Pacific Northwest
NATIONAL LABORATORY

# Talking Trash: Finding the Value in Plastic Waste Through Chemical Upcycling

June 8, 2021

**Lily Hale**
Post Doctorate Researcher


U.S. DEPARTMENT OF ENERGY
BATTELLE
PNNL is operated by Battelle for the U.S. Department of Energy
PNNL-SA-163266

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How Humans are Turning the World into Plastic; A brief history of plastic – TED-Ed video

1. **Today, plastics are everywhere**
2. **A linear plastics economy is bad for the environment and economy**
3. **The vision of a circular economy is that plastic never becomes waste**
4. **Chemical upcycling and catalysis will help enable a circular economy**

1
2
3
4

# DOE's 17 **national laboratories** tackle critical scientific challenges

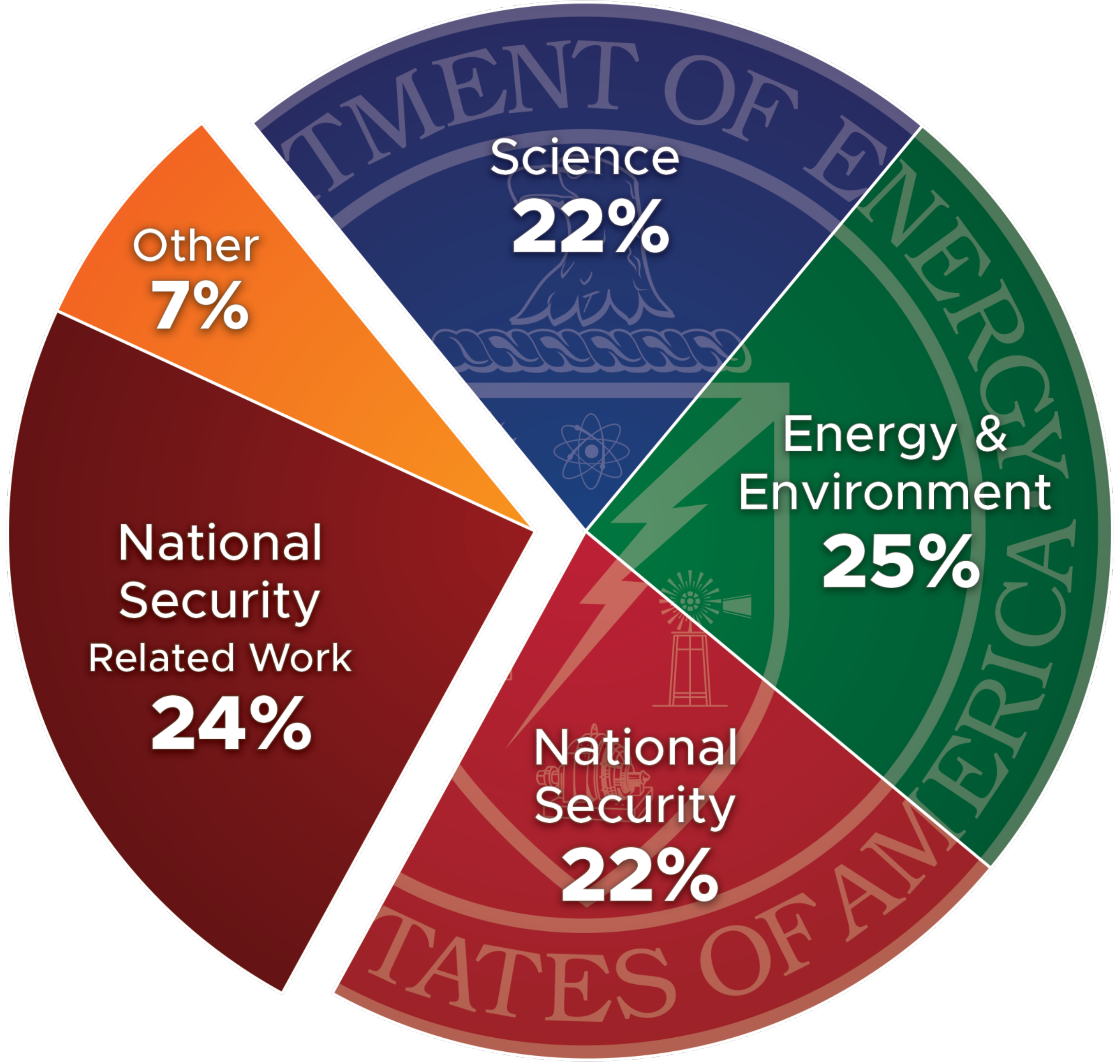
# PNNL is DOE's **most scientifically diverse national laboratory**

**5,000** Staff

**$1.1B** Spending

**1,280** Peer-reviewed publications

**340** Invention disclosures




**FY 2020 Staff**

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# Enriching our community through engagement, philanthropy, and volunteerism is central to our mission

*This photo was taken before the COVID-19 pandemic*

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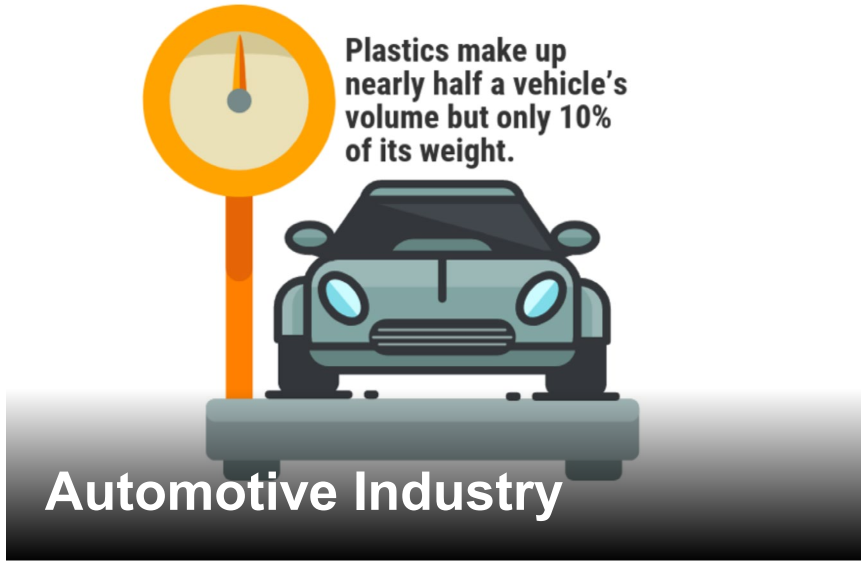
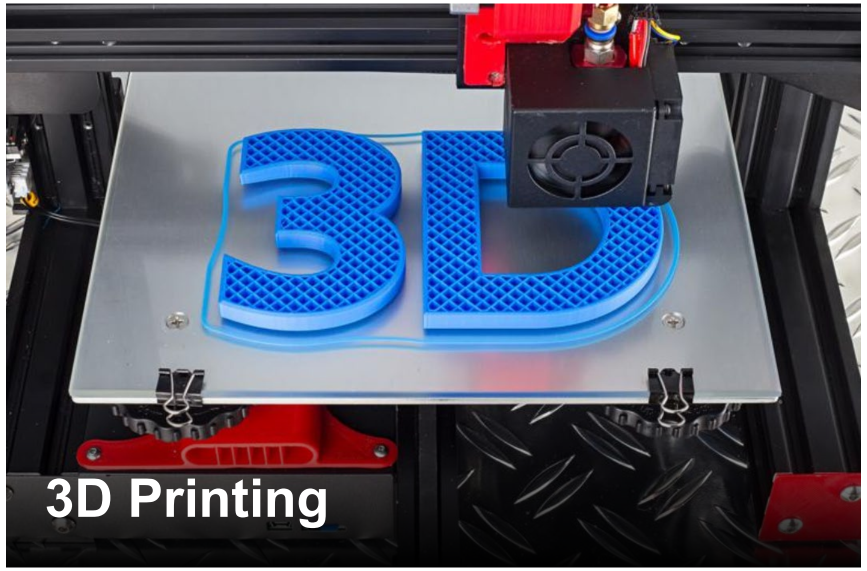
# Plastics are an integral part of our global society

