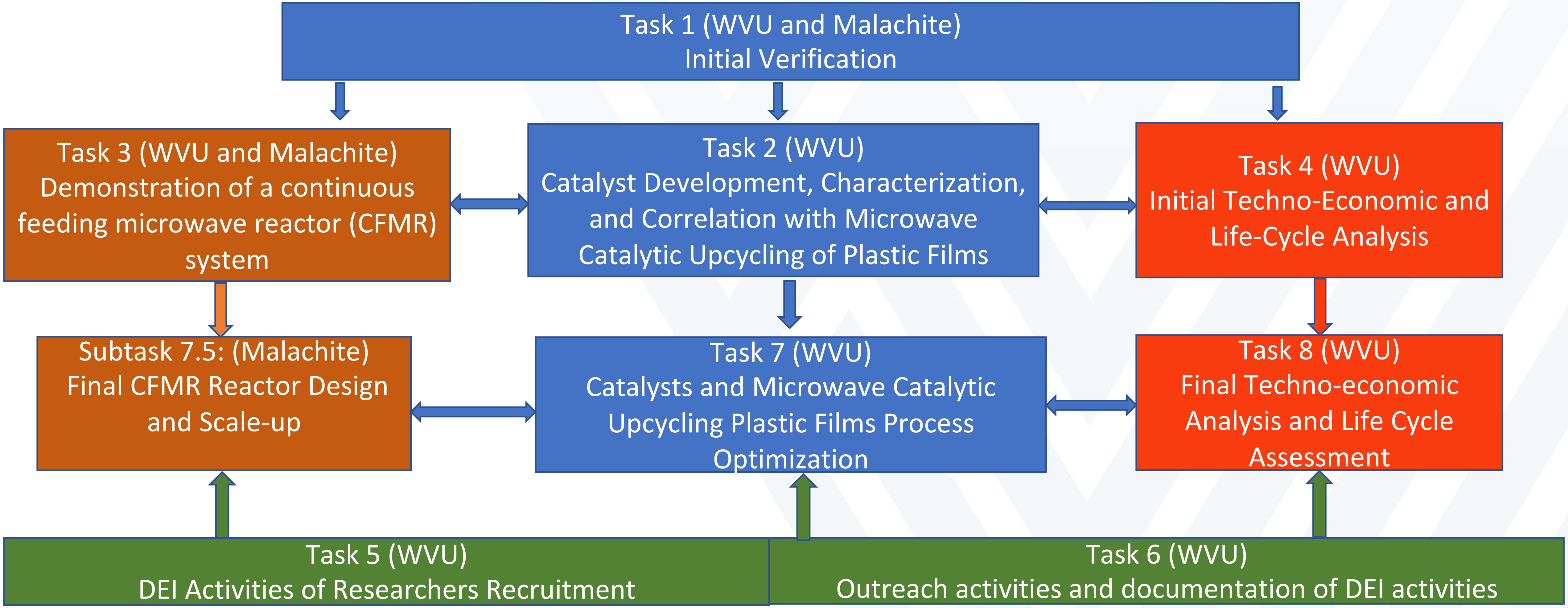
- Synthesis and characterization microwave upcycling catalyst.
- Evaluation the microwave catalytic upcycling performance of developed catalysts.
- Build preliminary techno-economic (TEA) and life-cycle analyses (LCA) Models.
- Design and construct an initial continuous feeding microwave reactor (CFMR)

In BP II,

- Optimization of catalysts, the process parameters, and microwave configurations.
- Optimization of CFMR reactor system.
- Perform the detailed TEA and LCA.

1 – Approach

Management, communication, and collaboration



1 – Approach

Potential challenges, risks, and mitigation strategies

BP 1:

High performance catalysts development, catalyst should have high catalytic activity as well as high microwave adsorbing ability. Meanwhile, catalyst coking should a challenge.

Research group has experience in microwave catalyst development for natural gas conversion, ammonia synthesis. This will help plastic depolymerization catalyst develop.

Continuous Feeding Microwave Reactor CFMR fabrication

Malachite has been designed a high-capacity H-filed cavity development for microwave ammonia synthesis at Kilograms/day scale in our collaborative ARPA-E project. This is experience will help CFMR reactor develop.

BP 2:

Keep the 100% conversion at 200 ◦C .

Besides catalyst optimization, the process parameters and microwave configuration also affected the plastic depolymerization performances. All these effects will be investigated.

