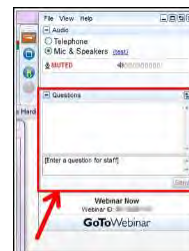
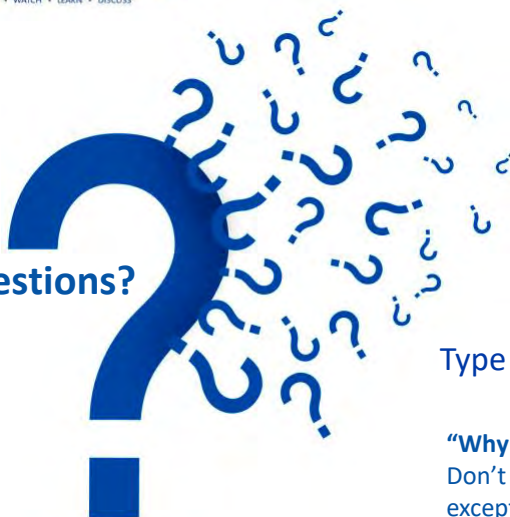




Have Questions?



Type them into questions box!

**“Why am I muted?”**

Don't worry. Everyone is muted except the presenter and host. Thank you and enjoy the show.

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1



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3



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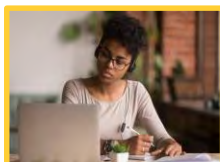
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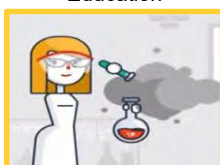
Virtual Career  
Consultants



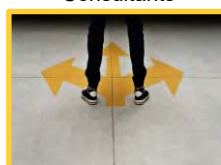
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ACS Scholars Endowment Founder Joe Vacca, retired Vice President of Chemistry, Merck & Co., meets with his 2018 ACS Scholar Johanna Masterson, now a grad student at Princeton University.

“Chemistry has been good to me...so I wanted to make a significant gift to provide that opportunity to others.”

9



Date: Tuesday, February 2, 2021 @ 7-8pm ET

Speaker: Davis Tran, Wakefield High School / Jason Love, Wakefield High School / Nelson Fuamenya, Wakefield High School / Ana Munoz, Wakefield High School / Hina Aftab, Wakefield High School / Verlese Gaither, Wakefield High School  
Moderator: Peter Dorhout, Iowa State University

[Register for Free!](#)

#### What You Will Learn:

- Ideas, insights, and perspectives on cultivating an equitable, inclusive STEM classroom
- Practical takeaways to encourage equity and inclusivity in the STEM classroom
- Overcoming challenges and barriers to achieving equity

Co-produced with: American Association of Chemistry Teachers, ACS Department of Diversity Programs, ACS Diversity, and the ACS Inclusion & Respect Advisory Board



Date: Wednesday, February 3, 2021 @ 2-3pm ET

Speaker: Brian Gboney, Brooklyn College and CUNY  
Moderator: Blake Aronson, American Chemical Society

[Register for Free!](#)

#### What You Will Learn:

- What are your graduate degree options in chemistry
- How to prepare for applying and attending graduate school in chemistry
- What to expect in graduate school in chemistry

Co-produced with: ACS on Campus



Date: Thursday, February 4, 2021 @ 2-3pm ET

Speaker: Jayshree Seth, 3M  
Moderator: Glenn Ruskin, American Chemical Society

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#### What You Will Learn:

- What the world thinks of science during the global pandemic and if skepticism gone up or down
- What the global public cares about the most as it relates to science
- What specific actions can we all take to advocate for science

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ACS Division of Polymer Chemistry, Inc.

2019 POLY Chair  
Sarah Morgan

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*The Value of a Good Mentorship*



Diana Gerbi, 2018 POLY Chair  
3M(retired)

"Being a member of POLY has helped me identify a network of colleagues and establish myself in the polymer chemistry community. For the small cost of a POLY membership, you can join a strong and passionate group of scientists that can assist you throughout your career, through discussions, networking, and guidance."



Marc Hillmyer, 2017 POLY Chair  
University of Minnesota

"...the next generation of polymer scientists is where we put a lot of our focus and we've really established a tremendous network of scientists at all points in their career. ...our more seasoned members are active in helping support and foster the growth of the next generation through mentoring and a very active awards program."



Karl Haider, 2016 POLY Chair  
Covestro

"... as the university relations manager, I knew I would need to connect with a wide variety of professors and students. The Division of Polymer Chemistry provided the perfect environment to build these connections."

[www.polyacs.org](http://www.polyacs.org)

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# SOLVING the plastic waste PROBLEM



Novel Chemical  
Pathway Upcycling  
& Chemical Recycling



Co-produced with the **ACS Division of Polymer Chemistry**

THIS ACS WEBINAR WILL BEGIN SHORTLY...



## Solving the Plastic Waste Problem: Novel Chemical Pathway Upcycling and Chemical Recycling



**Philippe Reutenauer**  
Sustainable Packaging Manager,  
Léa Nature



**Katrina Knauer**  
Senior Scientist, Materials Innovation  
Lead, BioCollection Inc.



**Peter Boul**  
Senior Research Scientist,  
Aramco Americas

*Presentation slides are available now! The edited recording will be made available as soon as possible.*

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# CHEMICAL RECYCLING: PERSPECTIVES FROM THE FAST MOVING CONSUMER GOODS INDUSTRY



Dr. Philippe REUTENAUER



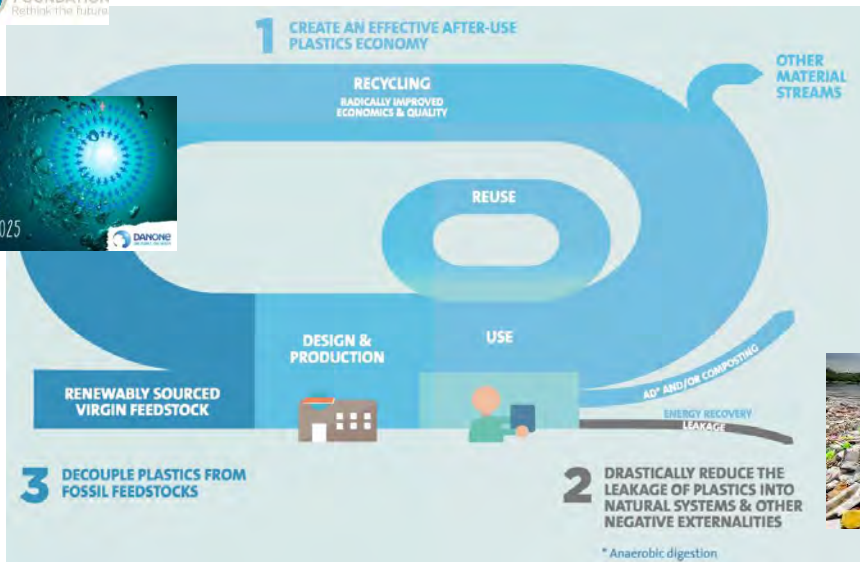
## DISCLAIMER

- The perspectives presented in this webinar are a collective from my professional experiences in the packaging R&D at Danone and Léa Nature. Any opinions are **my** professional opinions and do not represent those of my current or former employers.
- The situation depicted is the one I perceive from Europe.



