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DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

Development of Infinitely Recyclable Single-Polymer Chemistry Bio-based Multilayer Films Using Ethylene/Carbon Monoxide Copolymers

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Plastics Deconstruction and Redesign

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U.S. DEPARTMENT OF ENERGY

Project Overview

- ***Packaging is the leading contributor of plastic waste at 45%.*** *Within this plastic waste, polyethylene represents by far the largest fraction. The predominance of polyethylene in packaging waste is the direct result of its tunability and low cost.*

- *To solve the problem of* ***accumulating multilayer packaging waste*** *and* ***high carbon footprint*** *of these materials, we propose to redesign current multilayer packaging and develop* ***infinitely recyclable single-polymer chemistry bio-based multilayer films****.*

- *As polyethylene is the main source of plastic pollution, we believe that the only solution to create economically viable and sustainable packaging is through* ***synthesis of novel bio-ethylene-based copolymers****.*

Project Overview

- *Alternating ethylene-carbon monoxide copolymers generally possess mechanical properties comparable to high density polyethylene. The oxygen permeability of these polyketones is reported to be as low as ethyl-vinyl alcohol and polyamide. However, their* ***processing conditions and stability is substantially different than polyethylene****.*

- *In this project, we aim to design and develop at least on prototype of multilayer films based on* ***non-alternating ethylene-carbon monoxide copolymers*** *that can be used in standup pouches for packaging application, which compared to conventional multilayer packaging displays:*

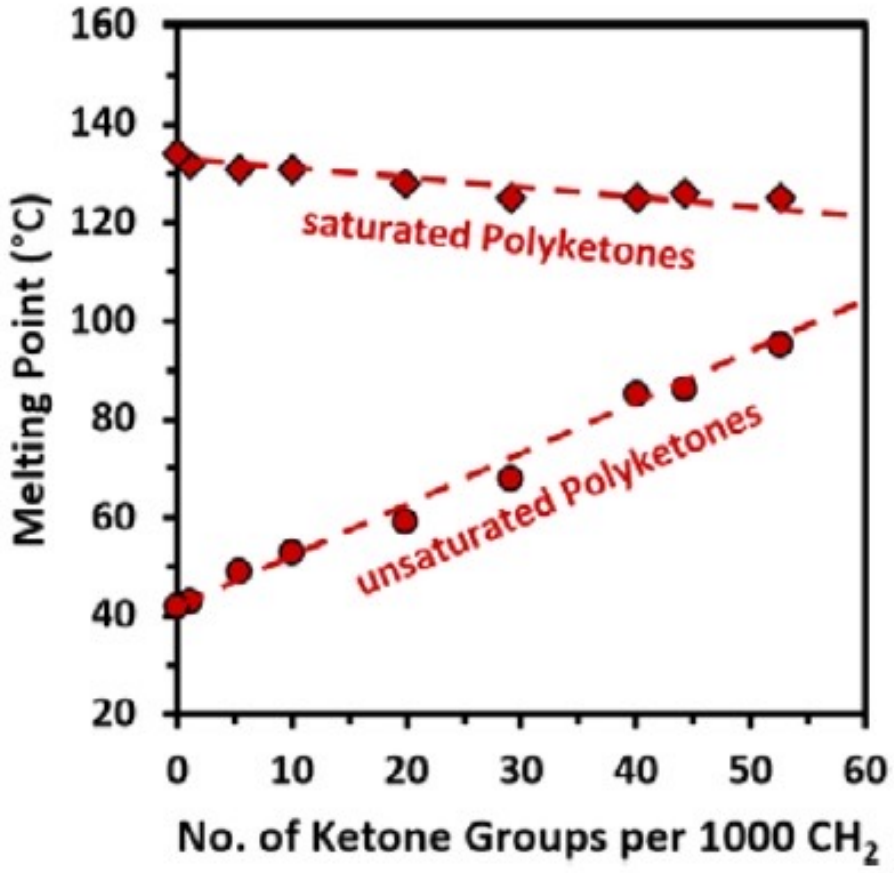
1) 10% cost reduction

2) Comparable performance

3) 60 to 80 wt% recycled carbon utilization in the final design

4) 60% energy saving during production

Approach



- *Non-alternating ethylene-carbon monoxide copolymers with lower amounts of carbon monoxide can potentially exhibit mechanical properties and barrier properties close to high density polyethylene and polyamide, respectively.*

