



# Innovation in Upcycling and Circularity in Plastics and Composites

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*Mariana Trench, February 2019*

*Source: The Guardian*





*The Arctic, August 2019*  
*Source: The Guardian*



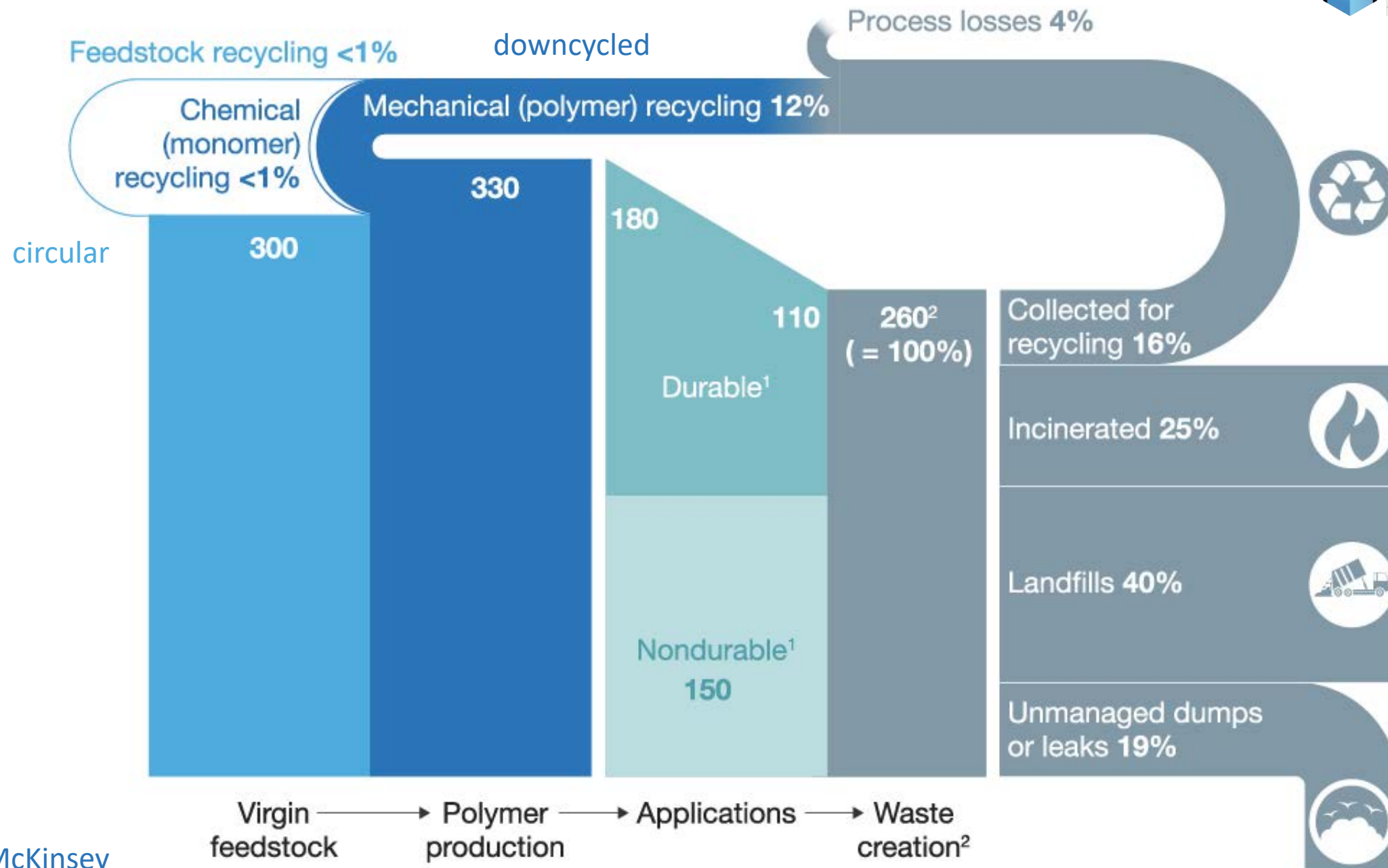


Goal: Zero Discharge





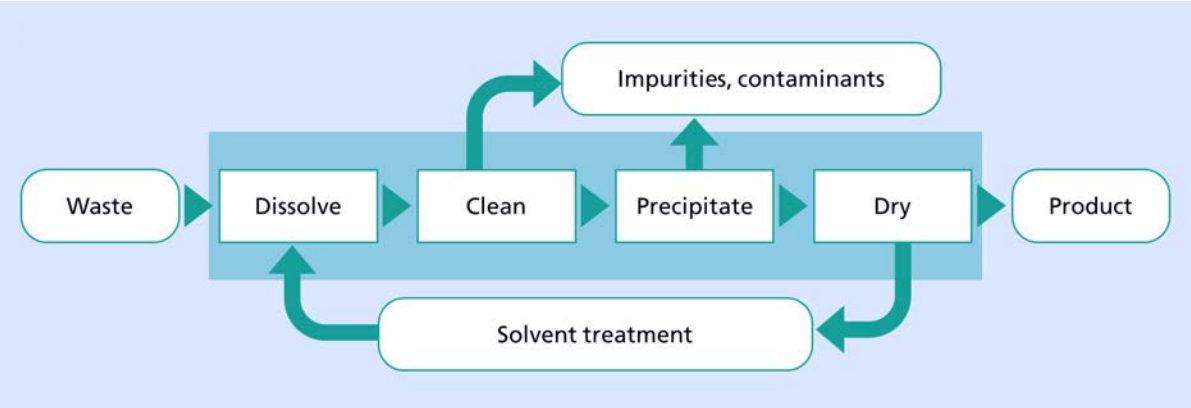
# Global polymer flows, millions of metric tons per annum, 2016



# Innovations in Process Address Progressive Chain Degradation During Mechanically Recycling of Polymers

WMF KPI 4: % Recycled Materials  
WMF KPI 6: EOL Recycling