17

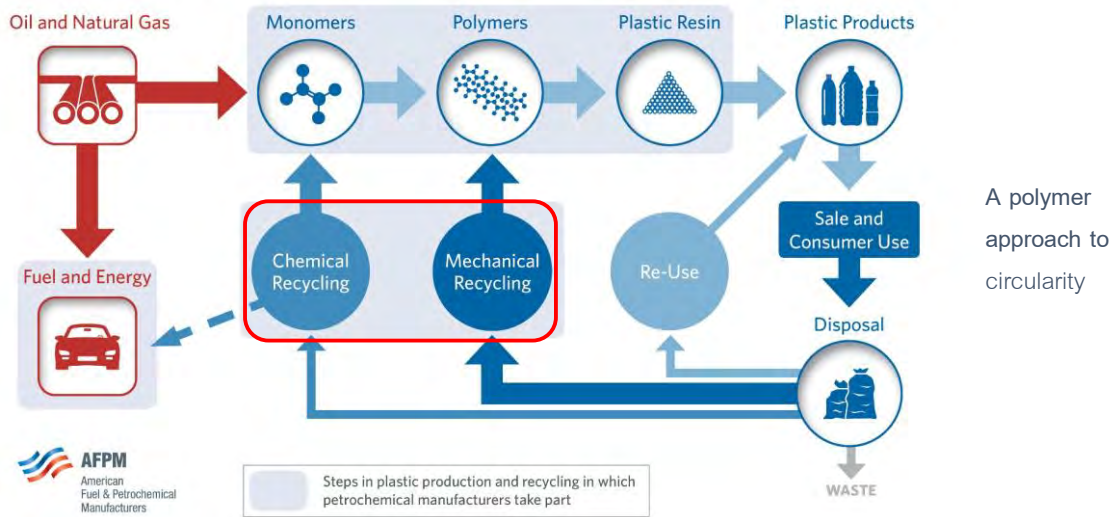
## CIRCULARITY APPLIED TO PACKAGING



18

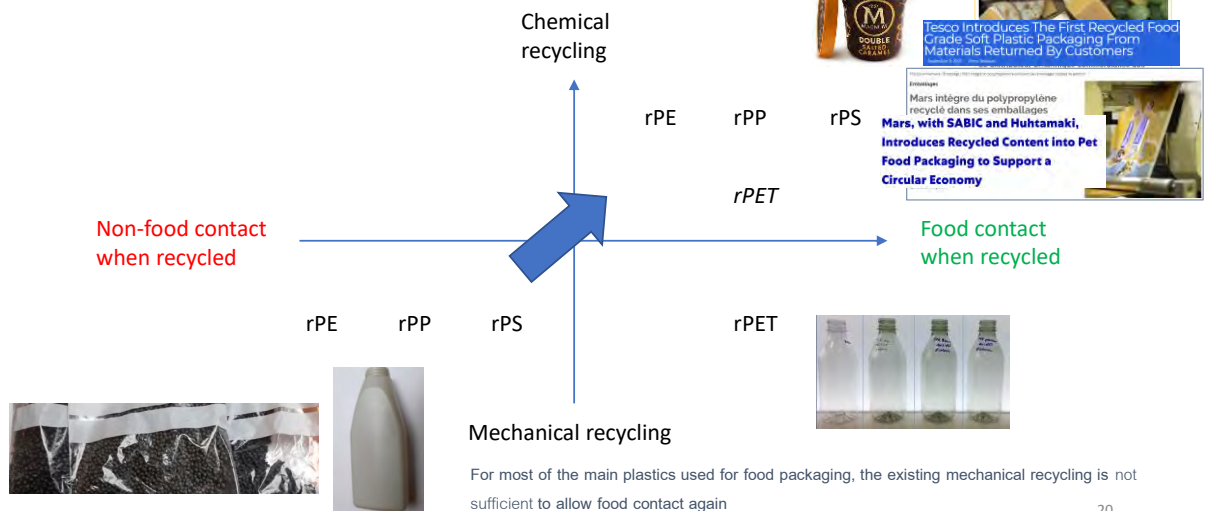
Provide a frame for thinking packaging material flux

# EVOLVING THE PLASTIC RECYCLING SUPPLY CHAIN



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# CHEMICAL RECYCLING EXTENDS THE RANGE OF FOOD CONTACT APPROVED RECYCLED PLASTICS



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## GLOSSARY

- **PEs : PolyEthylenes**

- LDPE: Low Density PolyEthylene
- LLDPE: Linear Low Density Polyethylene
- HDPE: High Density PolyEthylene (d> 940 g/L)

- **PPs : PolyPropylenes**

- **PETs : PolyEthyleneTerephthalates**

- **PSs: PolyStyrenes**



- r added before means recycled. e.g. rPET = recycled PET

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## Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



**Which of the following has the highest plastic recycling rate in the world?**

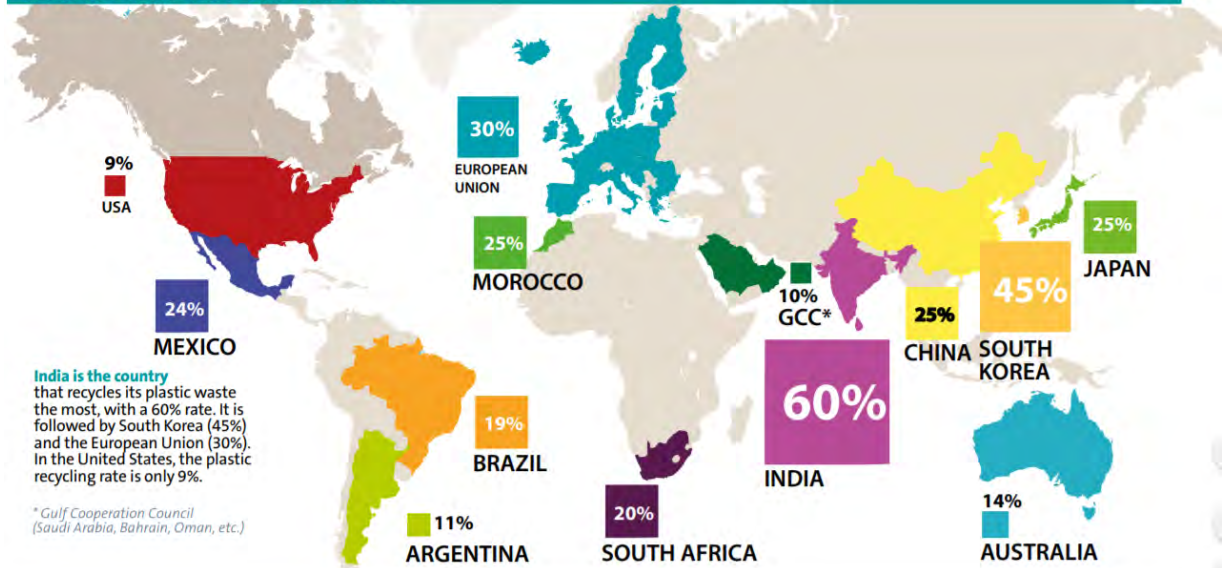
- United States
- Mexico
- India
- South Korea
- European Union



*\* If your answer differs greatly from the choices above tell us in the chat!*

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## PLASTIC RECYCLING WORLDWIDE



Source : Véolia, 2018

Plastic recycling rates vary a lot from one country to another.

