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# Modular, Distributable Systems for Plastics Circularity

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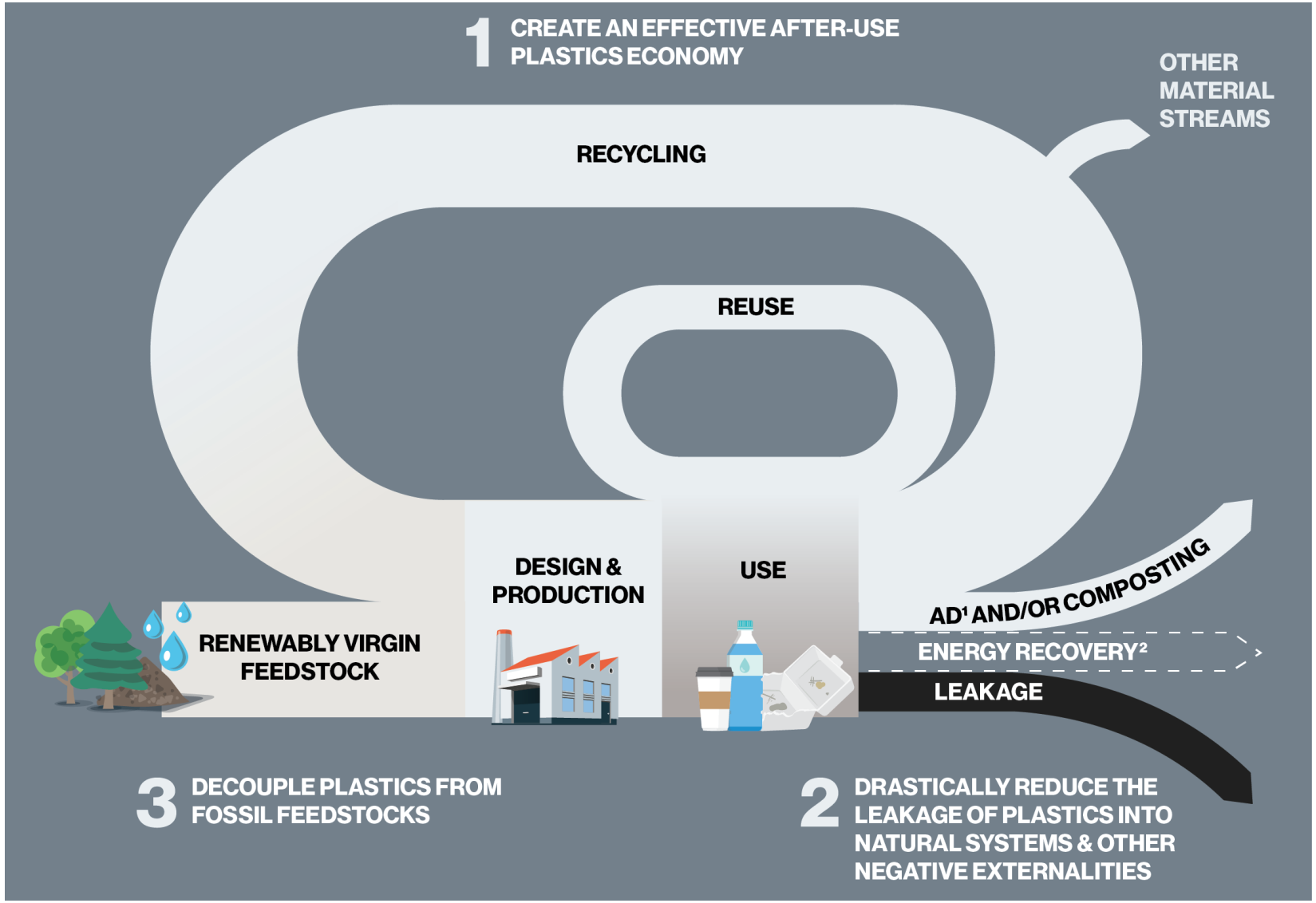
# What is Plastics Circularity?