## Chemical Recycling of Plastics by Dissolution



# Innovations in Catalysis and Separations Address Challenges of Chemical Recycling to Monomer

## Chemical Recycling to Monomer

WMF KPI 4: % Recycled Materials  
WMF KPI 6: EOL Recycling



PET

via  
hydrolysis or  
solvolysis



HDPE

via pyrolysis  
to  
naptha



PS

via pyrolysis  
to  
styrene oil



OTHER

via ring-closing  
depolymerization  
of nylon-6 to  
 $\epsilon$ -lactam





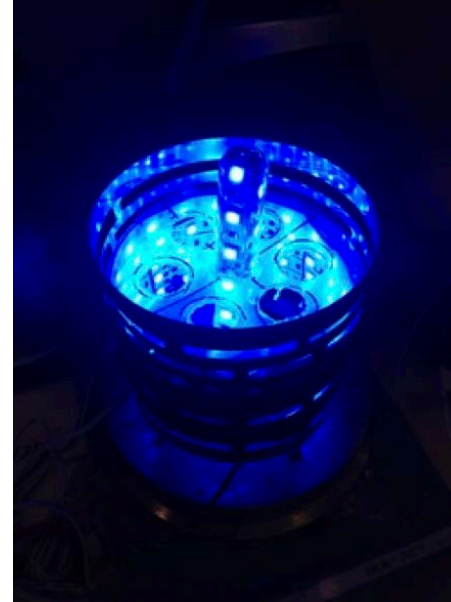
# Emerging Opportunities and Challenges for Sustainable Chemical Circularity in Plastics Recycling