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## MECHANICAL RECYCLING OF PET



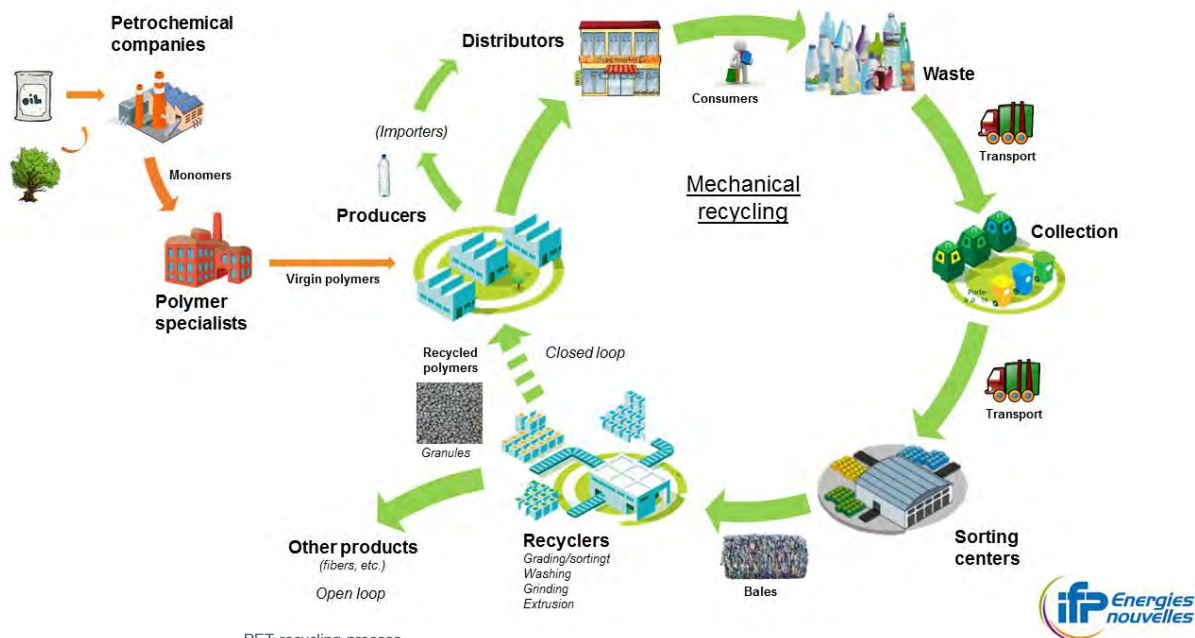
- Bottle Grade PET is the best recycled plastic.
- rPET is the only mechanically recycled plastic approved for food contact in Europe (by EFSA) operated at large scale.
- Still limited to recycling of PET bottles
  - Homogeneous in chemical composition
  - Almost only clear and light blue bottles are recycled bottles to bottles. With discoloration challenges ...
  - Colored bottles go to fibers
- Opaque PET bottles and PET trays recycling is starting

**NEW!**



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<https://www.intermarche.com/enseigne/magazine/bouteille-lait-recyclee>



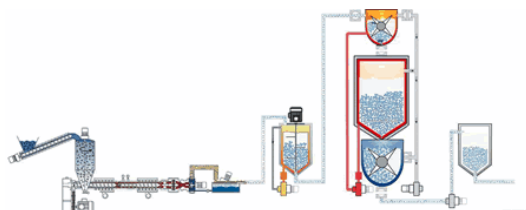
PET recycling process

... omitting one of the most important step: solid state polymerization

## MECHANICAL WAY TO rPET (AT RECYCLERS)



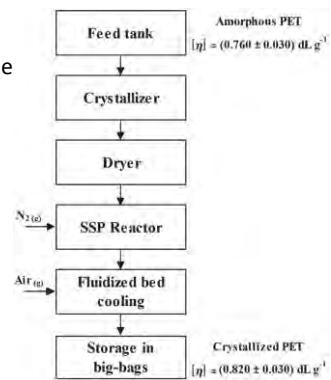
- PET bottle sorting (color)
- PET bottles washing
- Grinding
- Separation by floating
- Extrusion into pellets
- Solid state polymerization (SSP)



Removal of volatile contaminants

Creation of new ester bonds (equilibrium)

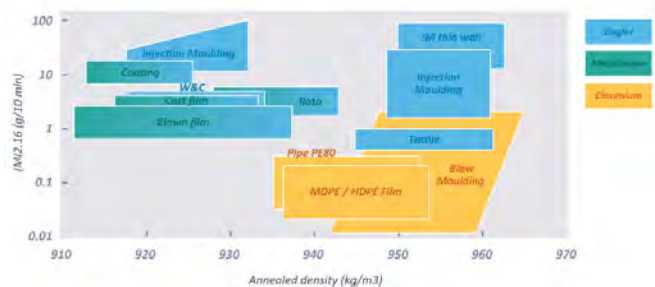
Specific to polyesters



# MECHANICAL RECYCLING OF PE

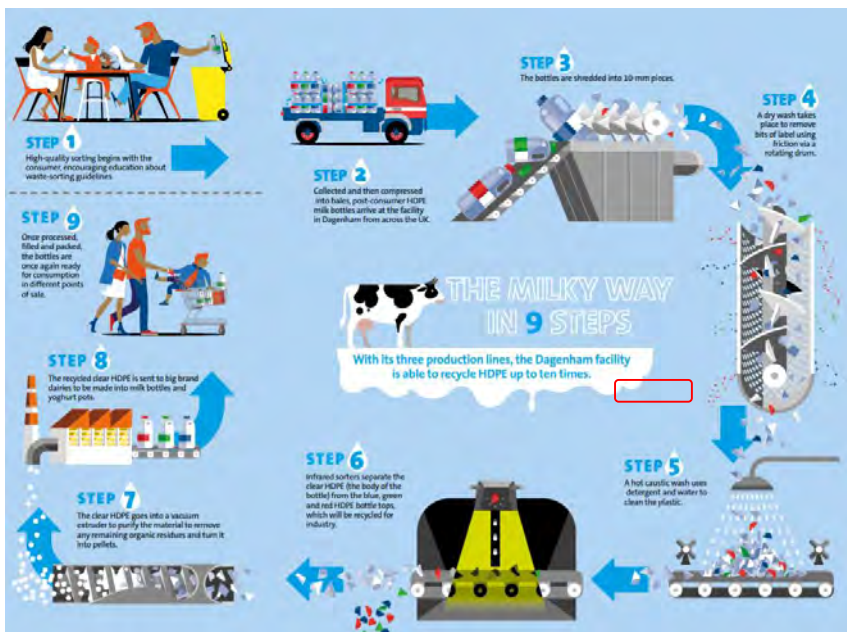
- Higher variety: LDPE, LLDPE, HDPE
- Even among HDPE, high variety of properties linked to chain composition -> comonomer type topology -> polymerization mechanisms polydispersity -> type of catalyst, reactor(s) type
- Colors ...
- Additivation
- Contaminations
- Only C-C bonds!
- What can be expected from such a mixture?