***they are light weight, durable, inexpensive, high performing sanitary, and more accessible than ever***


Food packaging



Automotive Industry

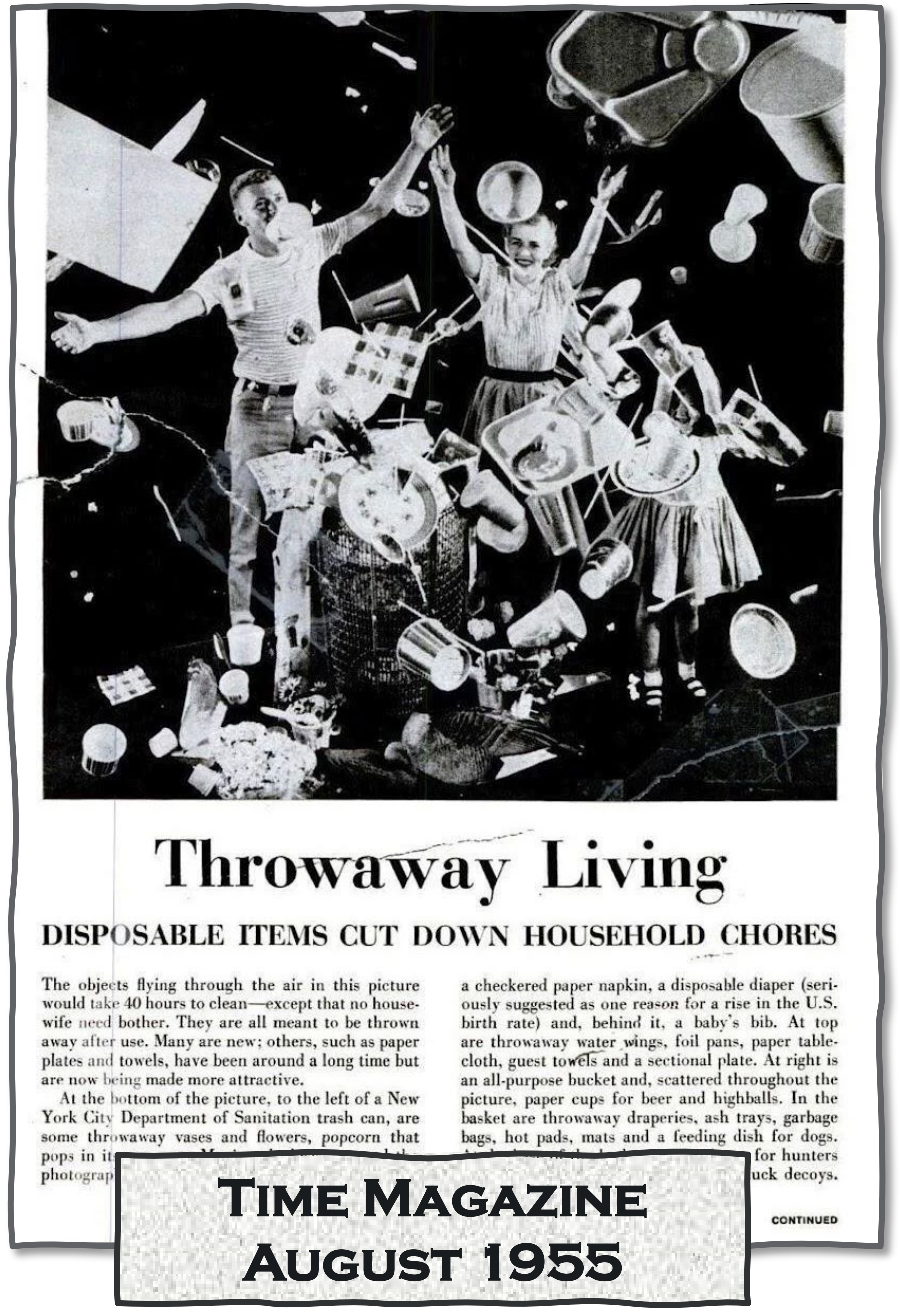


3D Printing


Modern Medicine


Flight & Aerospace

# From the golden days to today's plastic waste



# Throwaway Living

## DISPOSABLE ITEMS CUT DOWN HOUSEHOLD CHORES

The objects flying through the air in this picture would take 40 hours to clean—except that no housewife need bother. They are all meant to be thrown away after use. Many are new; others, such as paper plates and towels, have been around a long time but are now being made more attractive.

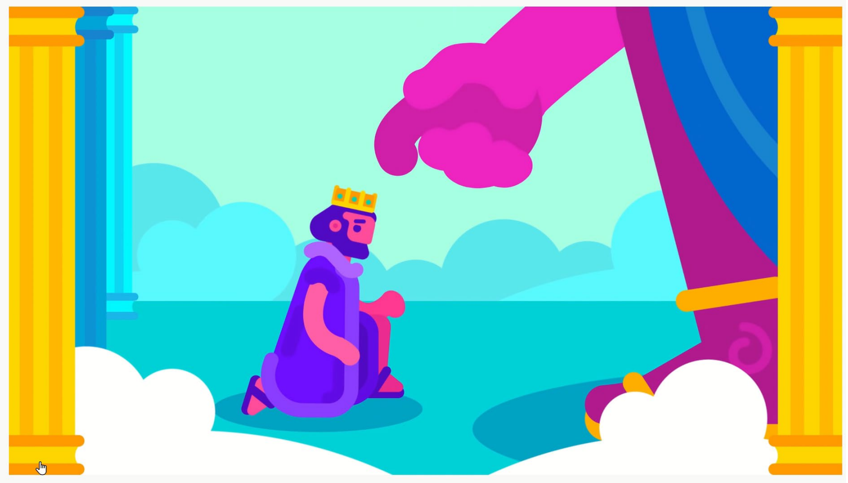
At the bottom of the picture, to the left of a New York City Department of Sanitation trash can, are some throwaway vases and flowers, popcorn that pops in it… photograp…

a checkered paper napkin, a disposable diaper (seriously suggested as one reason for a rise in the U.S. birth rate) and, behind it, a baby's bib. At top are throwaway water wings, foil pans, paper tablecloth, guest towels and a sectional plate. At right is an all-purpose bucket and, scattered throughout the picture, paper cups for beer and highballs. In the basket are throwaway draperies, ash trays, garbage bags, hot pads, mats and a feeding dish for dogs. … for hunters …uck decoys.

CONTINUED

TIME MAGAZINE
AUGUST 1955

***<u>Single-use plastics</u>***: primarily made from **fossil-fuel-based** chemicals and are meant to be disposed of **right after use**



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CONTINUED

**TIME MAGAZINE AUGUST 1955**

**2020, plastic bags pile-up around the US as they wait to be processed**

National Geographic, 2020

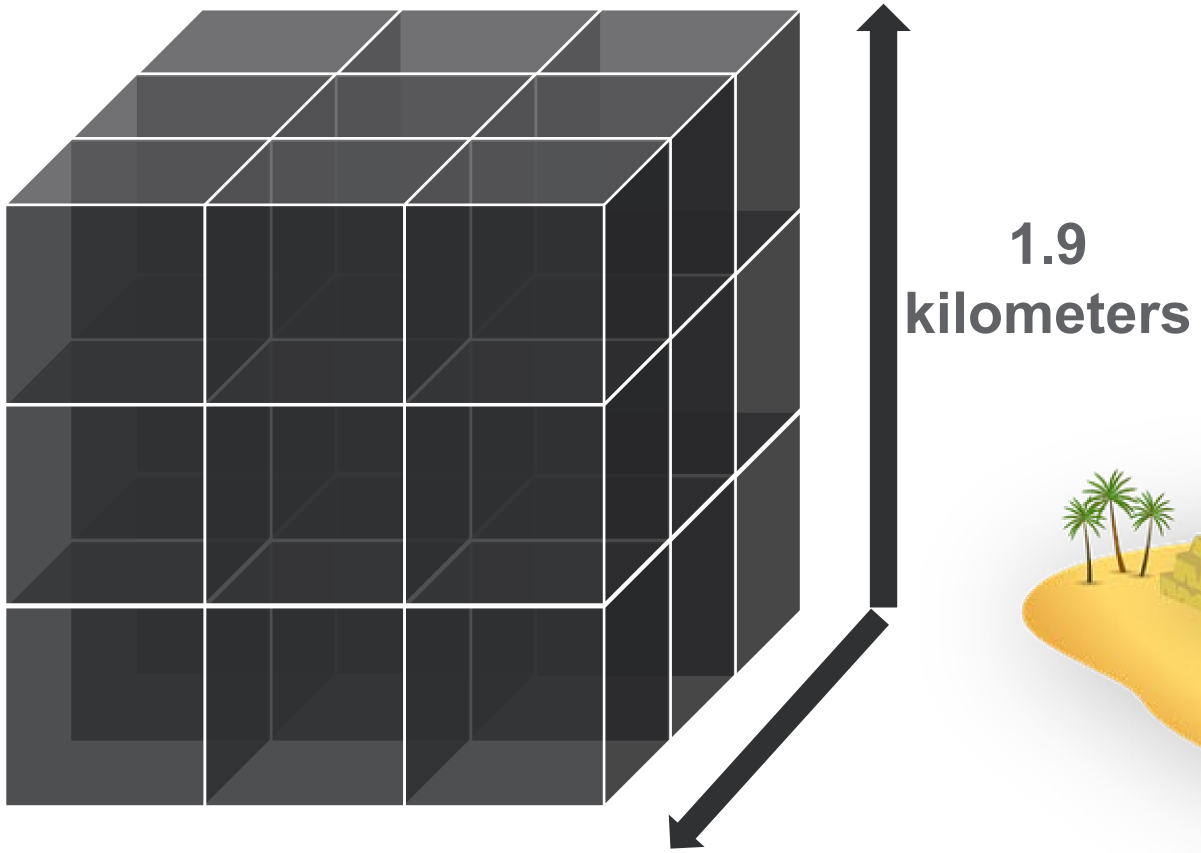
Videos: Plastic Pollution: How Humans are Turning the World into Plastic; A Plastic Wave – A documentary film on plastic pollution