Energy  
Intensity

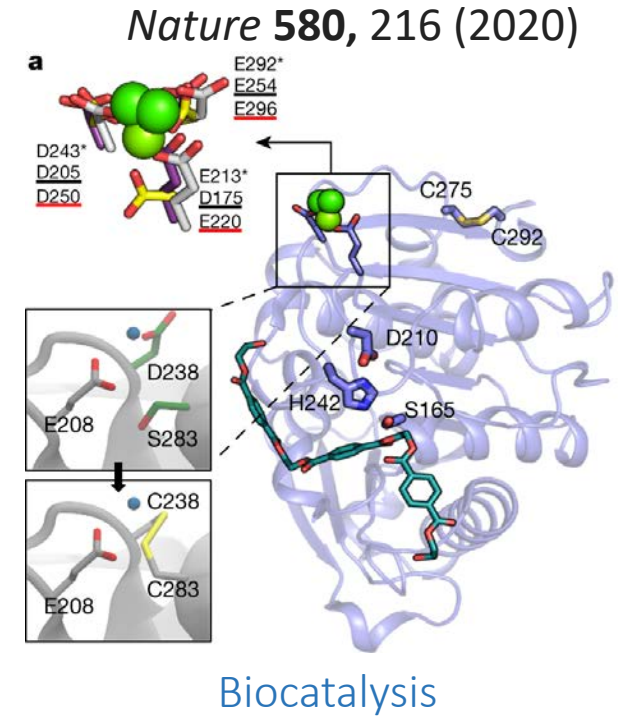
WMF KPI 7: Energy



Electrocatalysis



Photo(redox)catalysis



Biocatalysis

Carbon  
Intensity



Water  
Intensity