1 – Approach

Go/No-Go decision points

Decision Point	Success Criteria
End of BP1	• The plastic films conversion reaches 100% at a condition below ≤300 °C, the yield of valuable monomers >75% BTX yield or >60% olefins. • The initial CFMR reactor has been fabricated; • The initial first-principles process models set up for TEA/LCA.
End of BP 2	• The microwave catalytic system optimized, the plastic films will be 100% depolymerized at 200 ◦C, with light olefines and BTX as main products. • Compared to conversional ethane cracking process, the proposed technology will achieve the proposed technology will achieve 55-65% energy saving and 50-60% GHG reduction, 55-75% post-use carbon management, and 60-70% cost saving.

DEI Activities

- WVU Research Apprenticeship Program (RAP)
  A female undergraduate student is recruited and join in the project.
- WVU Summer Undergraduate Research Experience (SURE)
  PI is SURE faculty mentor, recruiting more undergraduate students.

2 – Progress and Outcomes

List of Milestones Completed and Tasks on-going

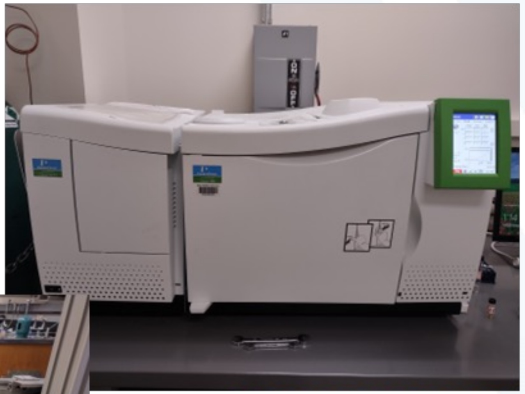
Currently, the project on Q2 (M4-M6)

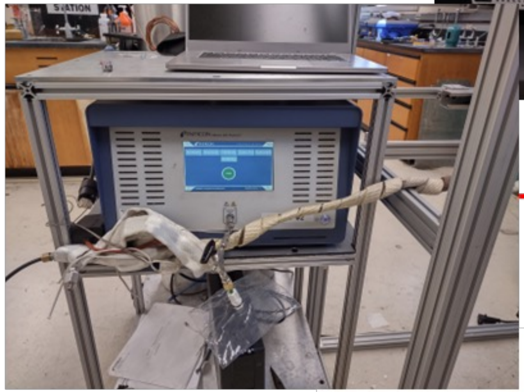
Task/Milestone #	Task/Milestone Description	Status
M1.0 (M1-M3)	The baseline data (80% PE films decomposition at 500 °C thermal catalytic conditions) and project targets (> 80% decomposition at 300 °C with microwave catalytic upcycling) will be experimentally verified.	Completed
M2.3 (M4-M9)	Real-word Plastic Films Pretreatment, different sizes of plastic film particles will be prepared for further microwave catalytic upcycling.	Completed
M 5.0 (M4-M18)	1-2 undergraduate students from the local disadvantaged communities will be recruited to work on this project, particularly female students.	Completed
Task 2.0 (M4-M15)	Catalyst Development, Characterization, and Correlation with Microwave Catalytic Upcycling of Plastic Films	On-going
Task 3.0 (M4-18)	Demonstration of a continuous feeding microwave reactor (CFMR) system	On-going
Task 4.0 (M4-18)	Initial Techno-Economic and Life-Cycle Analysis	On-going