# The scale of plastic production and waste

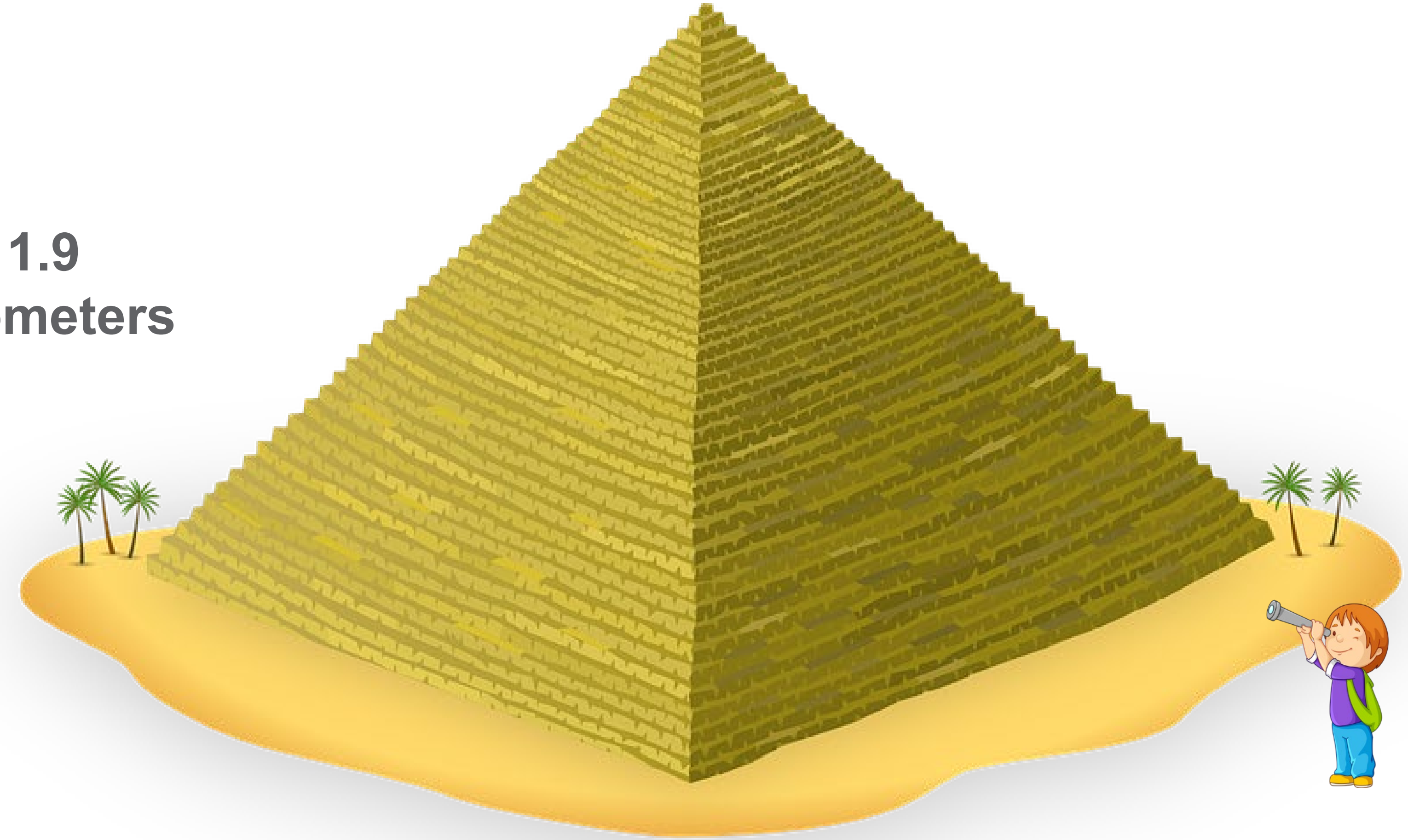
**8.3 billion metric tons of plastic was produced between 1950 and 2015**

***more than 6.3 billion metric tons of plastic has become waste***

***that is 79% of all plastic ever made***




**6.9 $km^3$ of plastic waste**

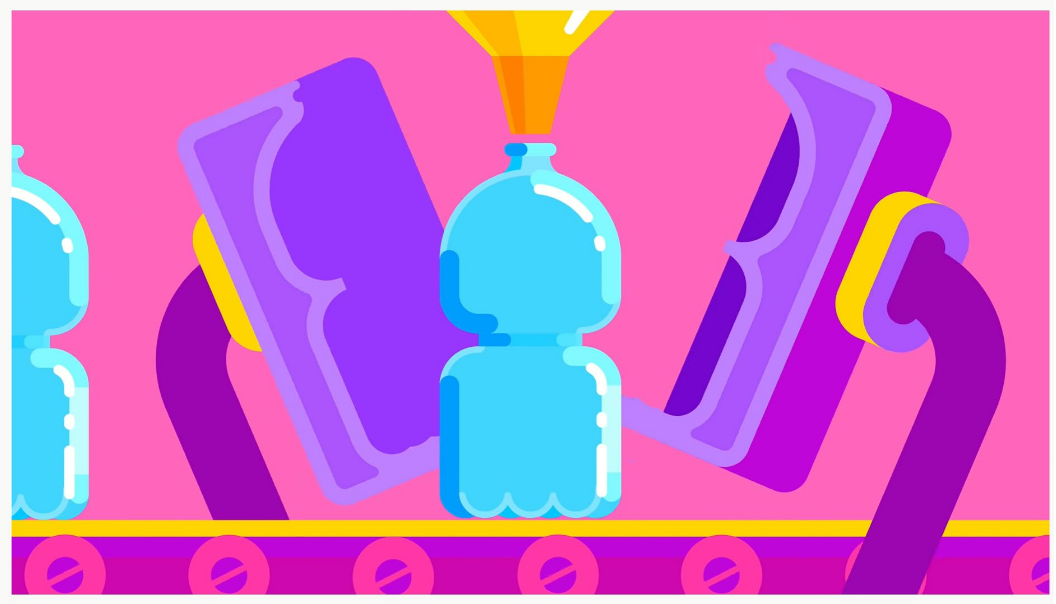


**Almost 3000x the volume of the pyramid of Giza**

Geyer, R.; Jambeck, J. R.; Law, K. L., Production, use, and fate of all plastics ever made. Science Advances 2017, 3 (7), e1700782.

# Plastic production relies on fossil fuel resources

**8.3 billion metric tons of plastic was produced between 1950 and 2015**



Videos: Plastic Pollution: How Humans are Turning the World into Plastic; A brief history of plastic – TED-Ed video

**Raw materials are cheap and readily available. But finite.**

**4-6% of petroleum worldwide is currently used to produce plastic**

**we will end up utilizing 20% of our petroleum resources on an annual basis by 2050**

**The New Plastics Economy: Rethinking the future of plastics & catalyzing action. Ellen MacArthur Foundation**

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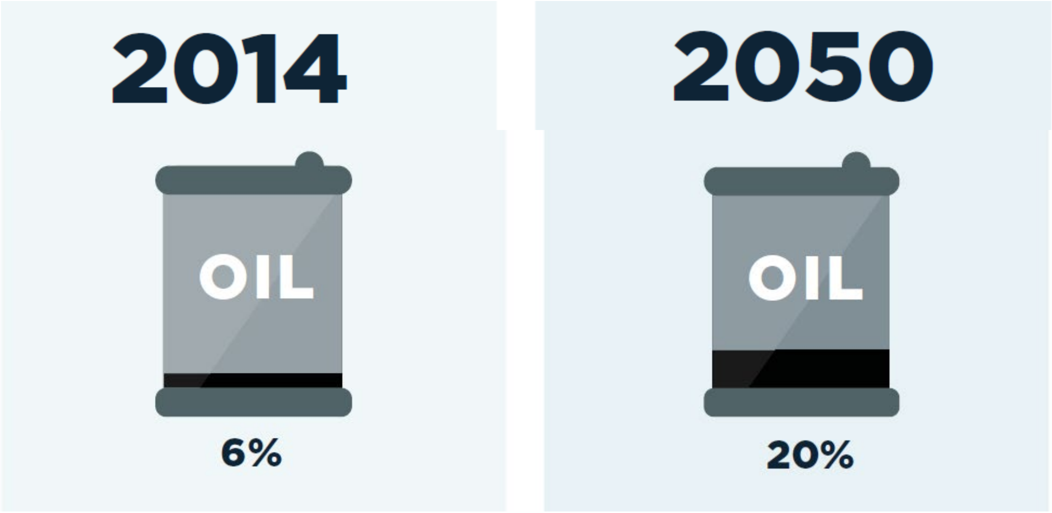


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The New Plastics Economy: Rethinking the future of plastics & catalyzing action. Ellen MacArthur Foundation

# 1) Reduce  2) Reuse  3) Recycle

but applying the three R's effectively toward single-use plastic is difficult

# 1) Reduce 2) Reuse 3) Recycle

bans on different plastic items (plastic bags, straws) aim to minimize single-use plastic

straws, lids, wrappers – are among the most common packaging items found in litter



The Breeze, OpEd. Kat Ellis
April 2018

# 1) Reduce 2) Reuse 3) Recycle

the Covid-19 pandemic reinforced our reliance on single-use plastic
At the same time…

- bans on plastic grocery bags were lifted
- coffee shops stopped accepting reusable mugs
- take-out and online businesses boom