# Circularity in Chemical Recycling Remains a Challenge for Thermosets and Composites



Image: Connora Tech



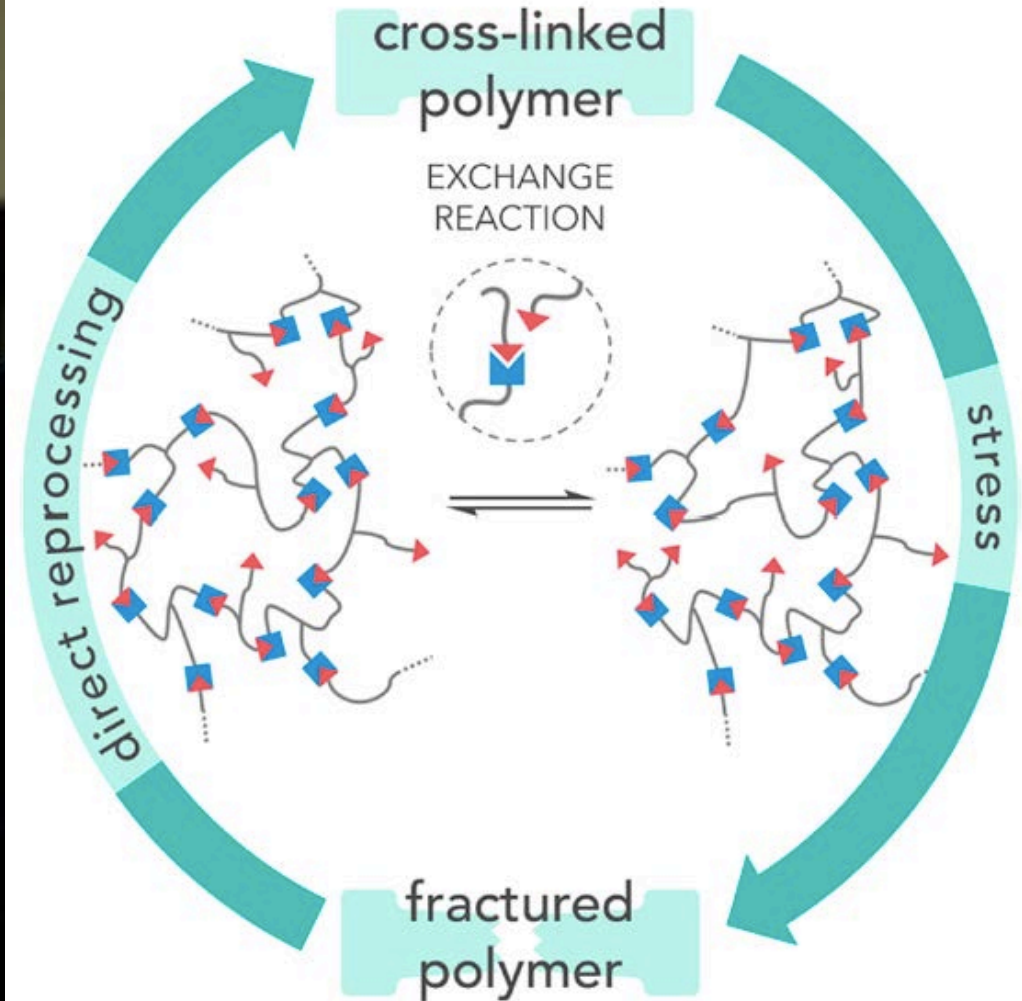
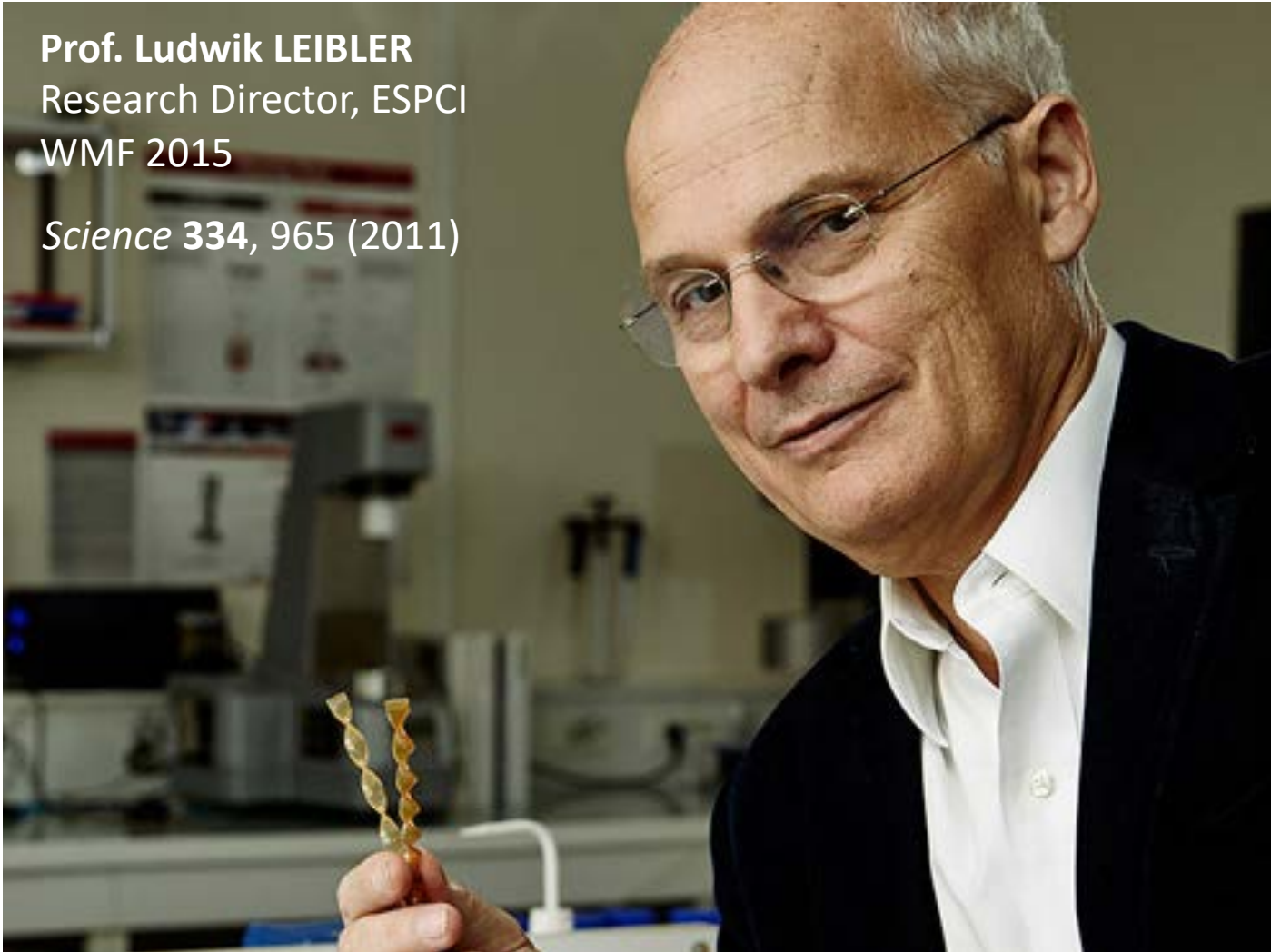
**Carbon**