• Mediocre properties, gray color, no food contact aptitude



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# HDPE RECYCLING: RARE CASE OF FOOD CONTACT w/HDPE



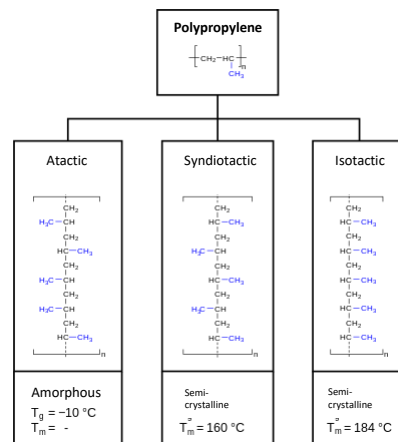
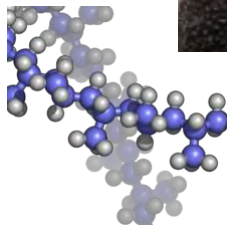
Specific segregated stream of HDPE bottles

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## MECHANICAL rPP'S CASE

- Even worse as even more dimensions:

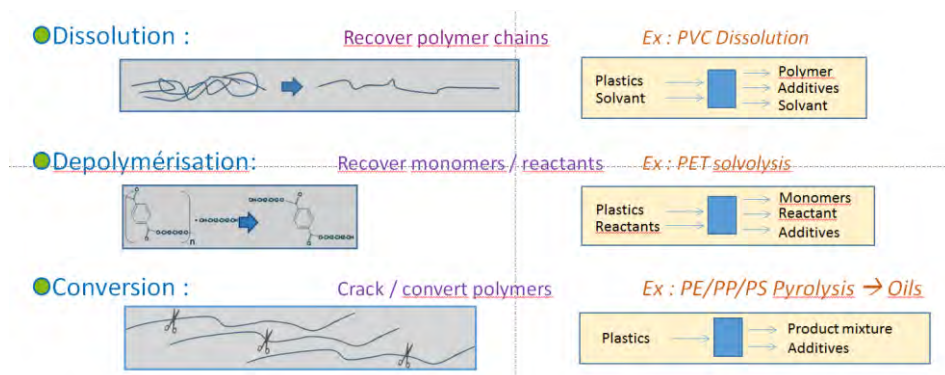
- Tacticity
- Ethylene content
- Chain topology (blocks)



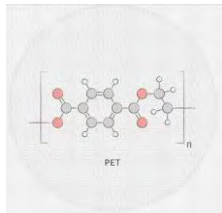
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## CHEMICAL RECYCLING OPENS NEW ROUTES

- **Polyester:** harnessing the reversibility of the ester bond
- **Polyolefins:** pyrolysis to cleave C-C bonds



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# CHEMICAL rPET

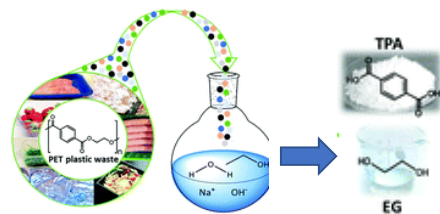
- **Diverse routes:** hydrolysis, methanolysis, glycolysis + enzymatic

Depolymerization followed by monomers separation

Difficulties: heterophasic + mixture chemistry

- **Address different feedstocks:** multilayer bottles, colored bottles, pouches (specially if monoPET), textile, carpets
- Selectively address polyesters in polymers' mixtures
- **Manage expectations:** purification cost will be high!  
->The cruder the starting material, the more difficult to go to high purity.

- **Example of actor:** Loop Industry



Solvolysis



Anellotech aims to convert large volumes of mixed waste plastics...

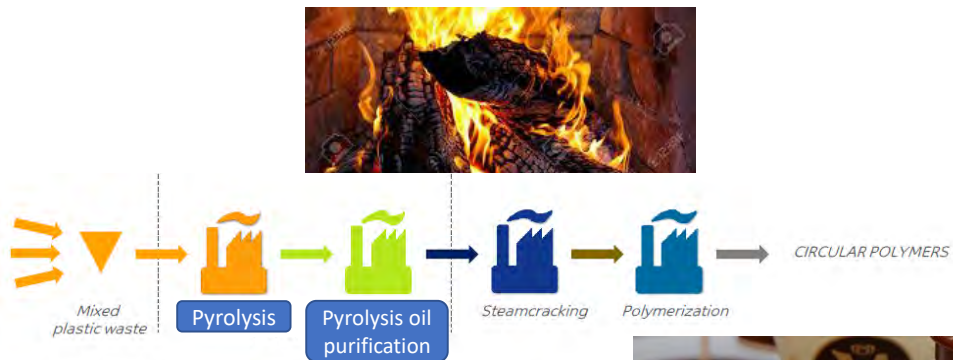


Could this become true ?

Where are the heteroatoms going?



# PYROLYSIS: CRACKING POLYOLEFINS WASTES



- + Produce from Mixed Plastic wastes virgin quality polyolefins
- Mass balance approach
  - > impossible to communicate to general audience
- Manage expectation



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## SABIC AND PLASTIC ENERGY SET TO START CONSTRUCTION OF PIONEERING ADVANCED RECYCLING UNIT TO INCREASE PRODUCTION OF CERTIFIED CIRCULAR POLYMERS

21/01/2021

... is expected to become operational in the second half of 2022



SABIC's certified circular polymers are produced using Plastic Energy's advanced recycling technology to convert low quality, mixed, and used plastic, otherwise destined for incineration or landfill, into TACOIL. The TACOIL produced in the new commercial unit will be used by SABIC in their production process as an alternative to traditional fossil materials to create new circular polymers.

Site of the new advanced recycling unit ready for construction in Geleen, The Netherlands.

# WHAT ABOUT PS?



## Press Release

**Total, Intraplás and Yoplait successfully demonstrated the feasibility of incorporating recycled polystyrene from chemical recycling into yogurt pots.**

**Paris, 7 December 2020** - Total, Intraplás and Yoplait announced today that they have successfully run a pilot test aiming at using certified chemically recycled polystyrene in yogurt pots. This is the first step of a collaborative initiative aiming at testing the use of chemically recycled polystyrene in yogurt pots, supporting the development of sustainable PS recycling in France

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# ADVANCED RECYCLING / TECHNOLOGIES

Waste %	INPUT (WASTE STREAM)			ADVANCED RECYCLING TECHNOLOGY	OUTPUT COMMODITIES			
70%	Polyethylene & Polypropylene	HDPE PP LDPE	 	Thermal Cracking	Solvent	Naphtha	Oil	Wax
15%	PET – Polyethylene Terephthalate	PET		Depolymerization	Monomers	Polymers (PET, PBT)		
10%	Polystyrene	PS		Solvolyis	Styrene	Polymers (EPS, PS)		
5%	Others	OTHERS		Thermal Cracking Solvolysis	Syngas	Monomers	Naphtha	Diesel