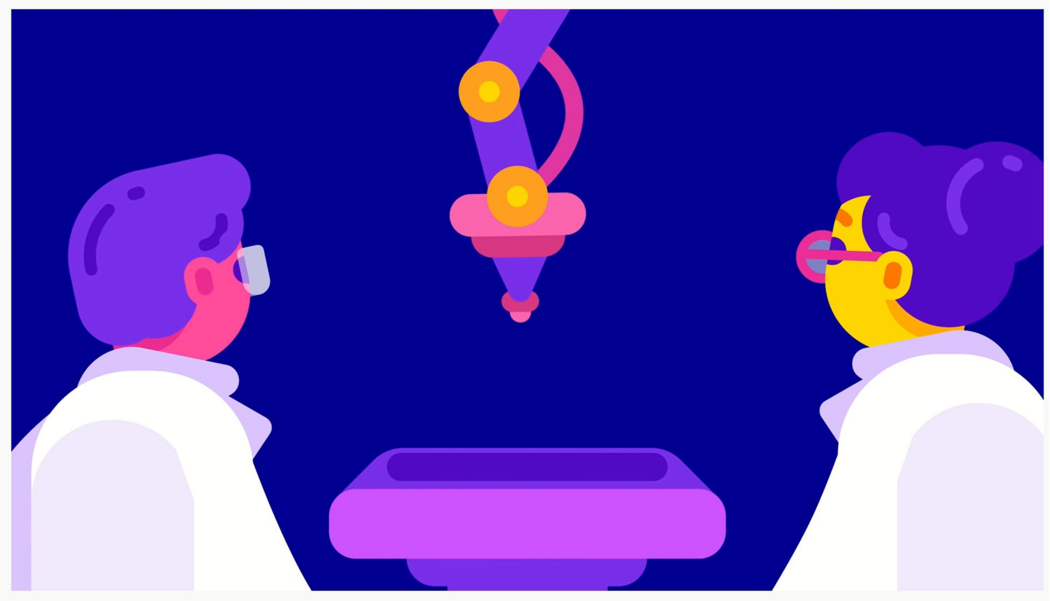

Seattle becomes first U.S. city to ban plastic utensils and straws
JULY 2018
CBS NEWS

The Breeze, OpEd. Kat Ellis
April 2018


personal protective equipment


vaccine distribution

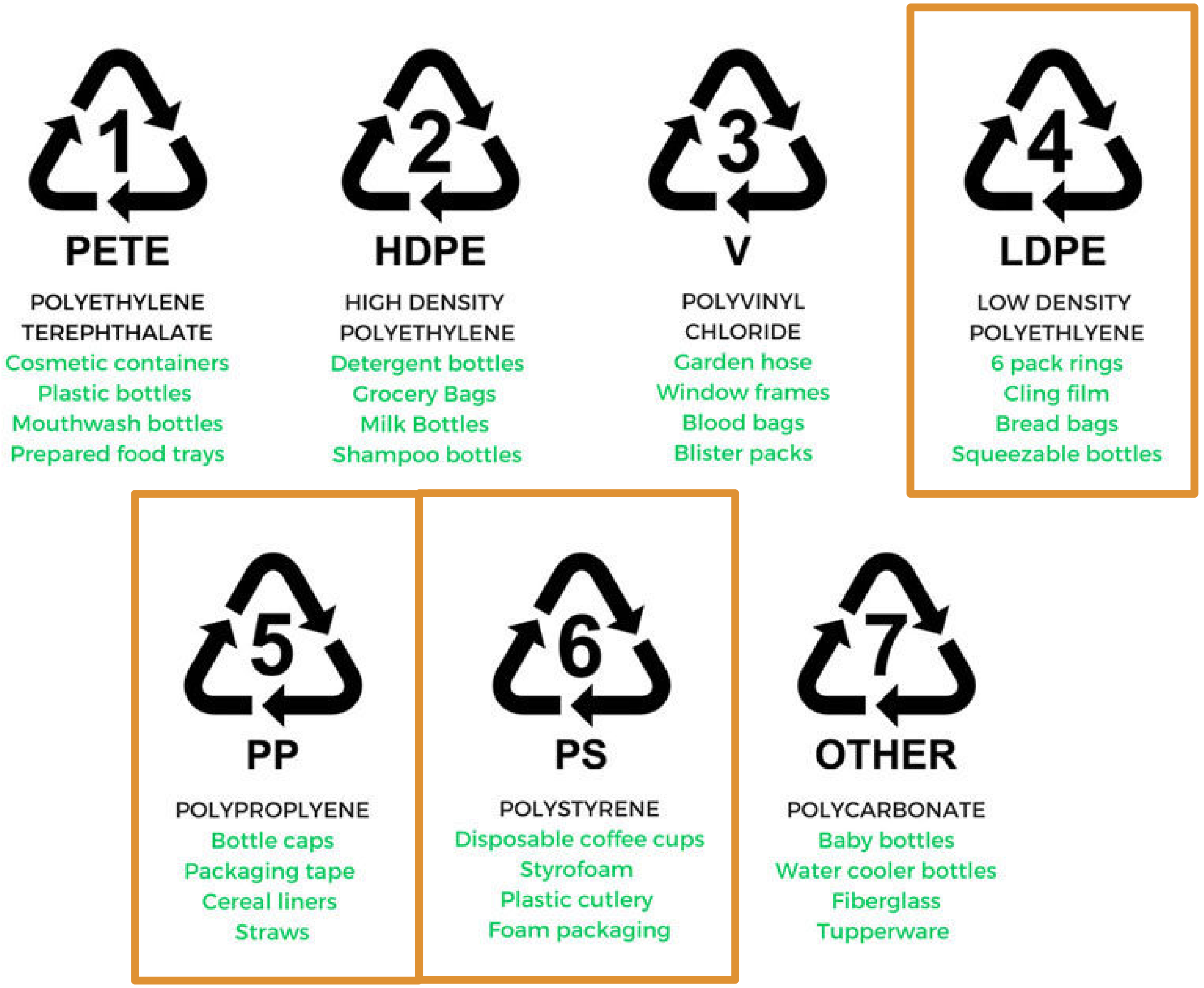
# 1) Reduce 2) Reuse 3) Recycle



95% of plastic packaging material value, or **USD 80–120 billion annually**, is lost to the economy after a short first use.

Plastics that do get reused/recycled are mostly **downcycled**

resin identification codes provide a guide to recyclability

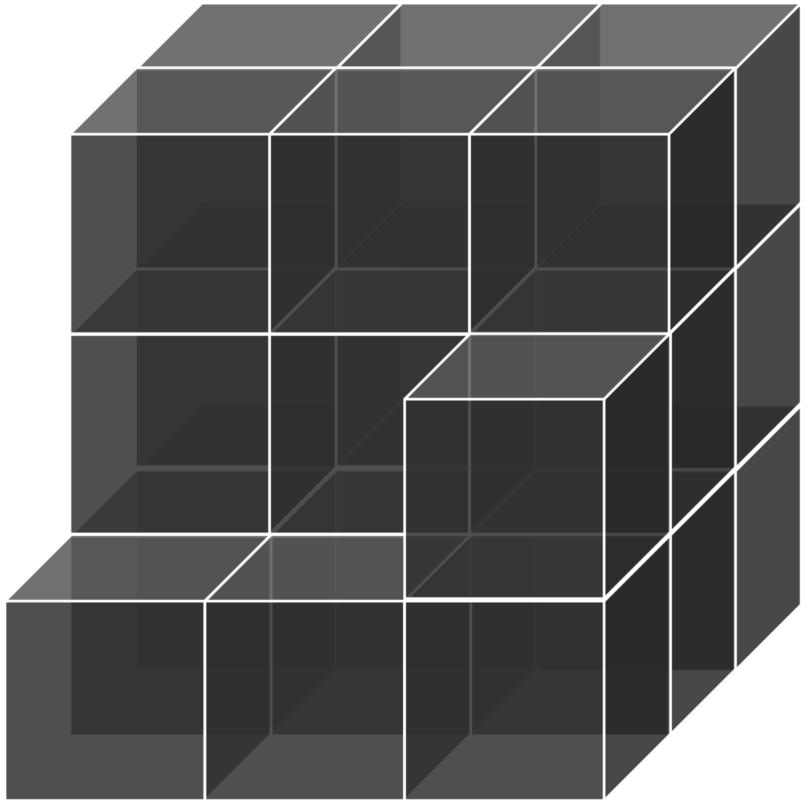



Single-use plastics are better targeted through initiatives that **reduce** rather than recycle

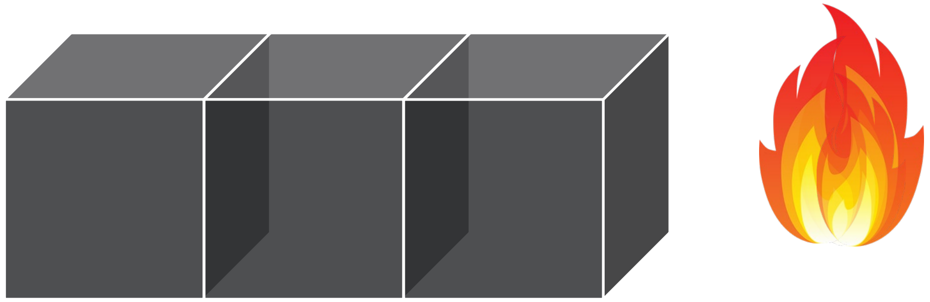
Video: Plastic Pollution: How Humans are Turning the World into Plastic

The New Plastics Economy: Rethinking the future of plastics & catalyzing action. Ellen MacArthur Foundation

# What about the rest of the plastic waste?



**Only 9% of all plastic waste has ever been recycled**



**12% was incinerated for energy recovery**

The New Plastics Economy: Rethinking the future of plastics & catalyzing action. Ellen MacArthur Foundation

# What about the rest of the plastic waste?

**By 2050 there could be more plastic than fish in the ocean**

**In the environment, plastics break down into microplastics**

**The Great Pacific Garbage Patch is a collection of microplastics floating in the Pacific Ocean with est. 1.8 trillion pieces**

**Plankton eat the microplastics, fish eat the plankton, we eat the fish**

**Impact on human health is unknown**

**The rest ends up in the landfills and in our environment**


Lebreton, L.; et. al.; Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific Reports 2018, 8 (1).
Video: Are you eating plastic for dinner?