2 – Progress and Outcomes

Experimental Design

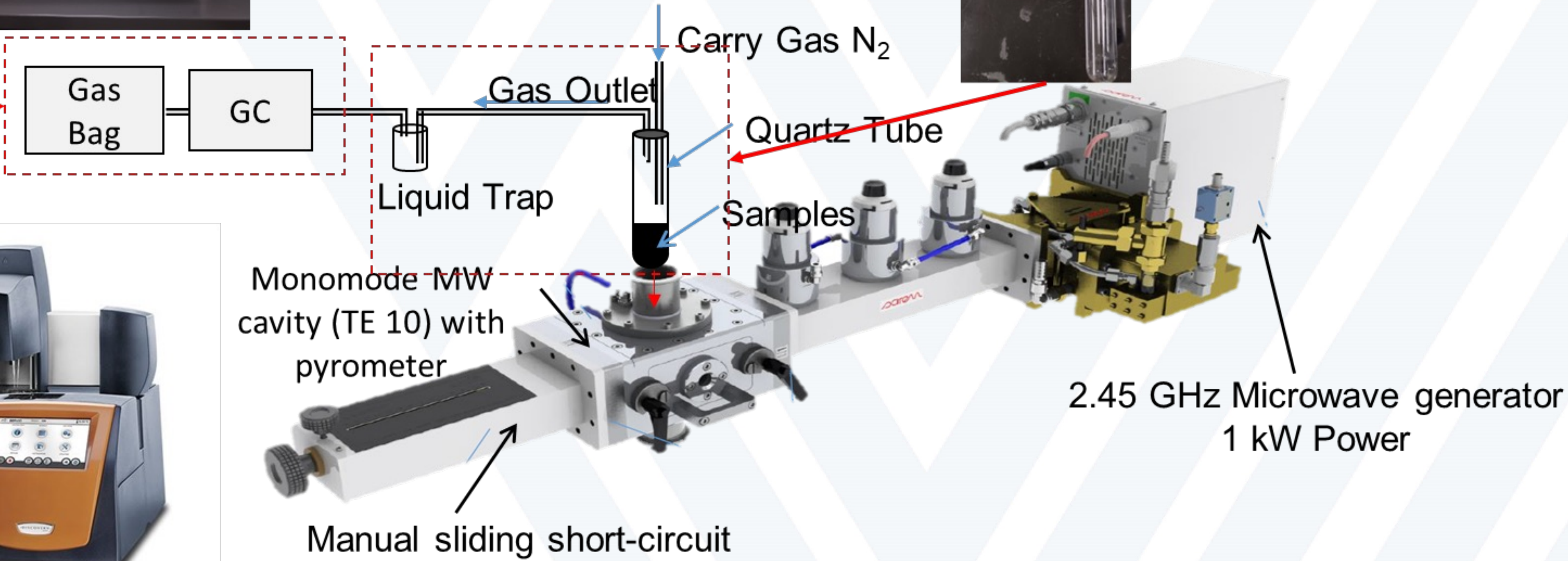
Liquid Products





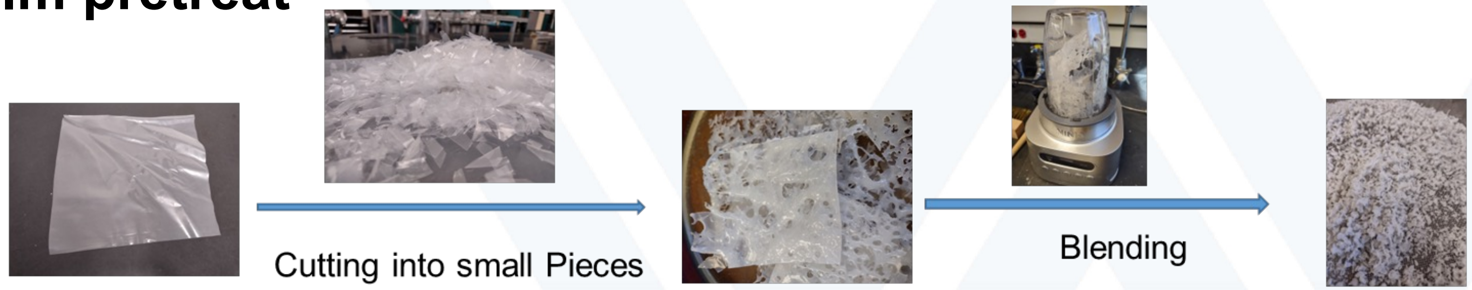
Gas Products

Solid Residue Products



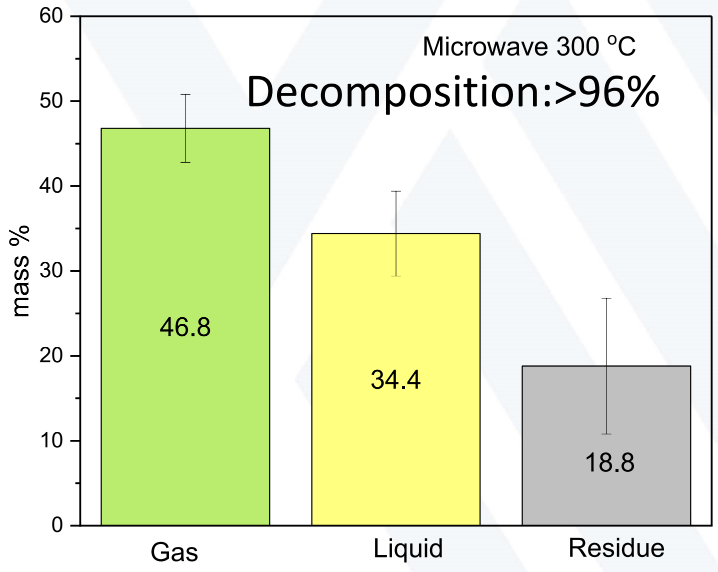
2 – Progress and Outcomes