Source: The New Plastic Economy, the Ellen Macarthur Foundation



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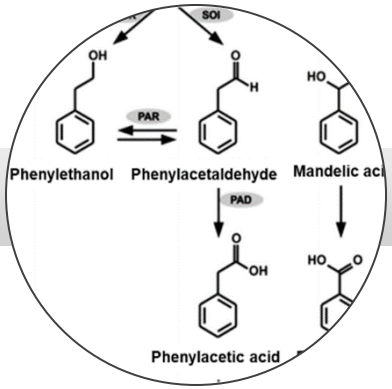
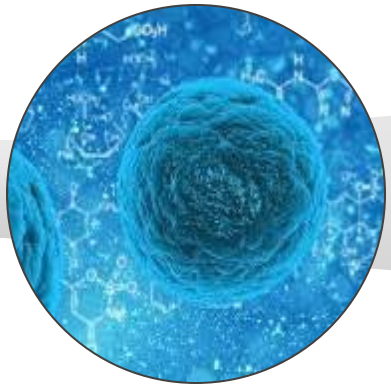
# Vision

**Use plastic waste as a feedstock for creating new classes of high value intermediaries**



Coatings

Toners

Adhesives

Foams

Additives

**Collect and Deconstruct**

**Upcycle to Intermediates**

**Generate New Products**



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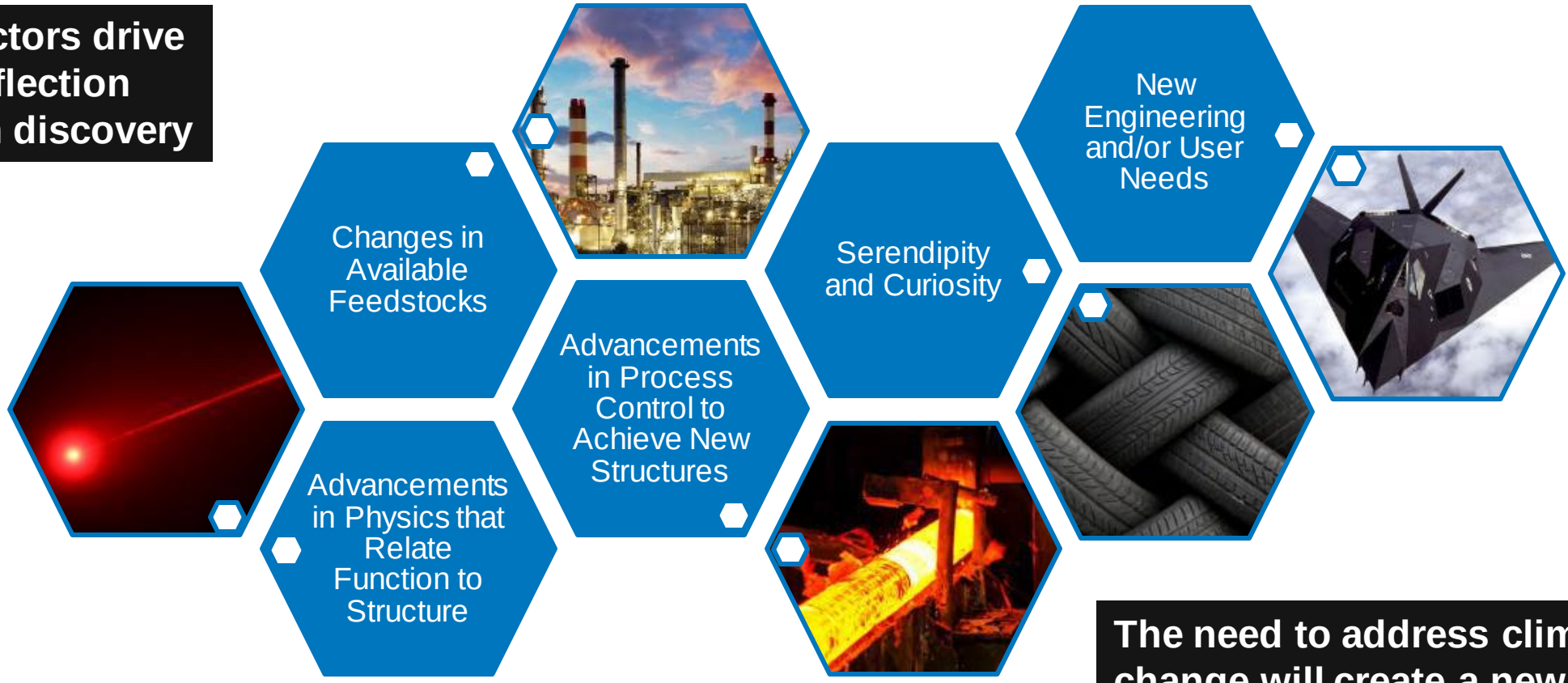
# Our Vision is Motivated by an Expected Inflection Point Created by a Need to Reduce Climate Impacts