# Recent Advances in Polymers Have Blurred the Lines of Conventional Thermoplastics and Thermosets

**Prof. Ludwik LEIBLER**  
Research Director, ESPCI  
WMF 2015

*Science* **334**, 965 (2011)

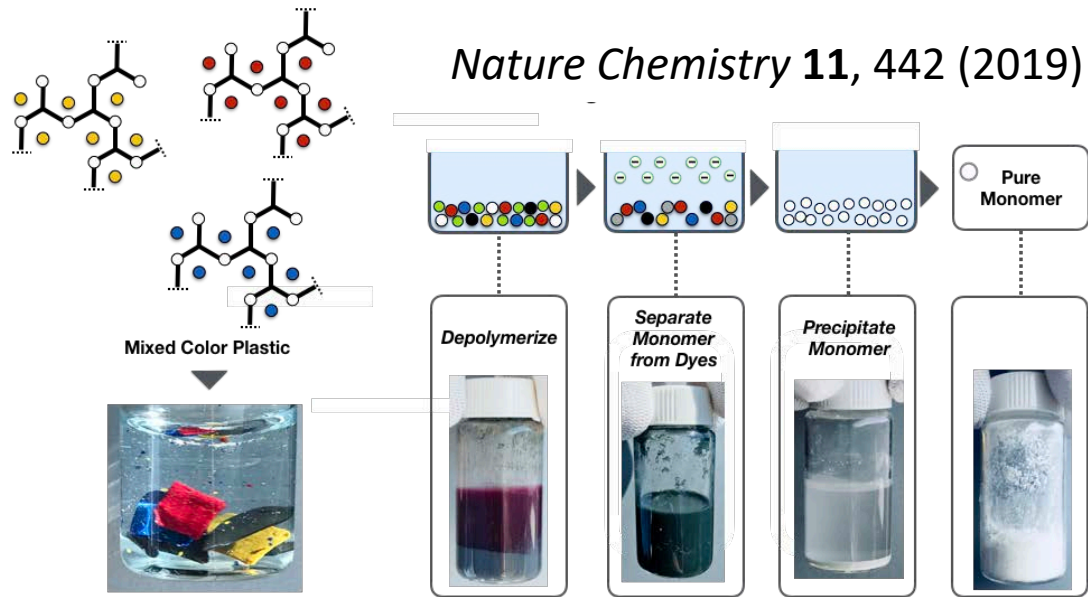


*ACS Sustainable Chem. Eng.* **6**, 11145 (2018)