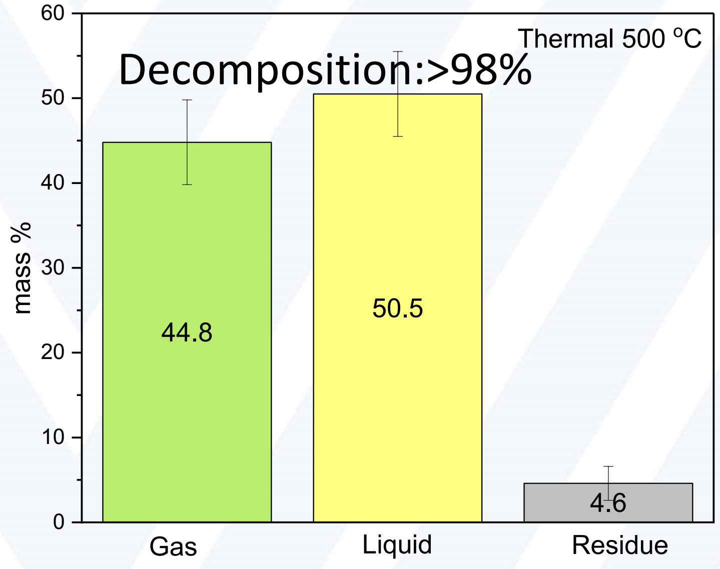
Real plastic film pretreat



Verification Testing

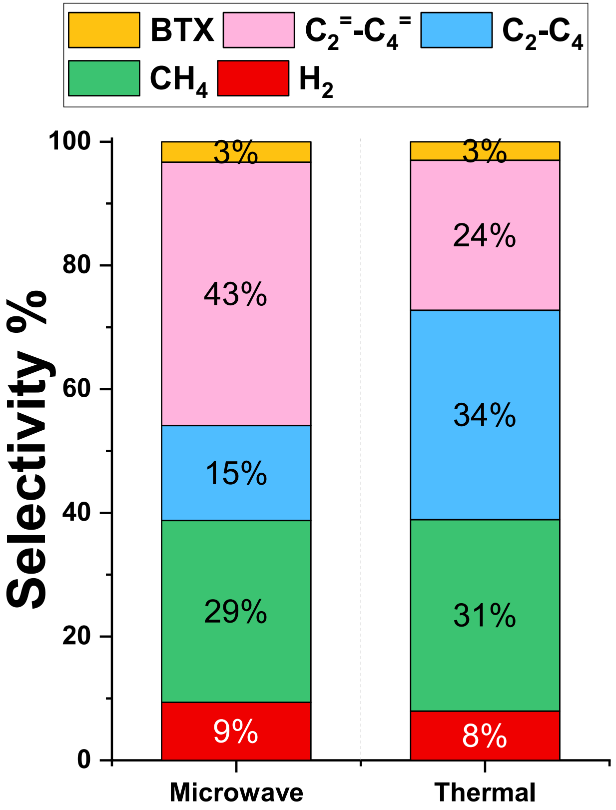
- Catalyst: $CsRu/CeO_2$ 3g
- Real Plastic Film, 1g
- Temperature: thermal 500 °C; Microwave 300 °C
- Ramping rate: 20 °C/min
- Time: 1 h