**A few factors drive major inflection points in discovery**




**The need to address climate change will create a new set of economically valuable feedstocks**

# Plastic Waste as a Future Feedstock

- Today, most chemicals & polymers are created new from petroleum & natural gas. Multiple drivers are making plastic waste an economically valuable feedstock for chemicals & polymers.

**Energy Demands**

*Reduce energy inputs by 50% relative to virgin production*

**CO2 and other GHG Emissions**

*Save >1,080 Mton/CO2 by eliminating resin production*

**Tipping Fees for Landfilling**

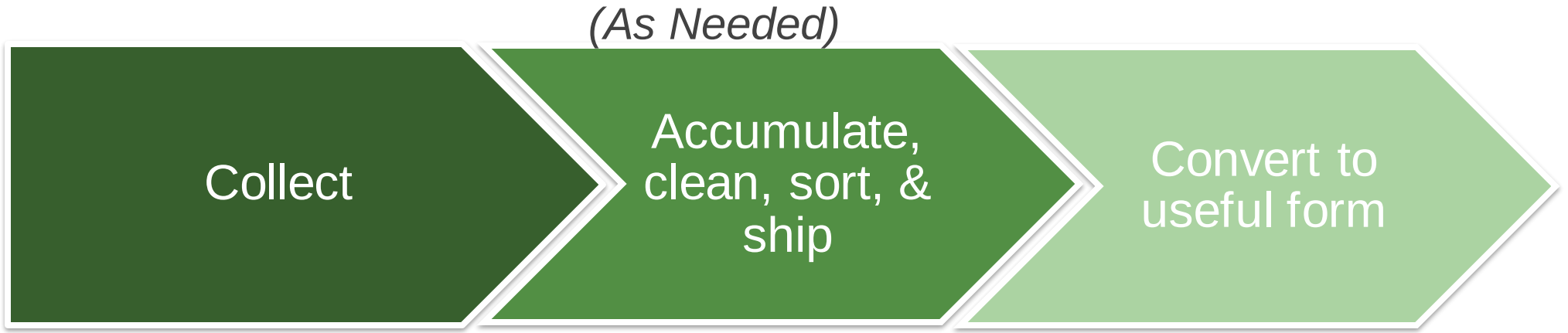
*Eliminate $53/ton (US) for landfilling plastic waste*

**Waste Leakage into Environment**

*Reduce economic impacts for remediation*

# First Step is To Develop Process to Unlock Value of Waste

## Collection and Deconstruction




- Simplest process is collect and convert. Figures of merit for conversion are:
  - Rate, Yield, and Specific Energy Consumption
- Accumulation, cleaning, sorting, and shipping to another central facility are all steps required because current systems:
  - Cannot convert dirty or mixed waste to useful format
  - Require large capital equipment to achieve low specific energy consumption