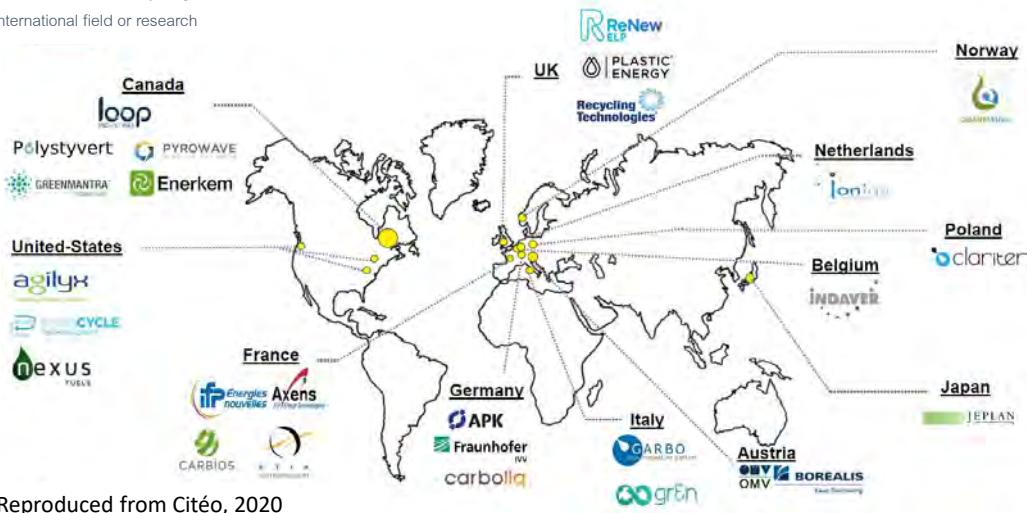


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## CHEMICAL RECYCLING IS AN ACTIVE FIELD

Some actors on chemical recycling (non exhaustive list)

A very international field of research



Reproduced from Citéo, 2020

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## CONCLUSIONS

- Effective recycling technologies are needed to allow us solving issue of single use plastic and save our lifestyles & planet
- The culture of plastic collection and sorting after use must spread
- Can plastic evolve to become more recyclable?



## THROUGH CHEMISTRY!



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## Upcycling Plastic Waste via Novel Chemical Pathways

January 28, 2021

- Kat Knauer, PhD; Senior Scientist, Materials Innovation at BioCollection

### The Problem: Polyethylene



*PE makes up over 1/3 of globally produced plastic!<sup>1</sup>*



<sup>1</sup>Geyer, R. et al. *Science Advances*. 3 (7)

There is a reason we can't go backwards...

**Plastics:**

- Strong
- Light-weight
- Flexible
- Durable
- Stable
- Anti-microbial
- Barrier properties



**These are not more sustainable materials...**



○

**The Solution:  
Innovative  
Recycling  
Technologies**



**Mechanical Recycling**



**Biological Recycling**



**Chemical Recycling**



## Audience Survey Question

ANSWER THE QUESTION ON BLUE SCREEN IN ONE MOMENT



### What types of plastic packaging can you NOT put in your recycling bin at home?

(select all that apply)

- HDPE grocery bags
- LDPE dry cleaning bags
- HDPE laundry detergent bottles
- Plastic liners for cereal boxes
- PET water bottles



*\* If your answer differs greatly from the choices above tell us in the chat!*

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## Mechanical Recycling



### Manufacturing

**Polymerization**  
(T, Catalysts, Water)



**Compounding**  
(Melting T, Other components)

### Industrial & Consumer Use

**Service**  
(exposure to T/Energy UV, Chemicals, pollutants, mechanical stress, etc)

### Recycling

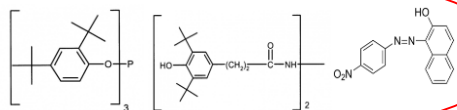
**Re-processing**  
(T/Energy, Chemicals, water)



Lower value,  
lower performance!

**Converting**  
(Processing T)

**Sorting, Cleaning**  
(Water, Chemicals)



**What happens when recycled products become oversaturated with "legacy" additives?**

**Some Common Plastic Additives**

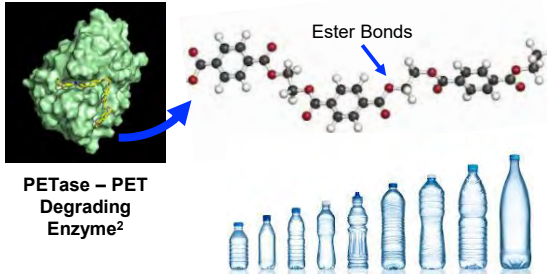
BioCollection Inc.

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# Biological Recycling



## Polyethylene Terephthalate (PET)



- PETase enzyme expressed from *Indeonella Sakaiensis* can cleave PET at the ester bonds and depolymerize the plastic
- Biorecycling process takes up to **six days** and has been demonstrated on low crystallinity PET films

<sup>2</sup>Palm et al. *Nature*, 10, 2019.

<sup>3</sup>PE Crystalline Phases: Miao, W. et al. *R. Soc. open sci.* 5, 2018.

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## Polyethylene (PE)



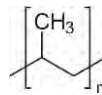
- Long carbon-carbon backbones with no functional groups for enzymatic attack
- Hydrophobic, highly crystalline plastics
- Low value of monomers do not justify the costs

# Chemical Recycling



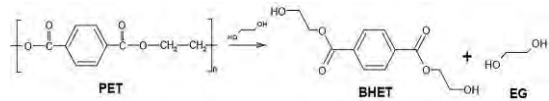
Chemical Extraction of PP

- Removal of small molecules (additives, pigments, etc.)
- "Virgin"-like polymer



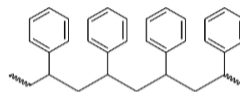
Depolymerization of PET

- Glycolysis
- Microwaves
- Diols and diacids



Depolymerization of PS

- Microwaves
- Heat + Catalysts
- Styrene monomers



Pyrolysis & Gasification

- 600-1000°C
- Mixed plastics
- Fuel/Naphtha



BioCollection Inc.

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047

## PE continues to be a significant challenge...

### Mechanical Recycling



- PE degrades during multiple heat processing
- Recycle streams become saturated with additives

### Biological Recycling



- PE structure not compatible with biological systems
- Very long time frames & high costs

### Chemical Recycling



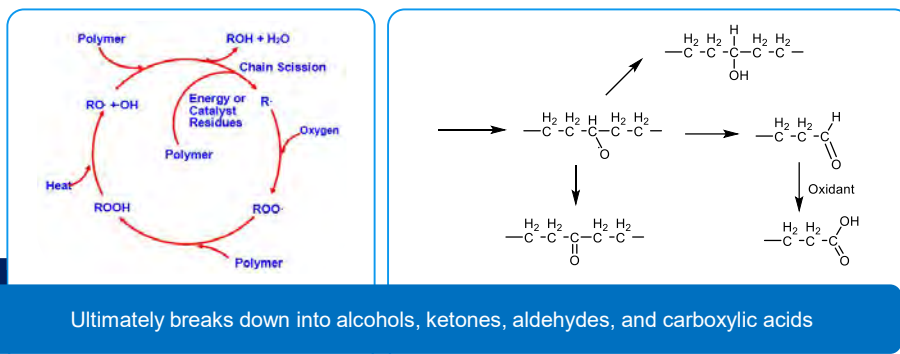
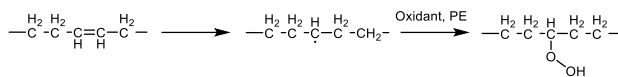
- Requires very high temperatures
- Multi-step process to achieve new polymer

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## Thermo-Oxidation of Polyolefins