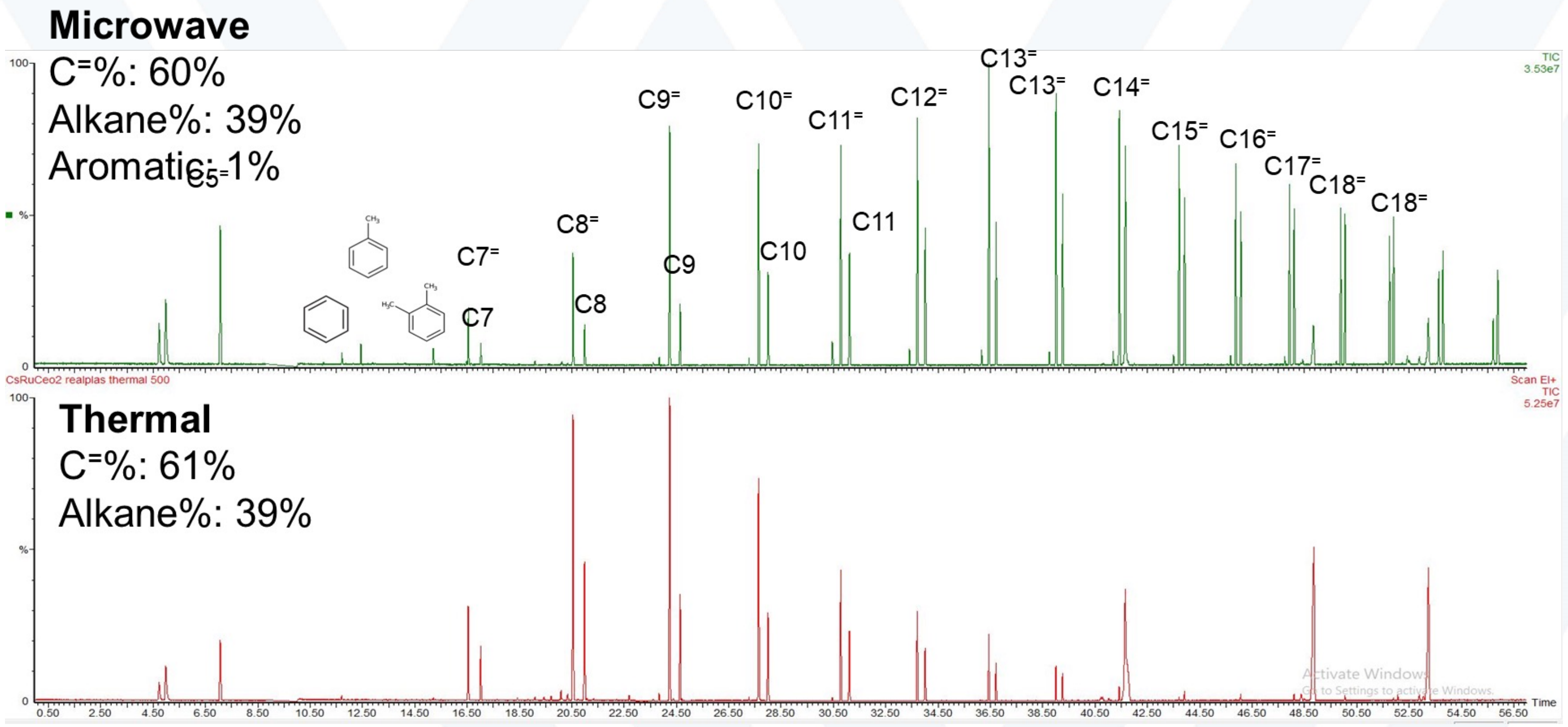


2 – Progress and Outcomes

Gas Analysis



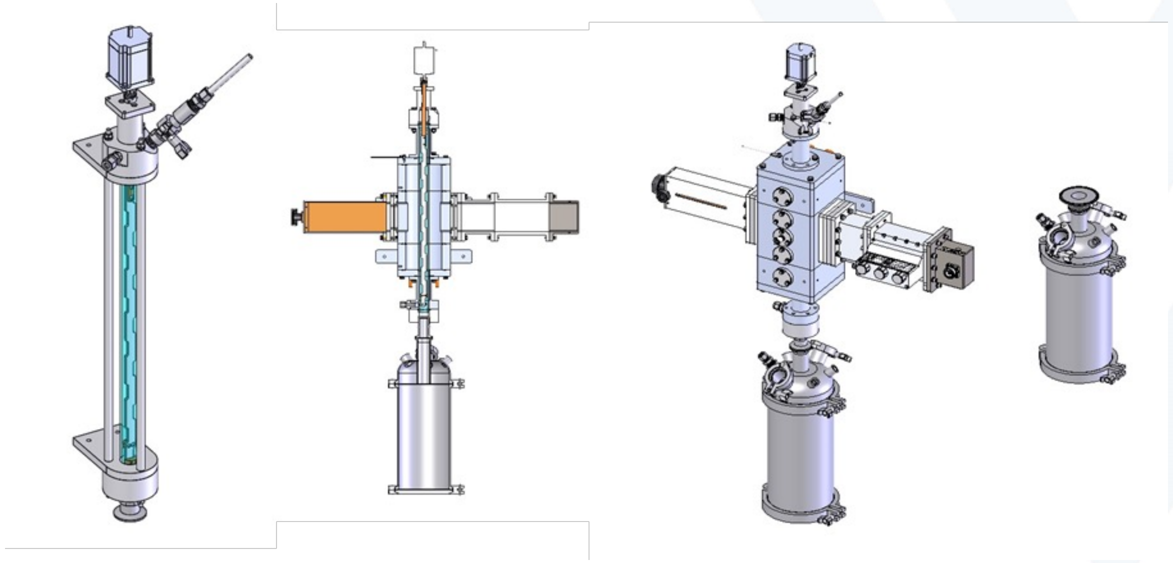
Liquid Analysis



Testing methodology and analysis protocols set up

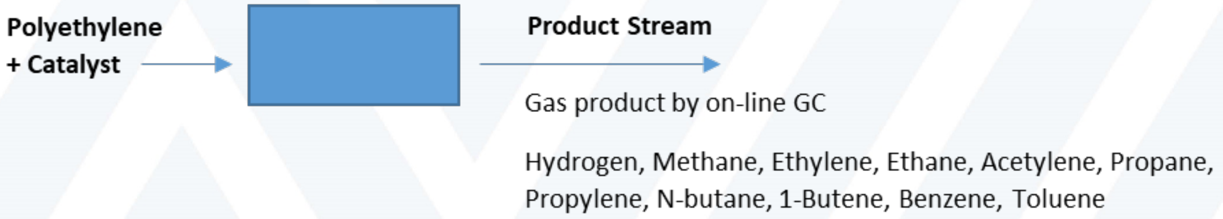
2 – Progress and Outcomes

Continuous feeding microwave reactor (CFMR) system development



Multiple reactors are in development and will soon be tested.

Initial Techno-Economic and Life-Cycle Analysis



A kinetic model for a lab scale reactor is in development based on experimental data. Later, this kinetic model will be utilized to develop a full-scale reactor and an initial first-principle process model will be developed by incorporating this reactor model. The whole work will be done in Aspen Custom Modeler (ACM).

3 – Impact

Scientific and Technical Impact

The project advance both basic and applied plastic upcycling research. Understanding the reaction mechanism at interface of catalyst-plastic under microwave irradiation is important for basic plastic upcycling research.

Expect the first publication coming soon.

Economic and Environmental Impact

Efficiently upcycle plastic films could lead to energy savings and GHG emissions reduction. Moreover, use the upcycled products as feedstocks could reduce the demand for virgin resin production and consequently lessen the need for upstream refining of petrochemicals.

Summary

- *The project focused on the microwave catalysis upcycling plastic films technology development.*