# So how can we incorporate plastics into society more responsibly?


1. **Today, plastics are everywhere**
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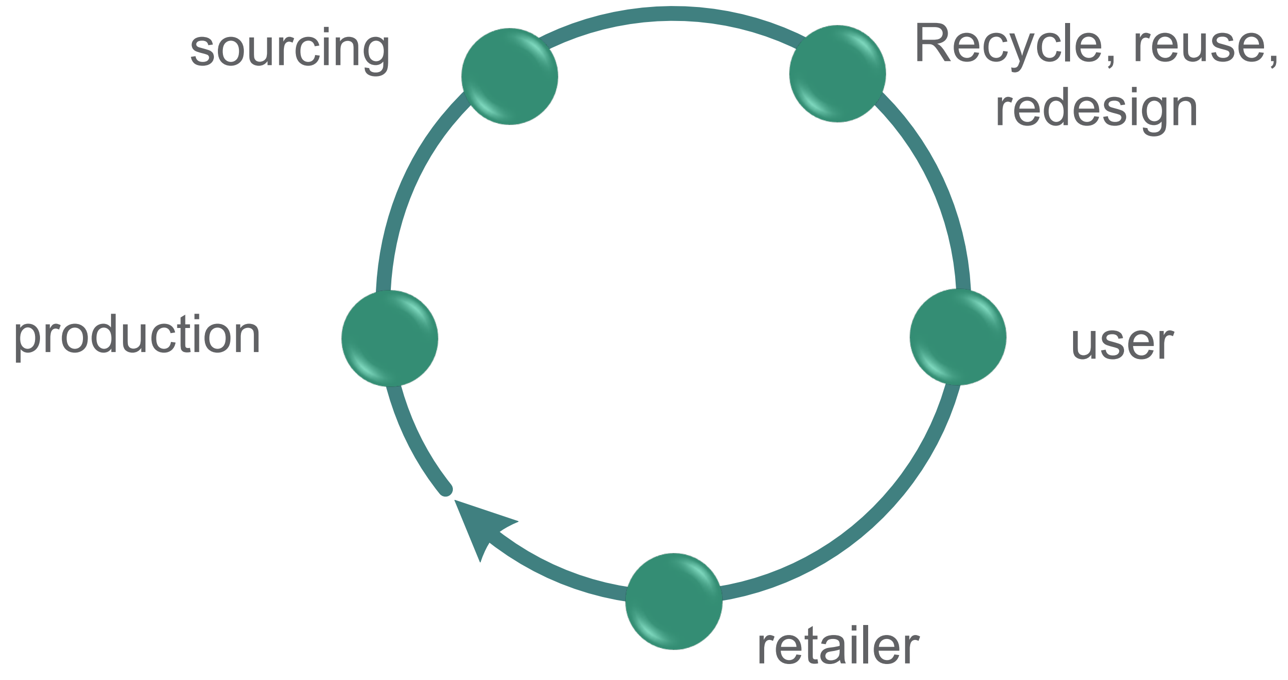
# So how can we incorporate plastics into society more responsibly?

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# So how can we incorporate plastics into society more responsibly?

**Chemical Upcycling:**

**The process of selectively converting discarded plastics into chemicals, fuels, or materials with higher value, ideally using a *catalyst to minimize energy input and consumption***

1. Today, plastics are everywhere
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4. Chemical upcycling and catalysis will help enable a circular economy

1

2

3

4

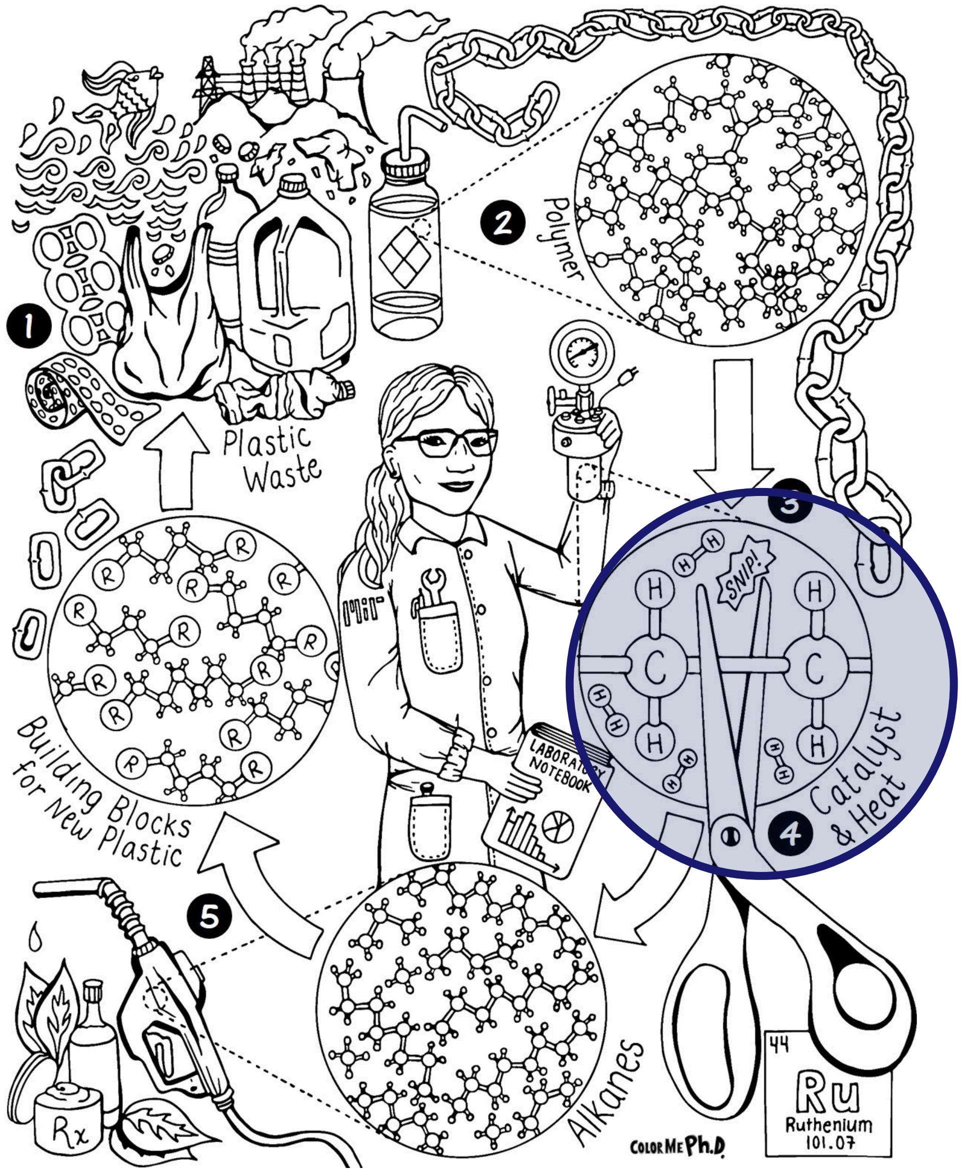
# How did I end up working on this problem?

**Grew up in the PNW**
**BS Chemistry, WWU, 2011**
**Undergraduate research - introduction into the world of catalysis**

**PhD in Inorganic Chemistry/Catalysis, 2018**
**University of Michigan**

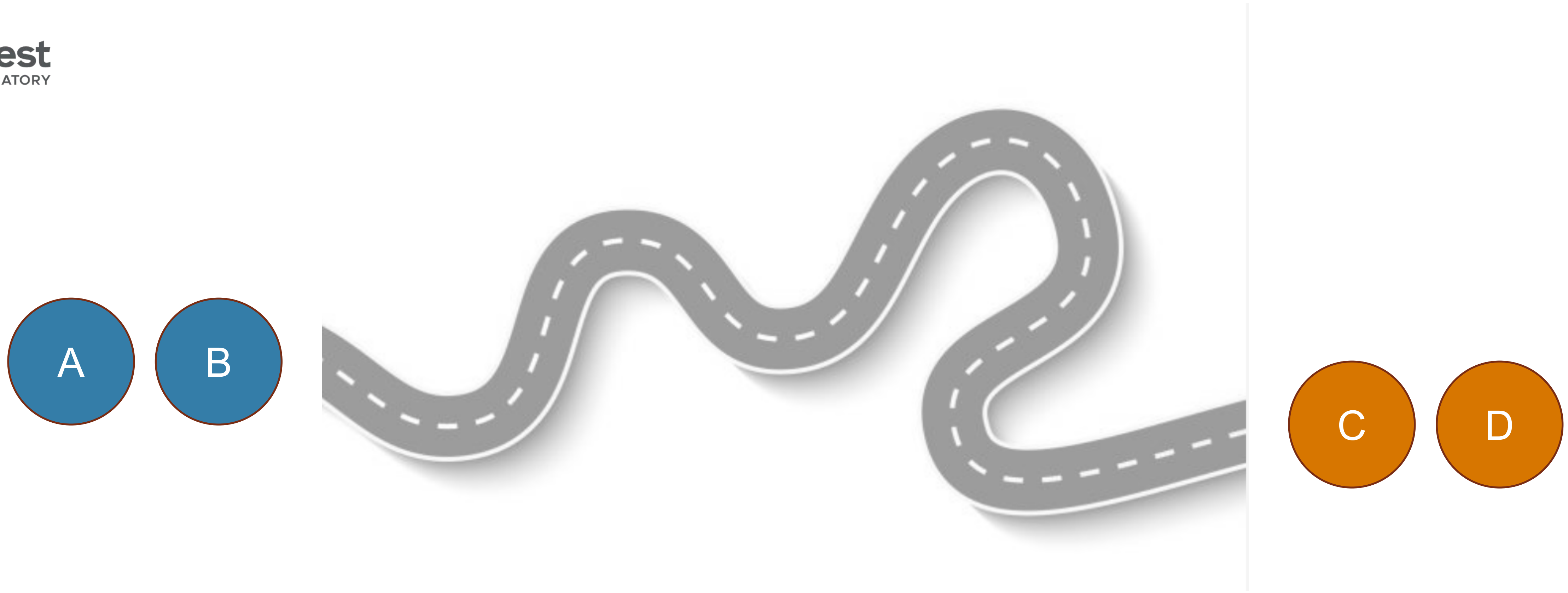
**Postdoctoral Research**
**Industrial Catalysis, 2018-2020**
**UC Berkeley w/ DOW chemicals**