# Chemistry Key to Unlocking Fully Closed-Loop Chemical Circularity Across All Polymer Sub-Classes

WMF KPI 1: % Innovative Materials  
WMF KPI 6: EOL Recycling

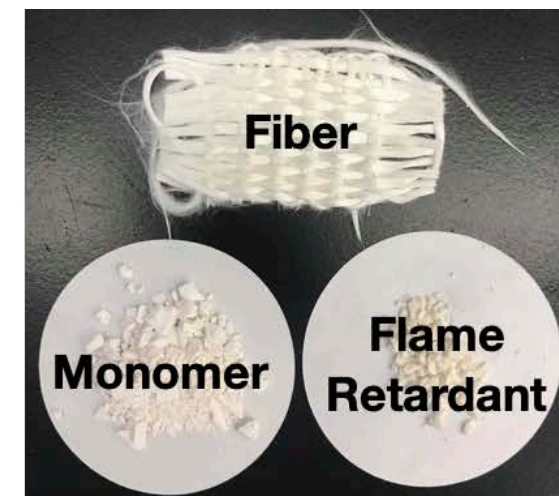
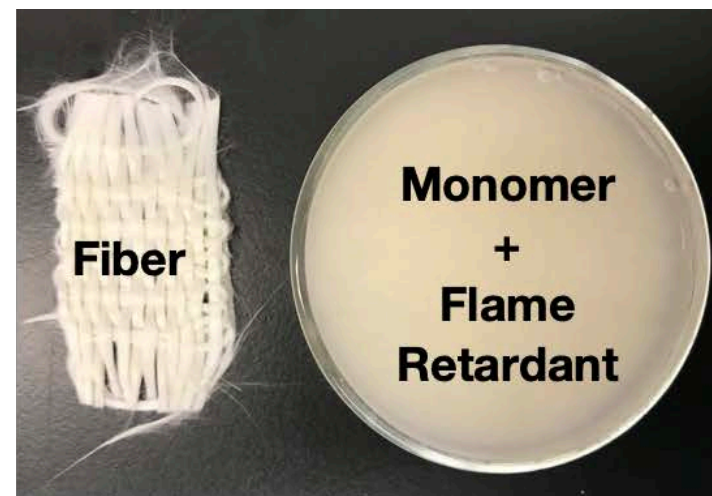
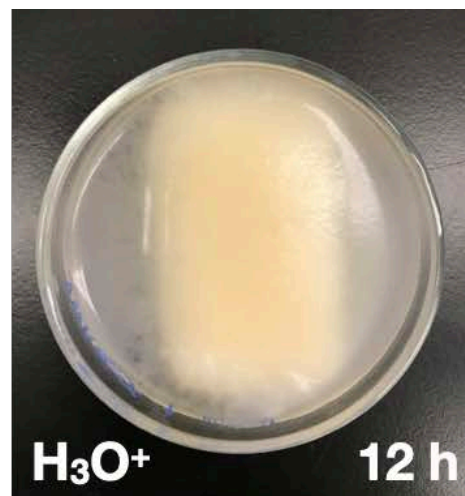
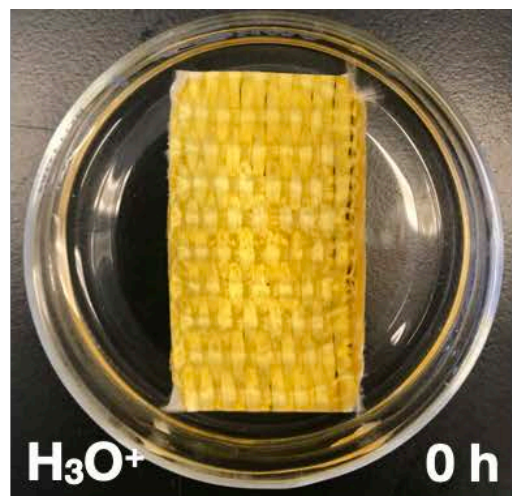
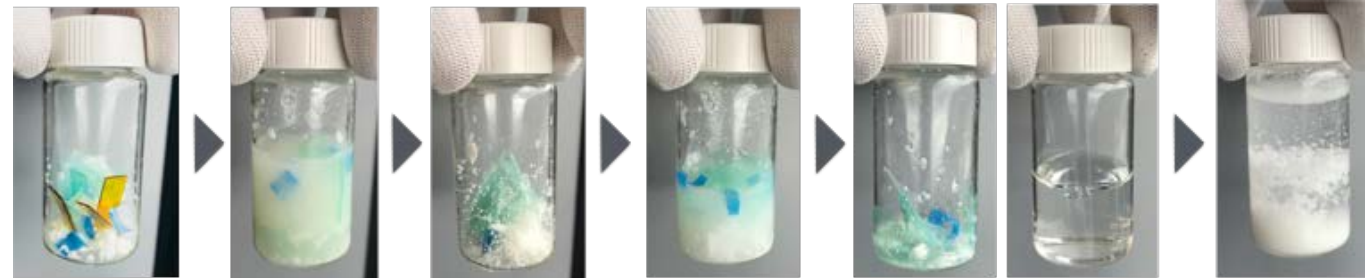