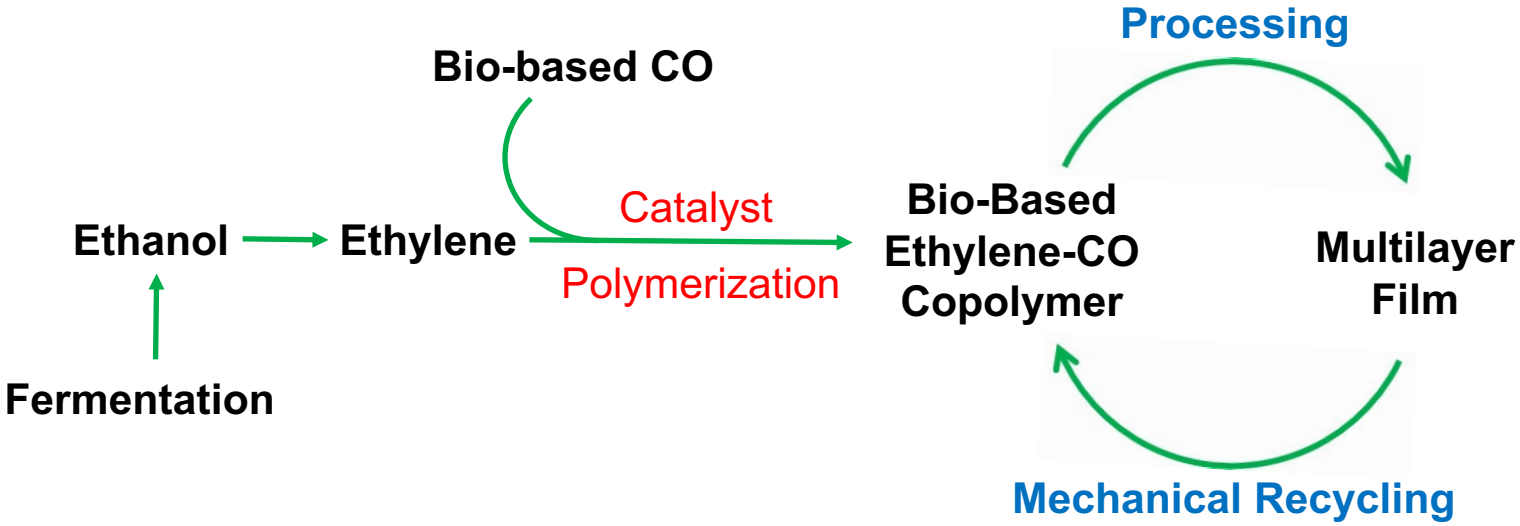
- ***Prof. Guironnet's** group at the **University of Illinois** has successfully demonstrated non-alternating catalytic copolymerization of ethylene and carbon monoxide. We will use this catalyst to synthesize ethylene-carbon monoxide copolymers under various polymerization conditions and define structure-property relationship for these novel ethylene-based copolymers.*

Ortmann P. et al. *ACS Macro Letters* **2015**, 4, 704.

Approach

- *We will focus on two designs for our proposed ethylene-carbon monoxide copolymer-based multilayer packaging.*

- *Proposed path for producing and recycling of the multilayer films:*



Approach

- *Go/No-Go decision points:*

  - ***Go/No-Go Decision Point 1 (M3):*** *Process information and data supporting the technology readiness level of the overall process, the unit operations within the process, and the original application. Technical metrics are based on preliminary data and represent a meaningful baseline and set of targets. Upon successful completion of the initial verification effort and Go/No-Go decision point, the project will commence with work on the Priority Areas as discussed.*

  - ***Go/No-Go Decision Point 2 (M21):*** *Provide two designs of ethylene-carbon monoxide copolymer based multilayer film, one in the form of multilayer made of one specific ethylene-carbon monoxide copolymer and one a multilayer film made of ethylene-carbonmonoxide copolymers with different CO content, that would have similar mechanical and oxygen barrier properties as the conventional multilayer film used in standup pouches for packaging application specified by* ***Unilever****. The ethylene-carbon monoxide copolymer based multilayer films should show similar or greater properties based on mechanical and permeability calculations. The values used for aforementioned calculations will be deduced from ethylene-carbon monoxide copolymers structure-property relationships.*

Approach

- *Diversity, equity, and inclusion plan:*

  - *Educate a diverse class of students at the **University of Illinois** and **Princeton University** through formal class materials discussing plastic life cycles and participation in research efforts.*
  - *Actively participate in campus efforts to recruit undergraduate researchers and underrepresented students of color.*
  - *Practice standard hiring procedures prioritizing underrepresented comminutes in the interview process.*
  - *Engage in educational outreach efforts with local schools with a particular focus on disseminating our knowledge in minority-serving institutions and other appropriate institutions serving underserved communities.*
  - ***WYSE High School Summer Camps** (High School), **PlastiVan Society of Plastics Engineers Foundation** (Grades 6 to 12), and **Science Day/Día de la Ciencia** are some of the outreach activities planned by our team.*