**Postdoctoral Research, 2020 - today**
**Catalyst design for Plastic Upcycling, PNNL**




Dr. Julie Rorrer/Color me PhD

# What is a catalyst?

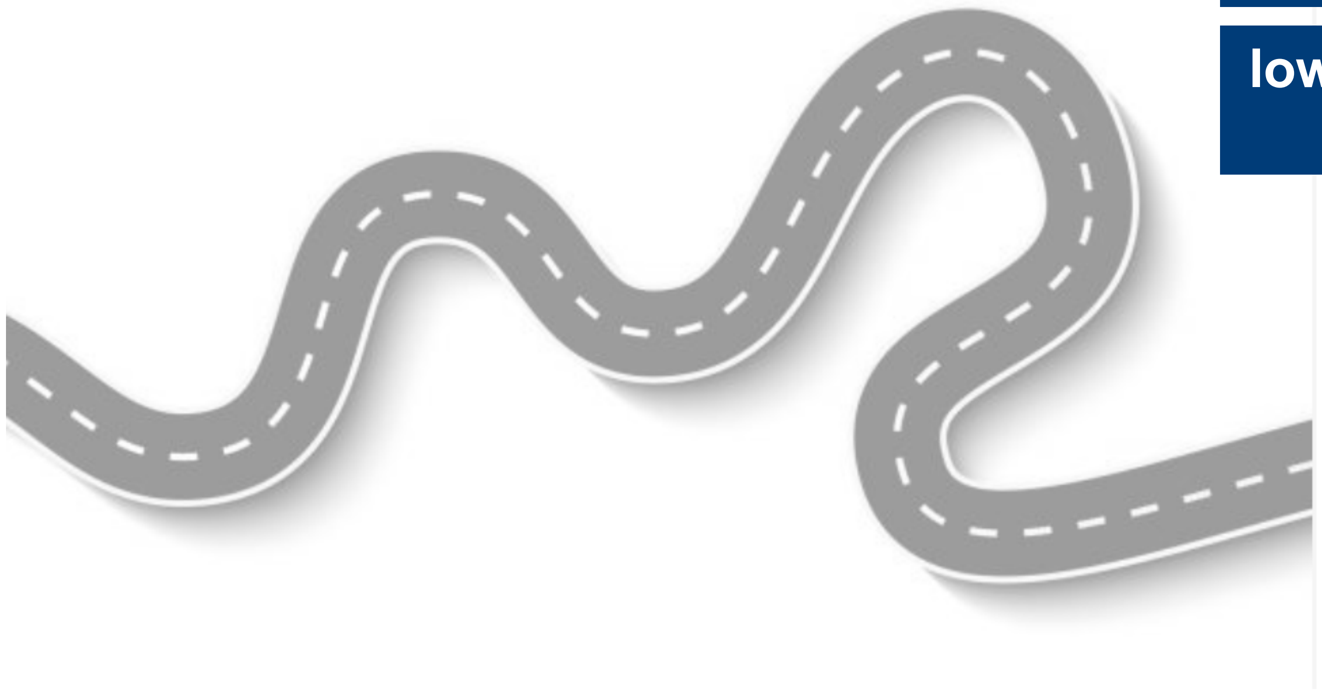


# What is a catalyst?

a catalyst speeds up a chemical reaction

lowers the energy required for a reaction to occur

A B



C D

provides an alternative pathway for the reaction

remains unchanged – is not used up in the reaction

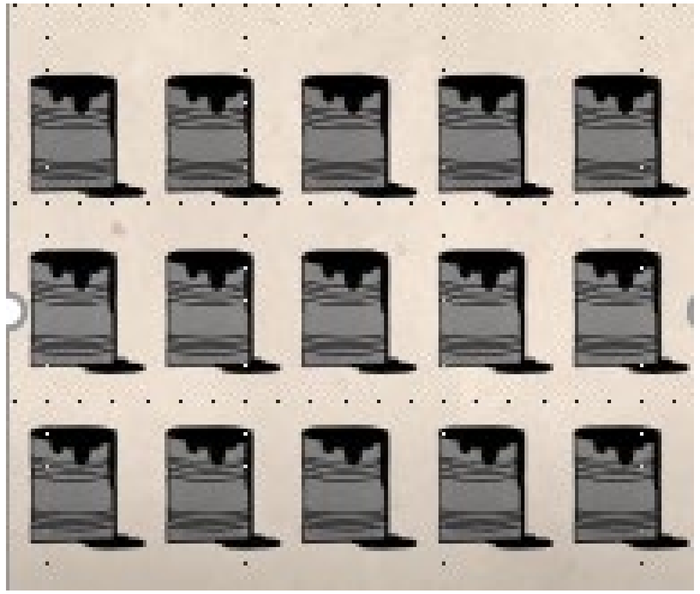
# Without catalysis we would not have…

**Catalysts are used to upgrade crude oil and fossil fuel-based chemicals into the products and materials we rely on**

plastics

fertilizer

fuels



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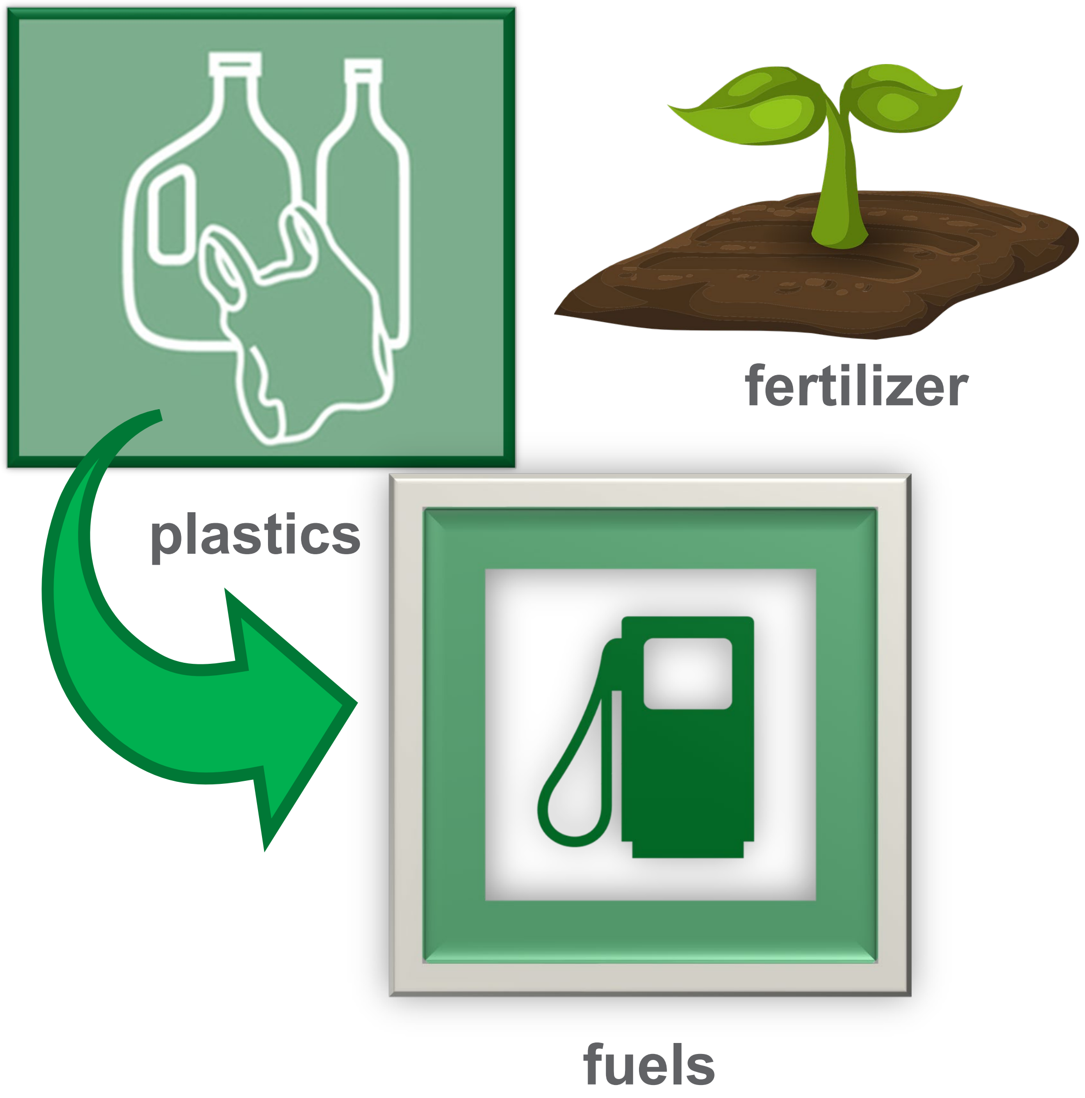


**Catalytic upcycling could enable production of these high value products directly from plastic waste, creating a closed looped process**

***We can use the tools of synthetic chemistry, material science, analysis, theory, and engineering to design new more efficient catalysts***

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# Plastic materials are made to last

Why are plastics so difficult to break down?