- *The project will address microwave sensitive catalysts development and process optimization, Continue Feeding Microwave Reactor (CFMR) development for process scaleup, as well as develop TEA and LCA to evaluate economic, energy, and environmental benefits.*
- *The concept of proposed technology was experimentally verified.*
- *The microwave sensitive catalysts, CFMR system, and TEA/LCA are in development and optimize.*

Quad Chart Overview

Timeline

- *Project start date 07/01/2022*
- *Project end date 06/30/2025*

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022)* *$0*	*(negotiated total federal share)* *$1,500,000*
Project Cost Share *	$0	$376,484

TRL at Project Start: 3
TRL at Project End: 5

Project Goal

The overall objective of the project is to develop a plastic films upcycling technology that are economically favorable, lower greenhouse gas (GHG) emissions, and efficient conversion of embodied energy of plastics to value added monomer.

End of Project Milestone

The microwave catalytic system will be developed and optimized for plastic films upcycling. With optimized catalysts and process parameters, the plastic films will be 100% depolymerized at 200 ◦C, with ethylene and BTX as main products. Compared to conversional ethane cracking process, the proposed technology will achieve the proposed technology will achieve 55-65% energy saving and 50-60% GHG reduction, 55-75% post-use carbon management, and 60-70% cost saving.

Funding Mechanism

FOA: DE-FOA-0002473; Topic Area: 1 Novel Approaches to Recycle and Upcycle Films; Year: 2021.

Project Partners*

- Malachite