Polyethylene readily undergoes auto-oxidation



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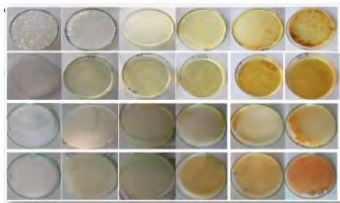
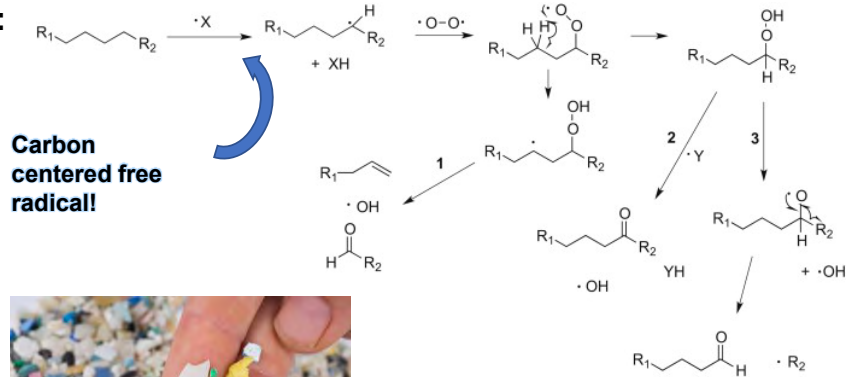


049

## Taking a closer look at PE oxidation...

### Auto-oxidation results in:

- Alcohols
- Aldehydes
- Ketones
- Carboxylic Acids
- Discoloration
- Microplastics



Degradation of PE over time

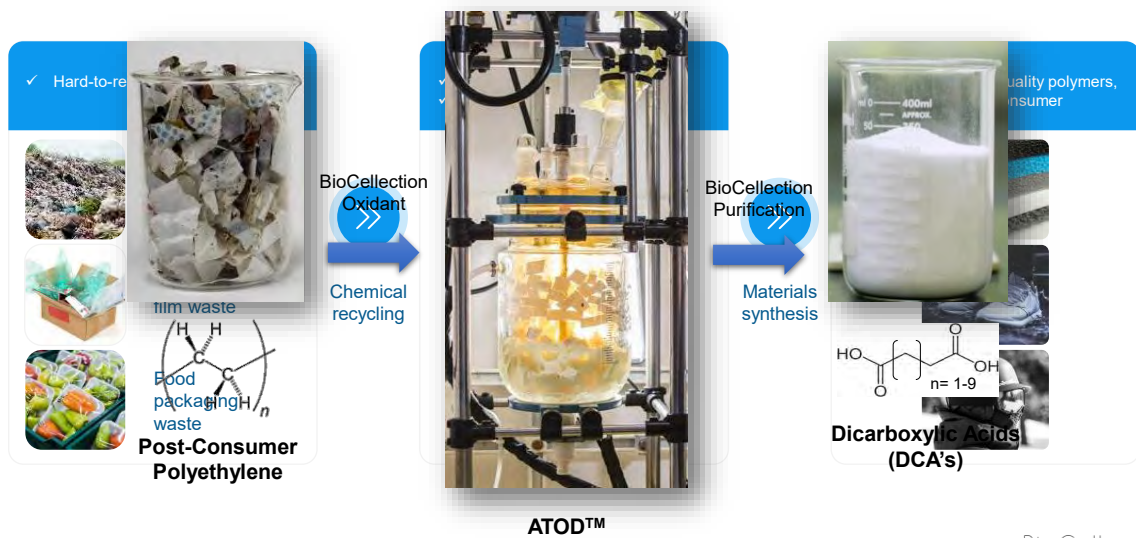


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Knauer, K. et al. *Polyolefins International Conference Proceedings*; February 2019.

050

## ATOD™ Chemical Recycling

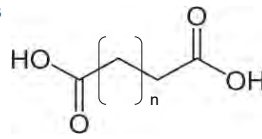

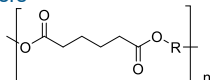

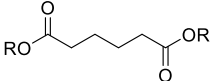
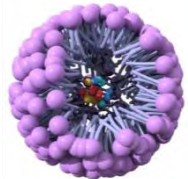



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# Upcycling Intermediates into New Products

Virgin quality monomers can be made into new, valuable materials

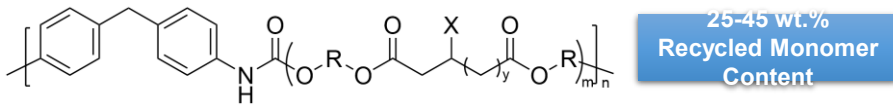
<p><b>DCA's</b></p> 	<p>Polyamides</p> 	<p>Polyesters</p> 
<p>Paints &amp; Coatings</p> 	<p>Esters</p> 	<p>Surfactants</p> 
<p>Polyurethanes</p> 		

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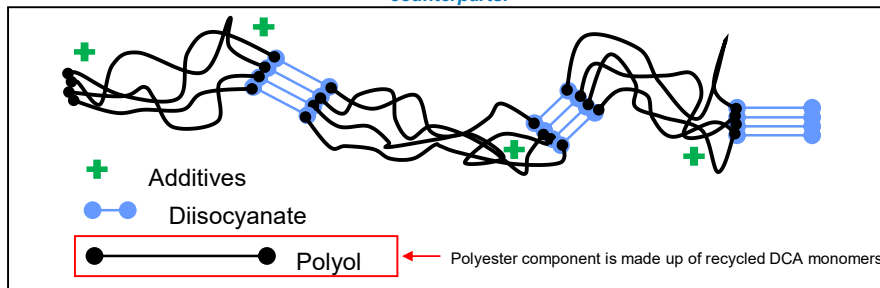
052

# Thermoplastic Polyurethane Elastomers

High performing polymers designed for long lifetimes



Unique functionality on polyester backbone yields higher tensile strength when compared to virgin counterparts!



Footwear



Sports Equipment



3D Printed Materials



Automotive

Knauer, et al. Patent Track 1: US4340.0050001  
 Knauer, et al. Patent Track 1: US4340.0060000

053

# What was once garbage...



Average Price of Virgin Polyethylene: \$0.75/kg



Average Price of Virgin TPU: \$5-15/kg



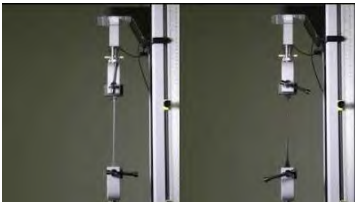
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Knauer, et al. Patent Track 1: US4340.0050001  
Knauer, et al. Patent Track 1: US4340.0060000

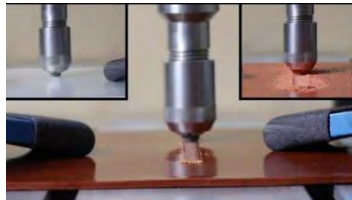
054

## XIRC TPU's in Action

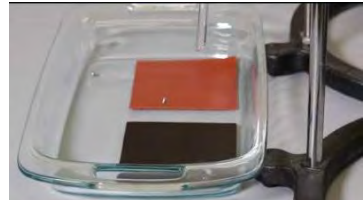
**Elongation:** XIRC vs. Virgin TPU



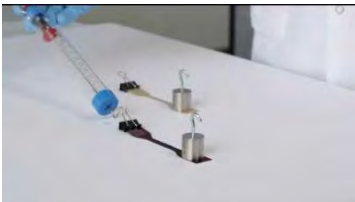
**Abrasion Resistance:** XIRC vs. Rubber & Virgin TPU