Mixed  
Plastic  
Waste

Selective  
Catalytic  
Depolymerization

Chemical  
Separations  
and Recovery

Virgin-Quality  
Monomer





# Emerging Opportunities and Challenges for Chemical Circularity in Thermoset and Composites Recycling

## Sustainability of Supply Chains



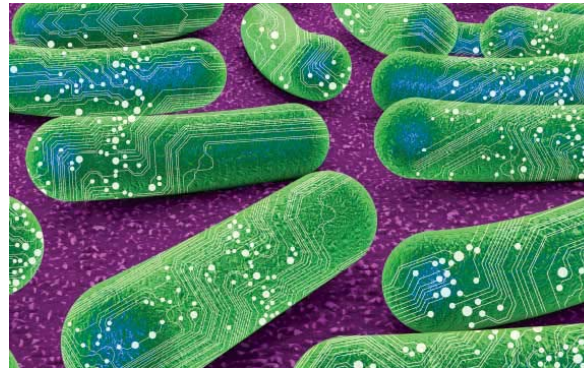
Petrochemicals



Waste to Monomer

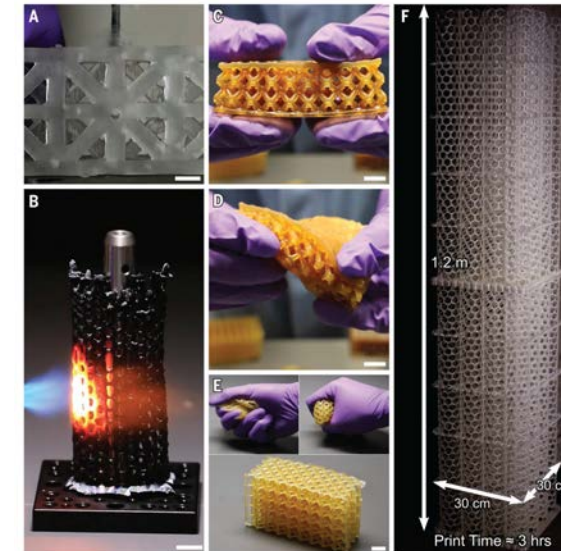
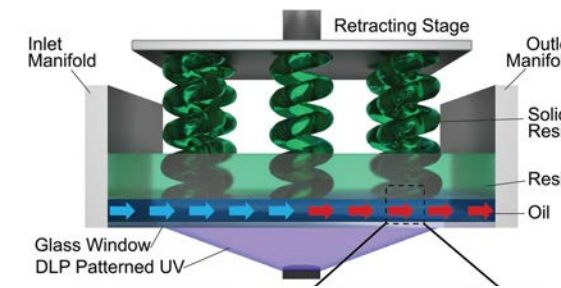


Biomass

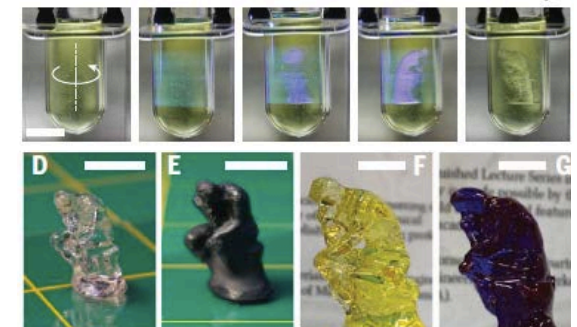
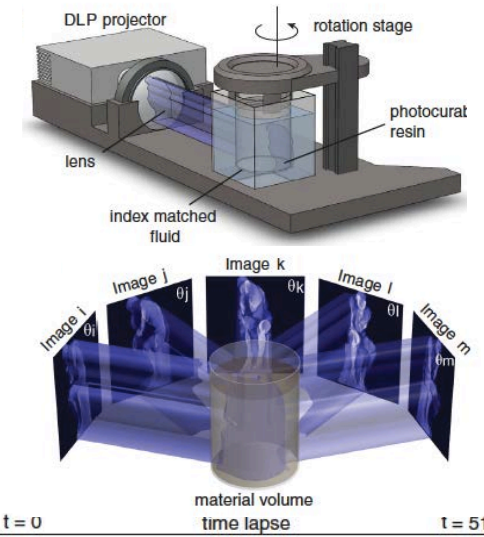