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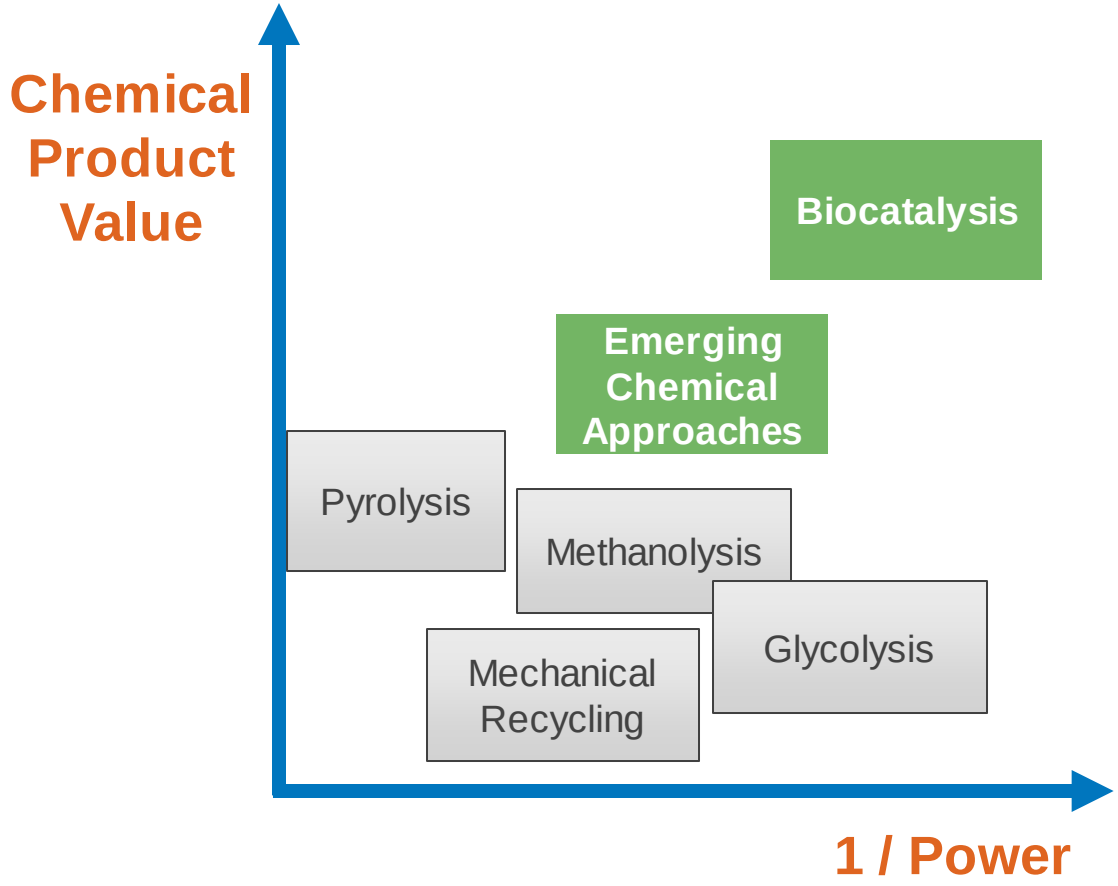
# Approaches to Deconstruction for Upcycling

Objective is to minimize power inputs and maximize value of product

- Biocatalysis offers the highest product value vs. operating power
- Emerging chemical approaches offer high potential for mixed waste streams