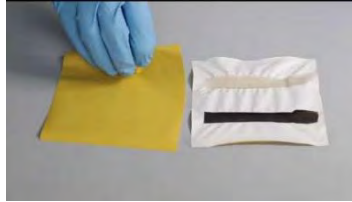
**Rebound:** XIRC vs. Synthetic Rubber & LDPE



**Grip Strength:** XIRC vs. LDPE



**Adhesion:** XIRC vs LDPE



**Strength:** XIRC vs. HDPE Bag

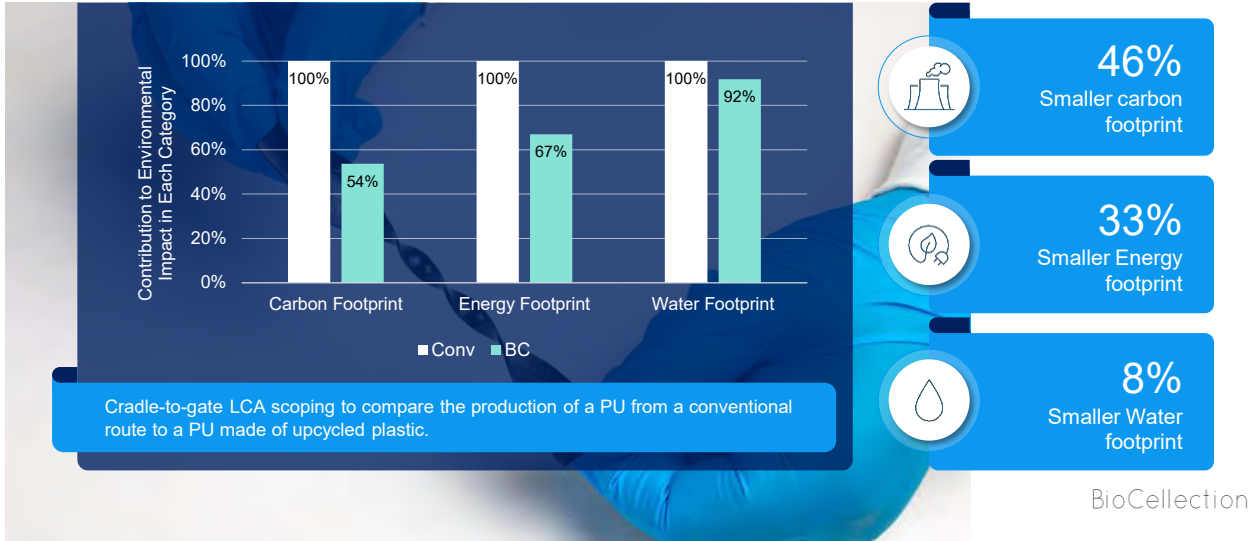


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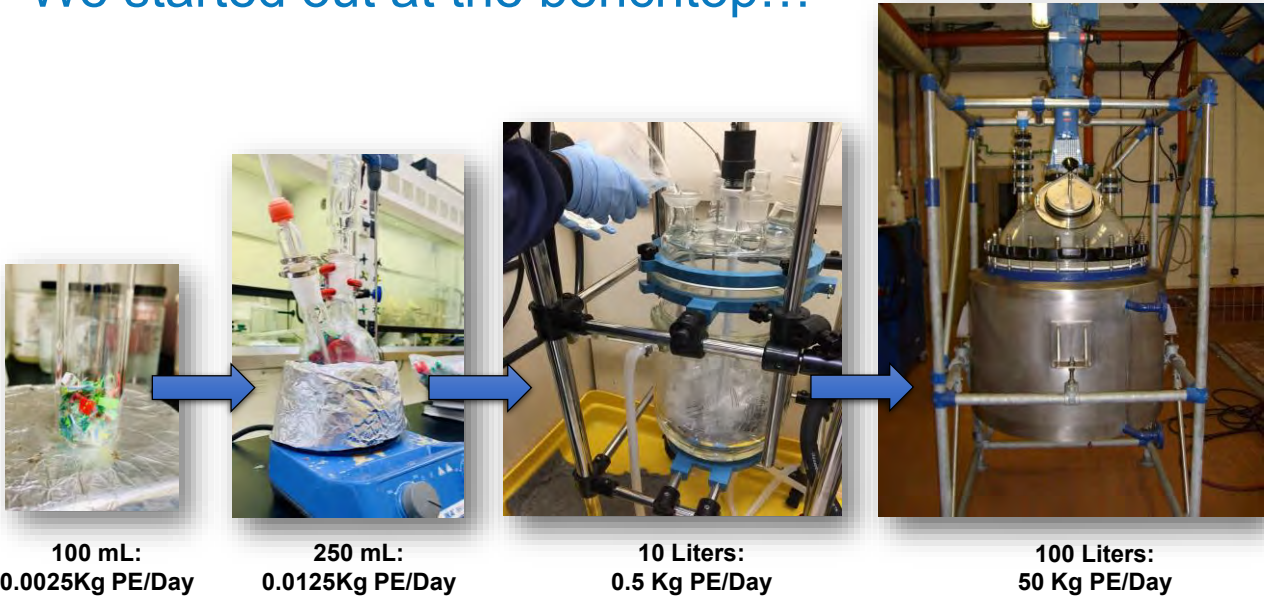
# Our Materials are Sustainable