Progress and Outcomes

- *Finalized **Task 1.0: Initial Task Verification** and proceeded with **Budget Period 1 Go/No-Go** decision.*

- *Began activities in **Budget Period 2**:*
  - ***Task 2.0:** Synthesis of ethylene-carbon monoxide copolymers*
  - ***Task 3.0:** Characterization of ethylene-carbon monoxide copolymers*
  - ***Task 4.0:** Study of nucleophilic addition to carbonyl groups of ethylene-carbon monoxide copolymers*
  - ***Task 5.0:** Characterization of conventional multilayer films used in packaging*

Impact

- *Reduce the environmental impact of multilayer packaging, enhancing the value of packaging waste as a resource, and limiting its presence in United States landfills and oceans.*

- *Enable the creation of new business opportunities that are adjacent to the core of this project proposal (manufacturing, compounding, and recycling). This will, in turn, create new jobs and spur economic growth within the United States.*

- *Draw polyolefin manufacturers, converters, and recycling companies to the innovative concepts contained within.*

Summary

- *In this project we will demonstrate the economic viability and sustainability of the innovative scientific and engineering concepts explored by producing at least one prototype of "Infinitely Recyclable Single-Polymer Chemistry Bio-based Multilayer Film" using ethylene-carbon monoxide copolymers that can be used in standup pouches for packaging applications.*

- *The outcome of this project will reduce the environmental impact of multilayer packaging, enable the creation of new business opportunities, and draw polyolefin manufacturers, converters, and recycling companies to the innovative concepts contained within.*

- *We have finalized Budget Period 1 tasks and began Budget Period 2 activities.*

Quad Chart Overview

Timeline

- Project Start: *10/01/2022*
- Project End: *09/30/2025*

	FY22 Costed	Total Award
DOE Funding	-	*$1,970,926.00*
Project Cost Share *	-	*$529,074.00*

TRL at Project Start: *TRL 3*
TRL at Project End: *TRL 6*

Project Goal

The goal of this project is to develop infinitely recyclable, cost competitive, high-performance bio-based multilayer films using ethylene-carbon monoxide copolymers.

End of Project Milestone

Produce at least one prototype of "Infinitely Recyclable Single-Polymer Chemistry Bio-based Multilayer Film" using ethylene-carbon monoxide copolymers that can be used in standup pouches for packaging applications, which compared to conventional multilayer packaging displays:

I) 10% cost reduction, II) comparable performance, III) 60 to 80 wt% recycled carbon utilization in the final design, and IV) 60% energy saving during production.