These approaches can enable distributed plastics upcycling



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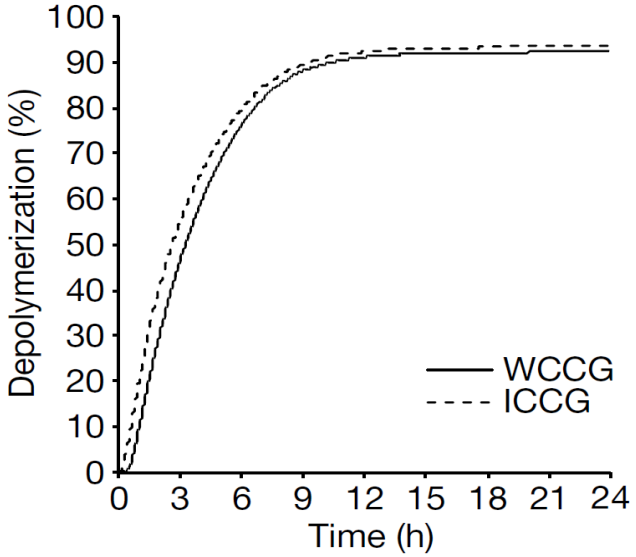
# Low Temperature Catalysts for Depolymerization: NREL's PETase Enzymes

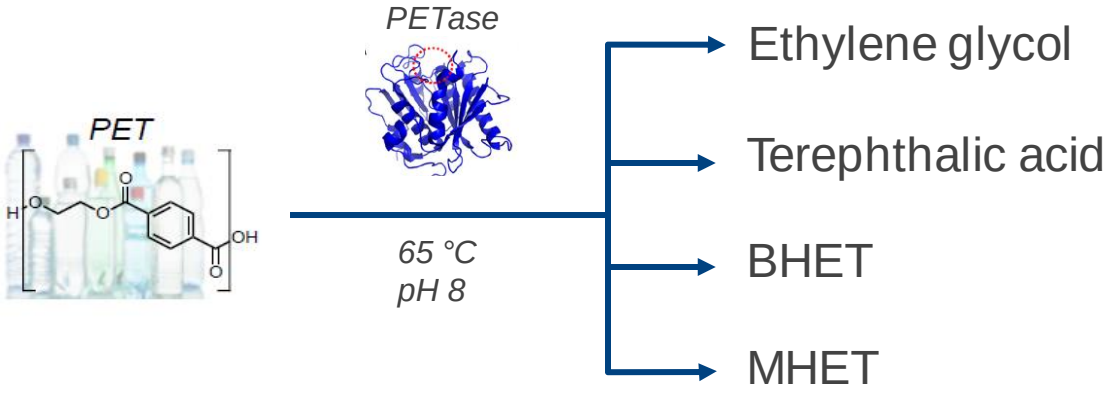
## Gregg Beckham Lab (NREL)

- High efficiency thermophilic enzymes that depolymerize PET, up to **>90% in 12 hours**.
- Shelf stable for months to years, thermally stable up to ~70 °C.
- NREL is optimizing enzyme structure to increase reactivity on crystalline PET.