## Superior Environmental Footprint to Existing Sources



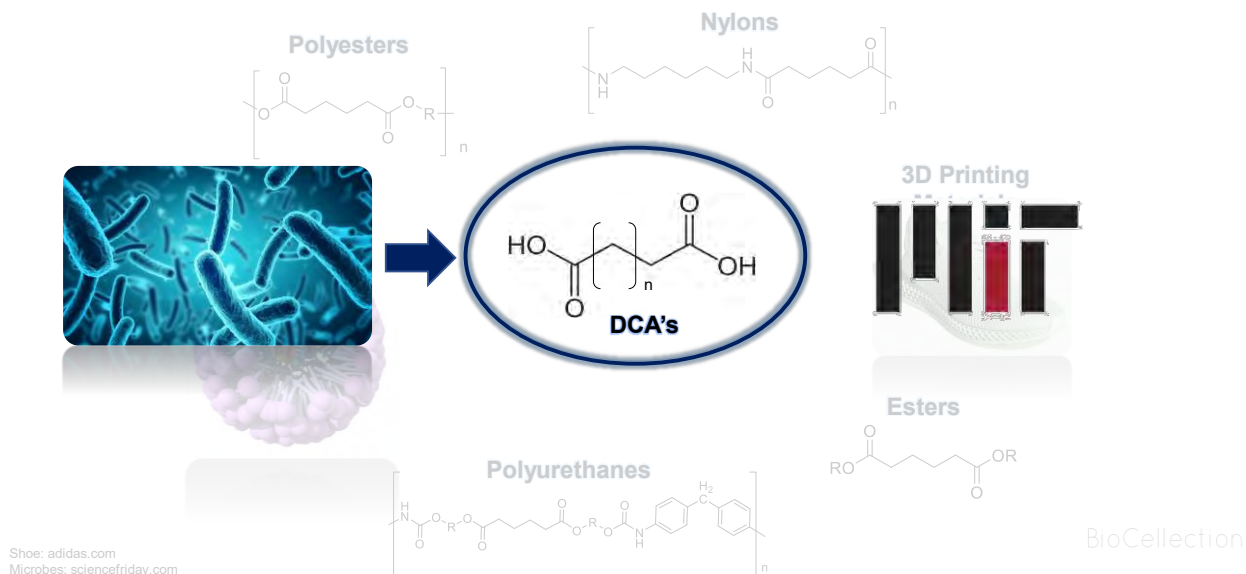
056

# We started out at the benchtop...



057

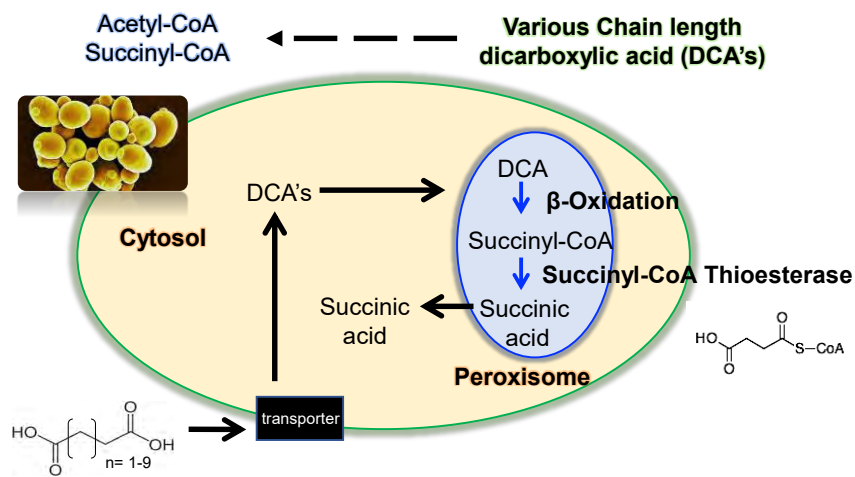
## What else can we do with DCA's?



058

## DCA's Are Excellent Microbial Feedstocks

*With unique metabolic pathways in yeast*

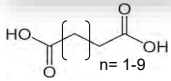


- DCA's act as a carbon source for aerobic growth of diverse microbial strains
- Succinyl-CoA enters TCA cycle to provide energy for host growth and metabolism
- Acetyl-CoA is a building block for **carotenoids**

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# Chemical + Biological Innovations



Dicarboxylic Acids (DCA's)

Conagen Fermentation



Carotenoid Production



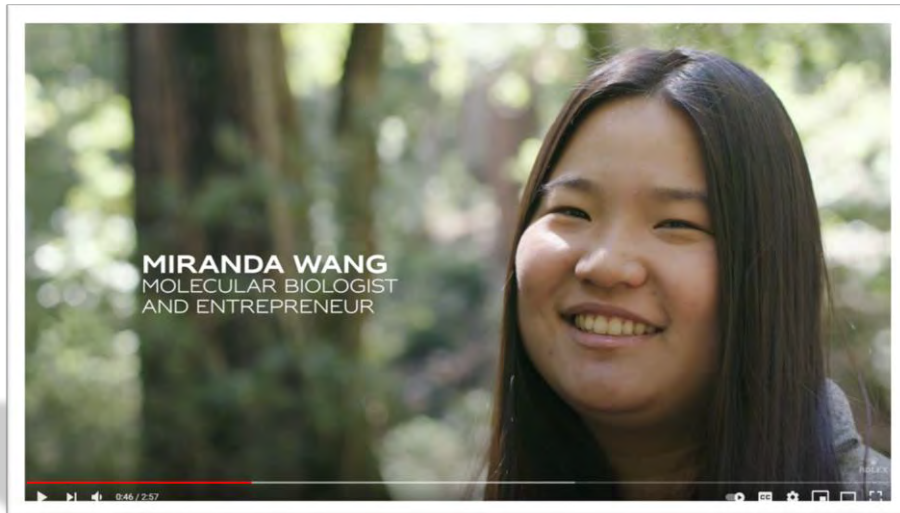
Beta-carotene, Vitamin A, Astaxanthin & Canthaxanthin

- **Cosmetic** → anti-aging, acne prevention, reduces wrinkles
- **Supplement** → Dietary supplements for eye and skin health
- **Animal Feed** → Feed for salmon and chickens for coloration



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## 2019 Rolex Awards Laureate Documentary: Miranda Wang



<https://youtu.be/eXqLISf7xkA>

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**Thank-you!**

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✉ [katrina@biocollection.com](mailto:katrina@biocollection.com)



## Solving the Plastic Waste Problem: Novel Chemical Pathway Upcycling and Chemical Recycling



**Philippe Reutenauer**  
Sustainable Packaging Manager,  
Léa Nature



**Katrina Knauer**  
Senior Scientist, Materials Innovation  
Lead, BioCollection Inc.



**Peter Bouli**  
Senior Research Scientist,  
Aramco Americas

*Presentation slides are available now! The edited recording will be made available as soon as possible.*

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*The Value of a Good Mentorship*



Diana Gerbi, 2018 POLY Chair  
3M(retired)

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Marc Hillmyer, 2017 POLY Chair  
University of Minnesota

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Karl Haider, 2016 POLY Chair  
Covestro

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# SOLVING the plastic waste PROBLEM



Novel Chemical  
Pathway Upcycling  
& Chemical Recycling



Co-produced with the ACS Division of Polymer Chemistry

ASK YOUR QUESTIONS AND MAKE YOUR COMMENTS IN THE QUESTIONS PANEL NOW! 64





Date: Tuesday, February 2, 2021 @ 7-8pm ET

Speaker: Davis Tran, Wakefield High School / Jason Love, Wakefield High School / Nelson Fuamenya, Wakefield High School / Ana Munoz, Wakefield High School / Hina Aftab, Wakefield High School / Verlese Gaither, Wakefield High School  
Moderator: Peter Dorhout, Iowa State University

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**What You Will Learn:**

- Ideas, insights, and perspectives on cultivating an equitable, inclusive STEM classroom
- Practical takeaways to encourage equity and inclusivity in the STEM classroom
- Overcoming challenges and barriers to achieving equity

Co-produced with: American Association of Chemistry Teachers, ACS Department of Diversity Programs, ACS Diversity, and the ACS Inclusion & Respect Advisory Board



Date: Wednesday, February 3, 2021 @ 2-3pm ET

Speaker: Brian Gibney, Brooklyn College and CUNY  
Moderator: Blake Aronson, American Chemical Society

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**What You Will Learn:**

- What are your graduate degree options in chemistry
- How to prepare for applying and attending graduate school in chemistry
- What to expect in graduate school in chemistry

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Date: Thursday, February 4, 2021 @ 2-3pm ET

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Moderator: Glenn Ruskin, American Chemical Society

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**What You Will Learn:**

- What the world thinks of science during the global pandemic and if skepticism gone up or down
- What the global public cares about the most as it relates to science
- What specific actions can we all take to advocate for science

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