Synthetic Biology

## Aligned with Future Manufacturing



Continuous 3D Printing

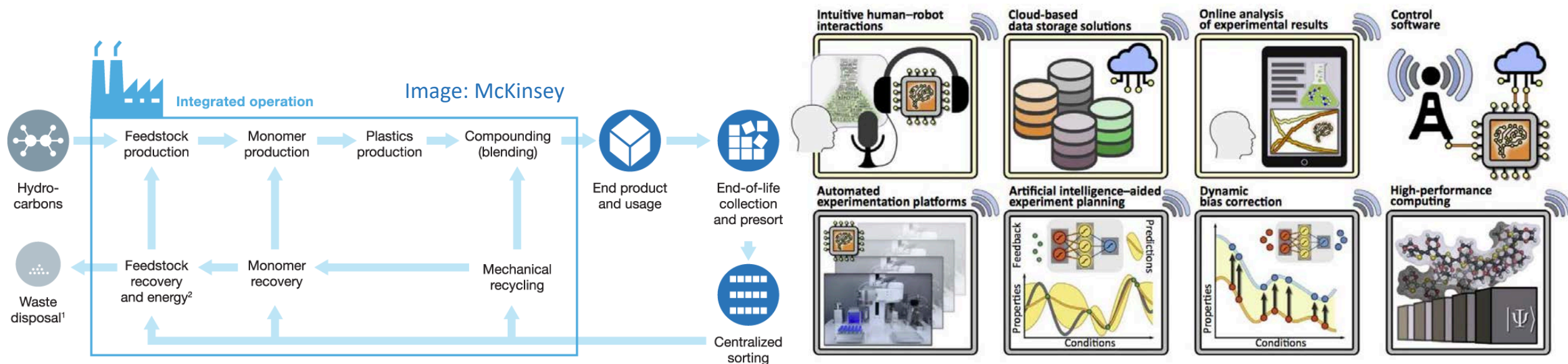


Volumetric 3D Printing

*Science* **357**, 1242 (2017); *Science* **360**, eaas9793 (2018); *Science* **363**, 1075 (2019); *Science* **366**, 360 (2019).



# Accelerating Innovation Across the Ecosystem





04-19-2019 Fri 19:14:51

Liquids

Measure

Solids

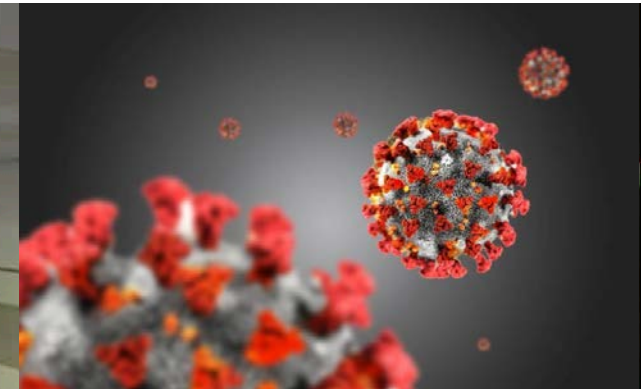
Racks

Testing  
Station

Racks



- Autonomous
- Driven by AI



Camera 02

Manual testing rate = 1 sample per day  
Autonomous rate = 85–100 samples per day





WORLD  
MATERIALS  
FORUM