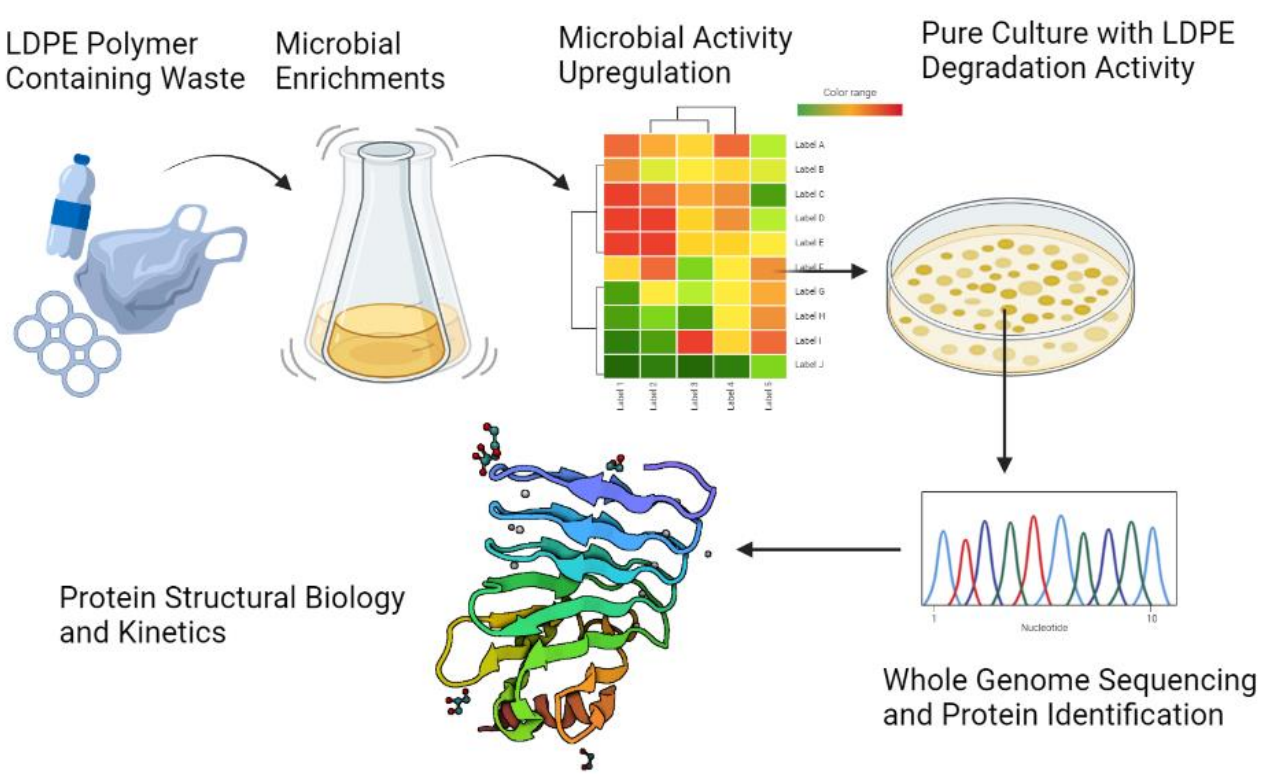

*(Data from DARPA ReSource Program)*

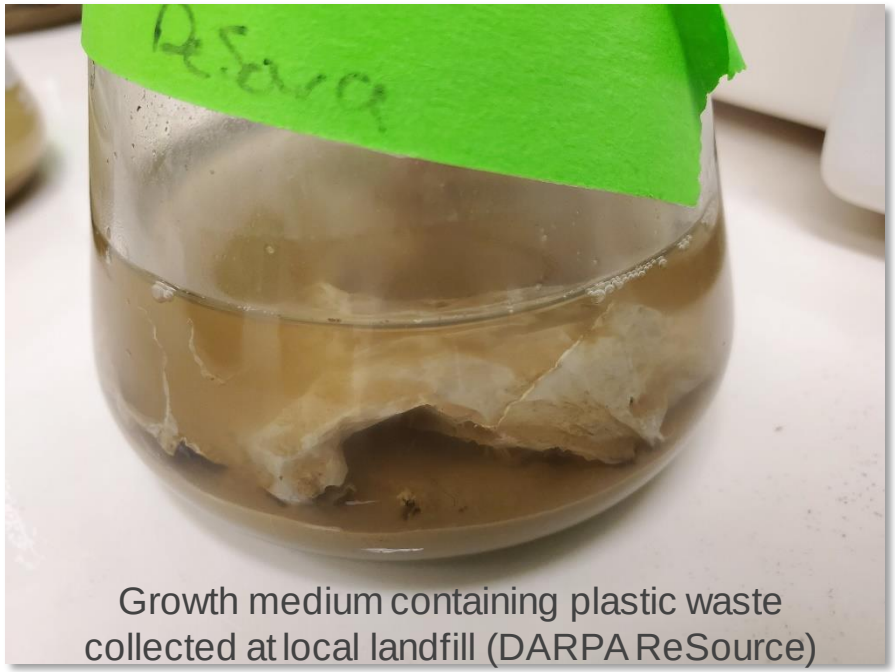



Tournier, V., et al. "An engineered PET depolymerase to break down and recycle plastic bottles." *Nature* 580.7802 (2020): 216-219.