How do we design a catalyst that can break them down fast and into products that we want?


https://futurism.com/plastic-decomposition

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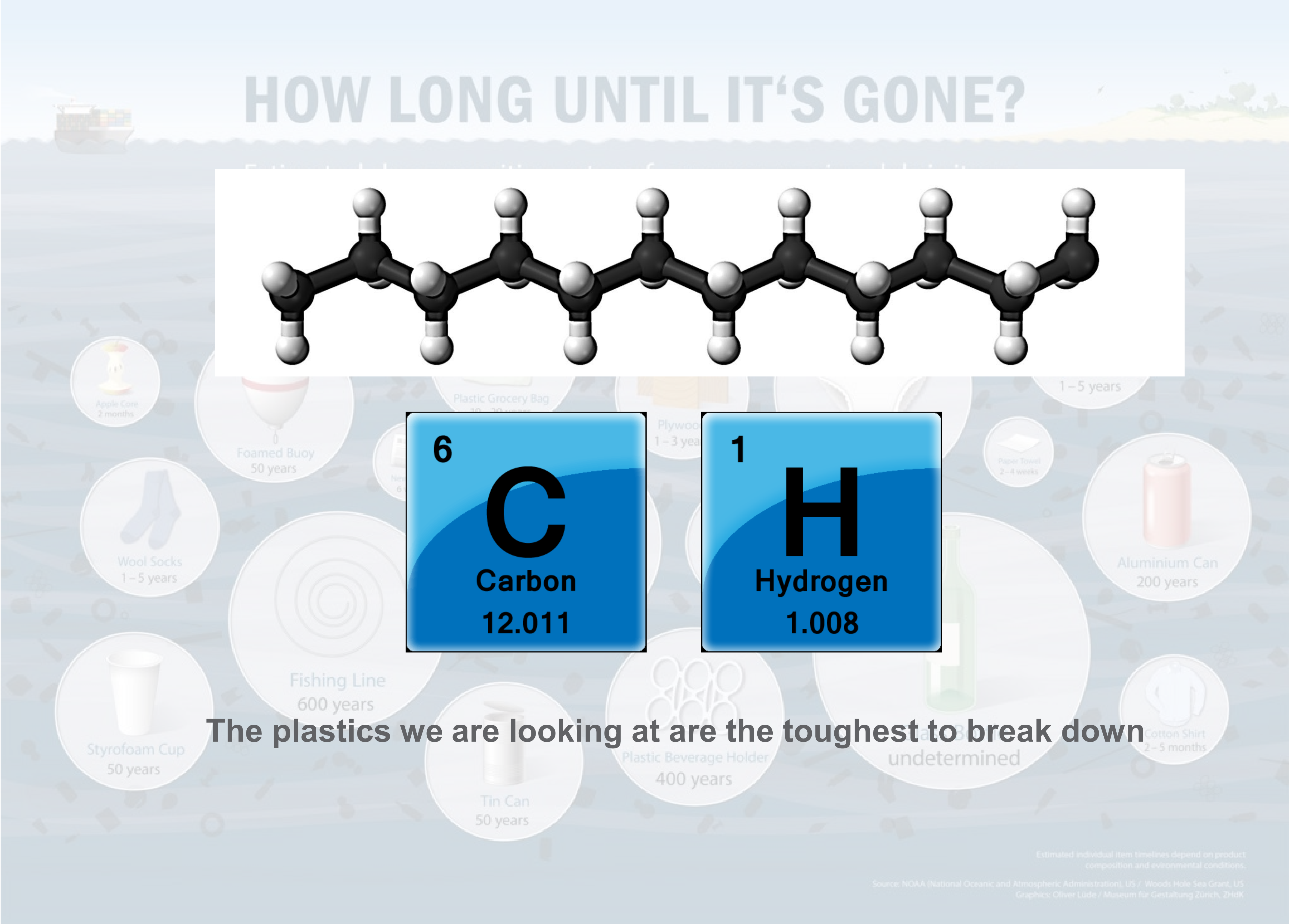
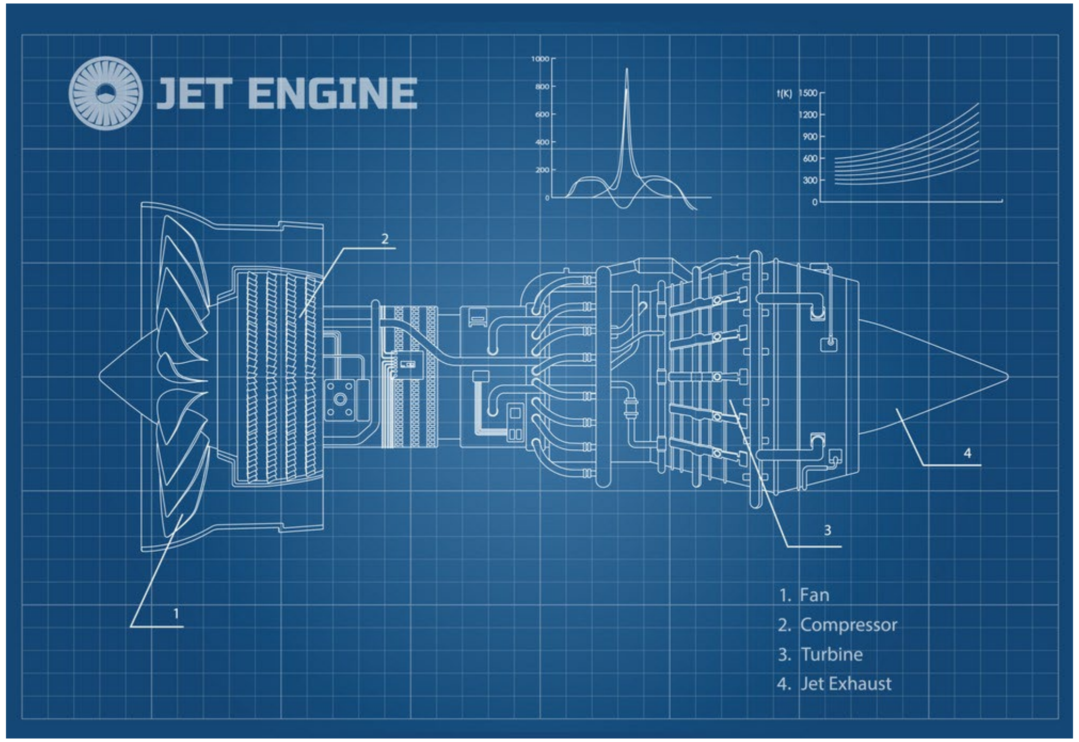
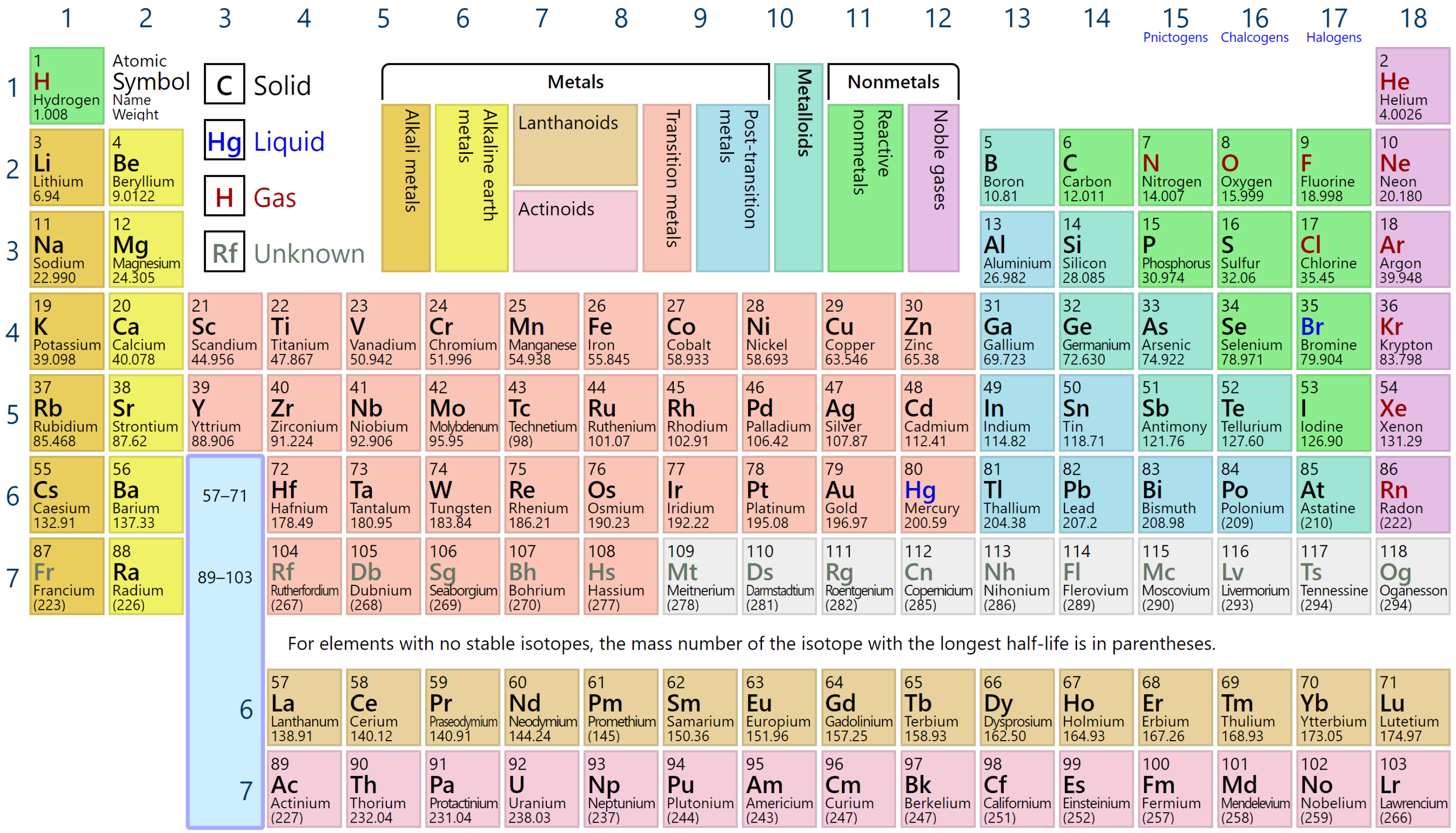