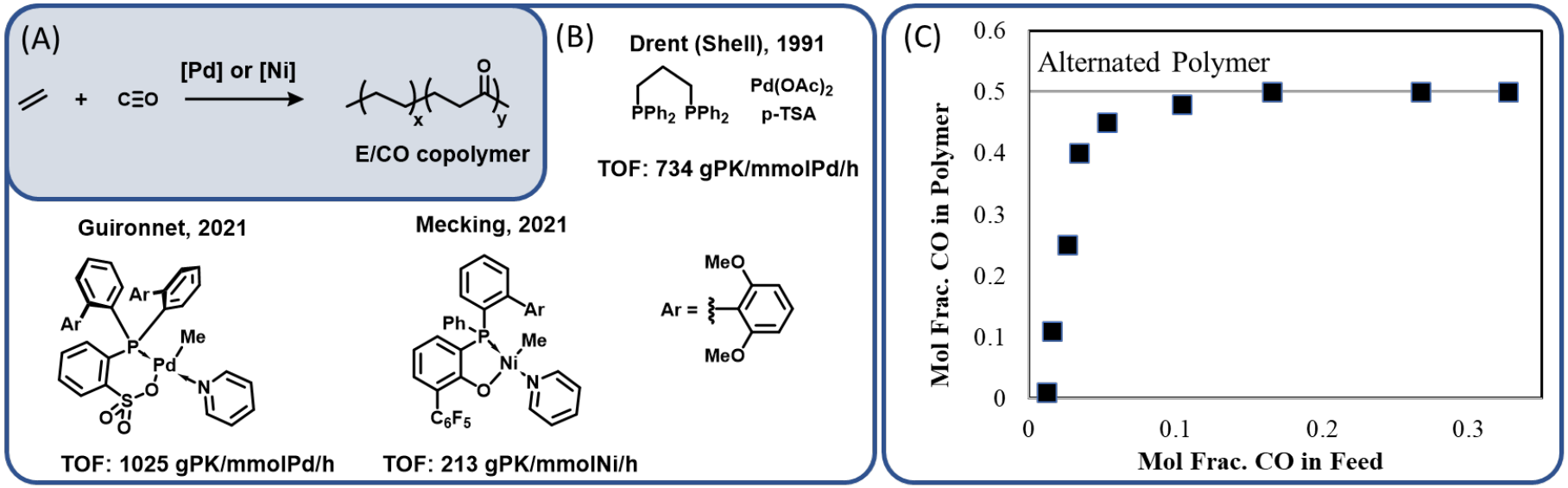
Funding Mechanism

DE-FOA-0002473, Single-Use Plastics Recycling (SUPR), 2021

Project Partners

- Princeton University
- University of Illinois Urbana Champaign
- Uniliver

Additional Slides

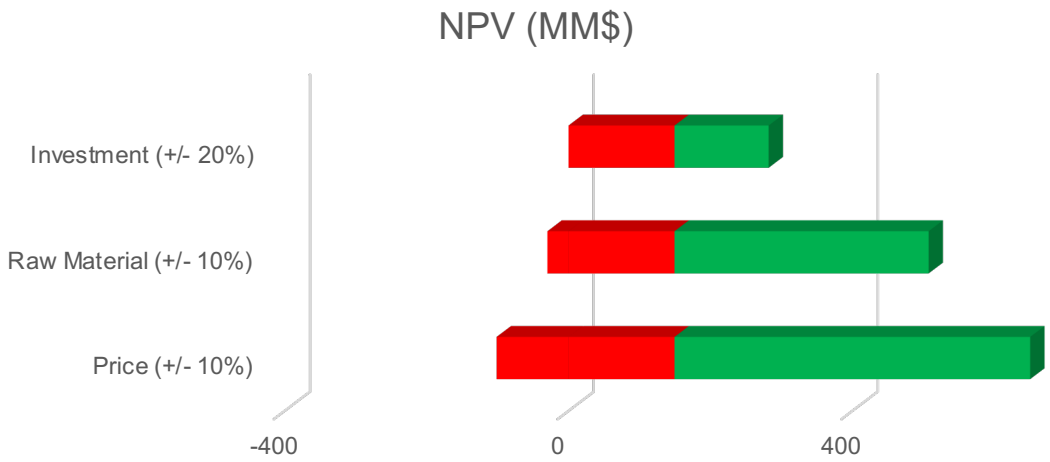


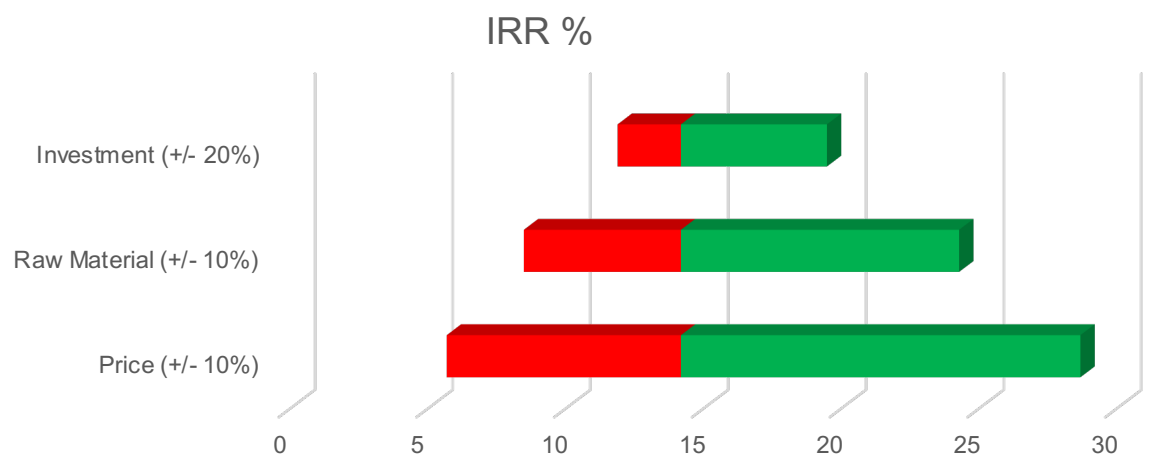
(A) Catalytic copolymerization of ethylene and carbon monoxide for the synthesis of non-alternated polyketone. (B) Examples of catalysts used for the copolymerization of ethylene and carbon monoxide. Rates of the catalysts are reported in turnover frequency (TOF, mass of polymer produced per mmol of metal per hour). (C) Experimental results obtained by Guironnet for the copolymerization of ethylene and CO. The ketone content in the copolymer is varied from 0 to 50 mol% by varying the monomer composition (polymerizations performed at a constant pressure)

Base case NPV=$149MM IRR% = 14.2%

Assumptions:

CAPEX & OPEX from IHS RW 2013-12 report, 400 KTA process
20-yrs project
90% capacity utilization





Sensitivity results for NPV and IRR of bio-based ethylene-CO copolymers production.