# Discovery and Engineering of Biocatalysts for Degradation



Growth medium containing plastic waste collected at local landfill (DARPA ReSource)

- Biosourcing for microbial communities with ability to degrade plastic polymers
- Identification and/or engineering of proteins with catalytic ability to convert polymers to high value by products
- Kinetic conversion rates of polymer with purified enzyme to obtain optimal degradation rates



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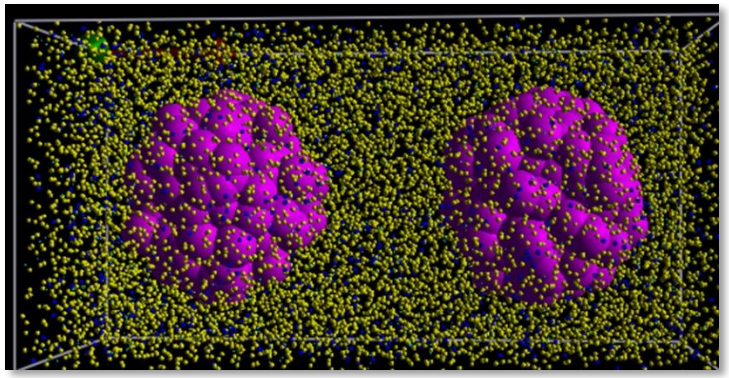
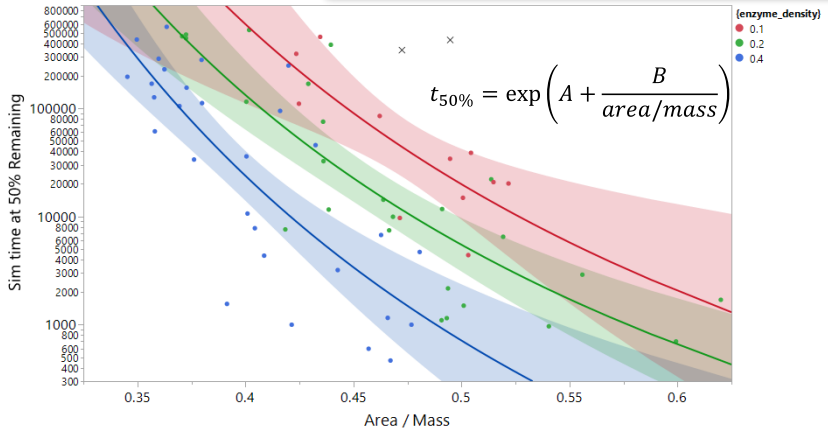
# Modeling & Methods for Discovery of High Activity Biocatalysts

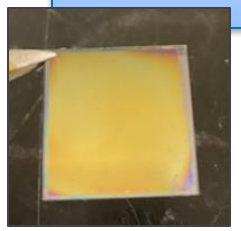
## Modeling Biocatalysis






Developing models that relate heterogenous catalyst activity and mass transfer to predict degradation rates and understand trade offs

## Analytical Tools

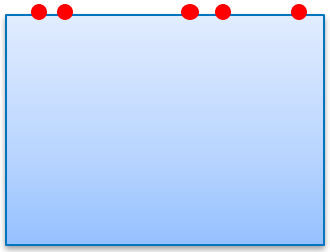


Polymer thin film made at Battelle

Polymer film

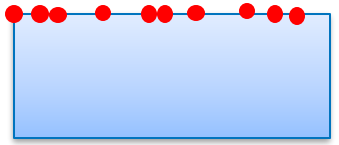
*Exposure to Catalyst*

Oxidation



Surface chemistry characterization

Nanoscale thickness reduction



Nanoscale thickness characterization

Developing hypersensitive analytical tools to detect surface degradation in mins to hrs for high throughput discovery of catalysts.



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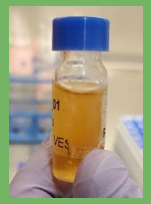
# Vision: Densify Waste Regionally in Distributed Systems

*Recycling Processes to Densify Value*

**Biological**

## PET Bottles Upcycled to Bio-Lubricant

Enzyme/ microbes



**Chemical**

## LDPE Food Wrapper Upcycled to Lubricant

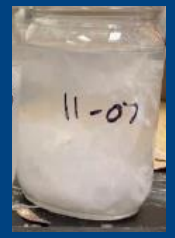

energy/ catalyst

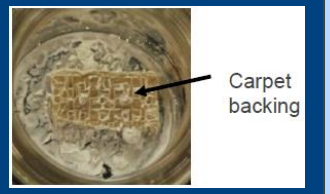
**Chemical**

## Nylon-6 Resin Recovered from Complex Waste

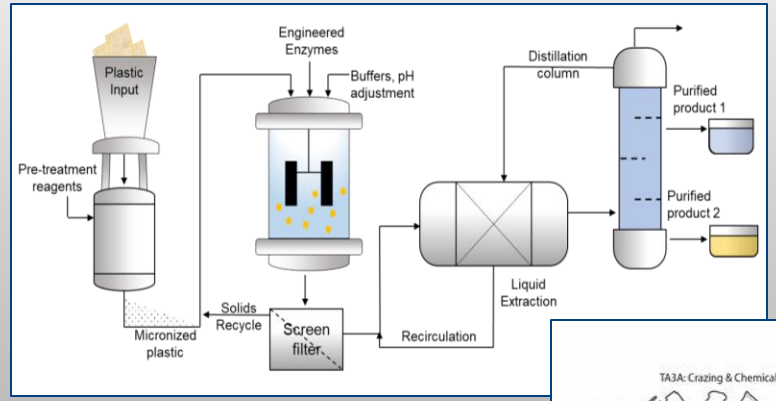
Carpet

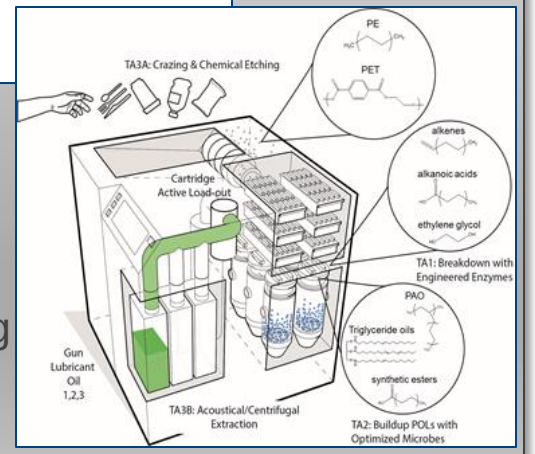
solvent




## Distributed Modular Systems for Upcycling and Recovery




- ✓Small/Intermediate Scale
- ✓Reconfigurable
- ✓Minimized Need for Sorting



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# Our Technical Team

## Battelle Team

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Erica Gilliland
Joey Caley
Anurup Krishna

## Collaborators

NREL National Renewable Energy Laboratory
INL Idaho National Laboratory
JGI Joint Genome Institute
Ginkgo Bioworks
The University of Tennessee Knoxville
Pacific Northwest National Laboratory

## Industry Partners

Multiple partners spanning polymer manufacturers, foam blowers, food packaging manufacturers, consumer product manufacturers, and waste management facilities.

**Actively seeking more partners**

Thank you!