**The plastics we are looking at are the toughest to break down**

https://futurism.com/plastic-decomposition

# How do we design a catalyst for plastic upcycling?




**Just as engineers fit together parts to build a complex machine…**
**Chemists use the periodic table to combine elements into a working catalyst**

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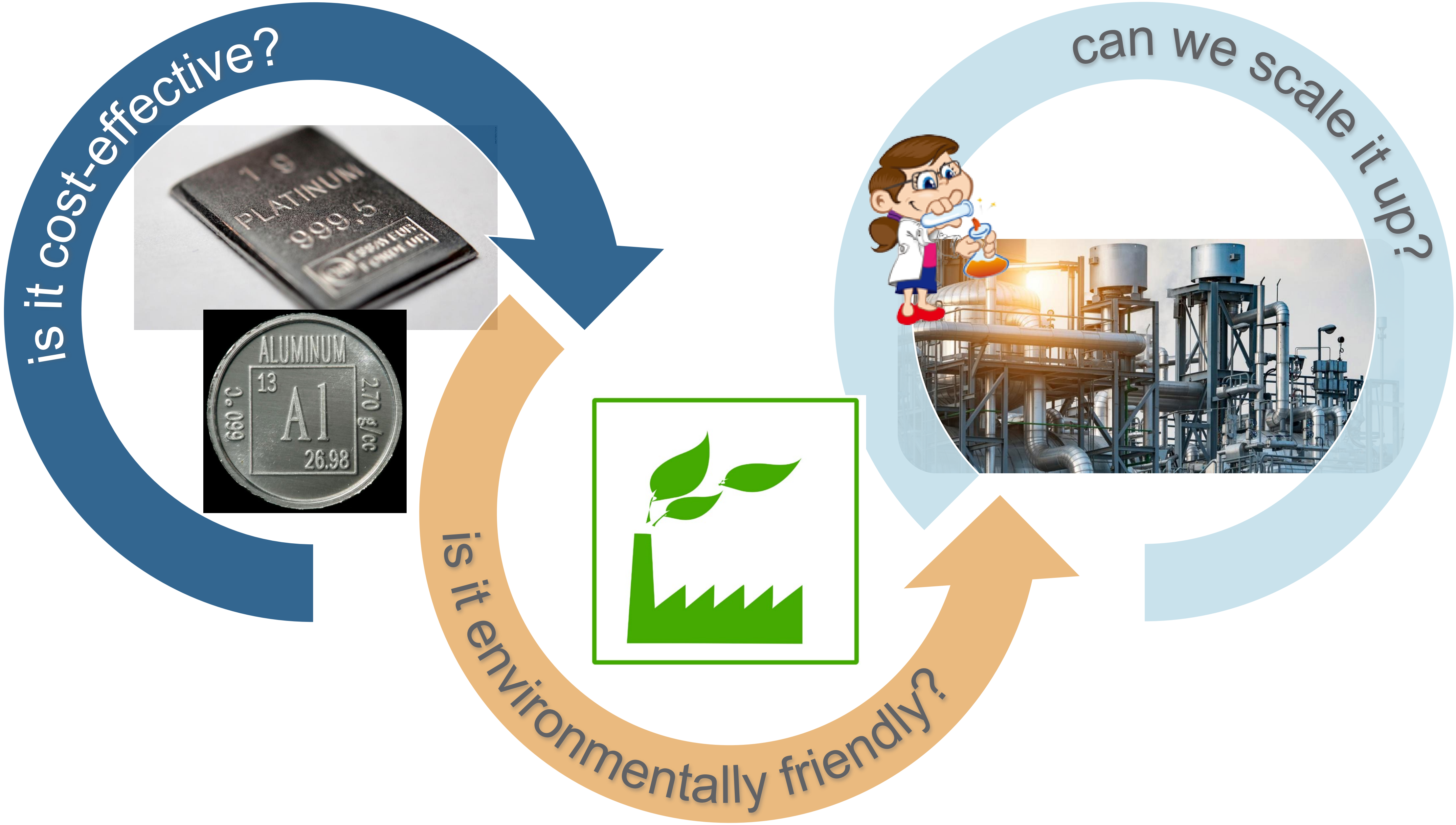
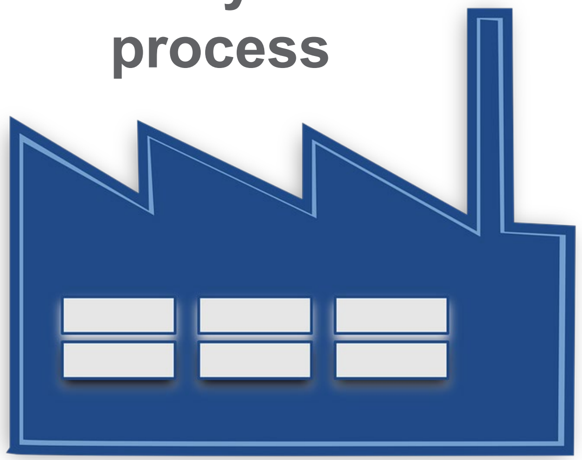
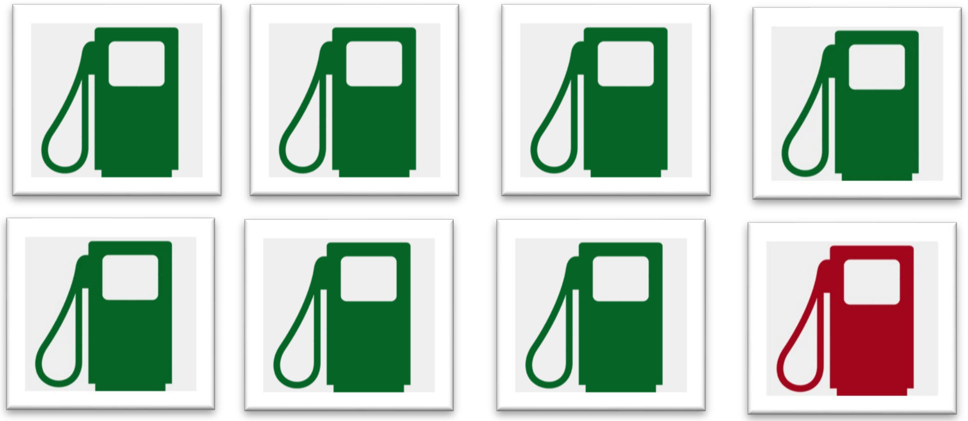
# Choosing the right catalyst for a sustainable process



# We are pioneering low-temperature catalytic processes for upcycling plastic packaging

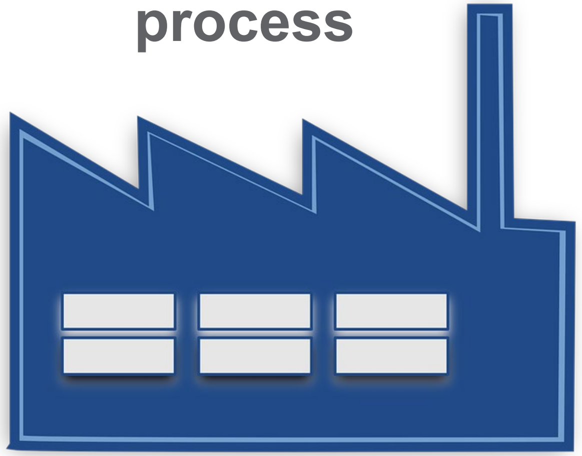
catalyzed process

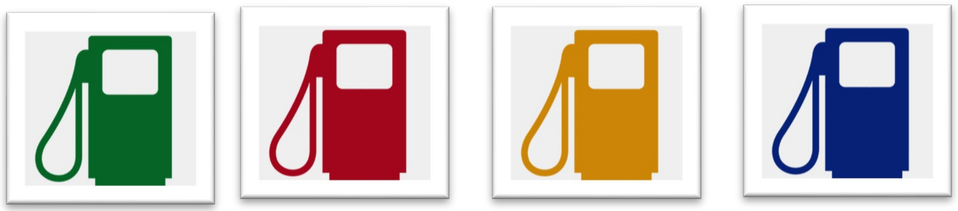




Plastics feedstocks

uncatalyzed process

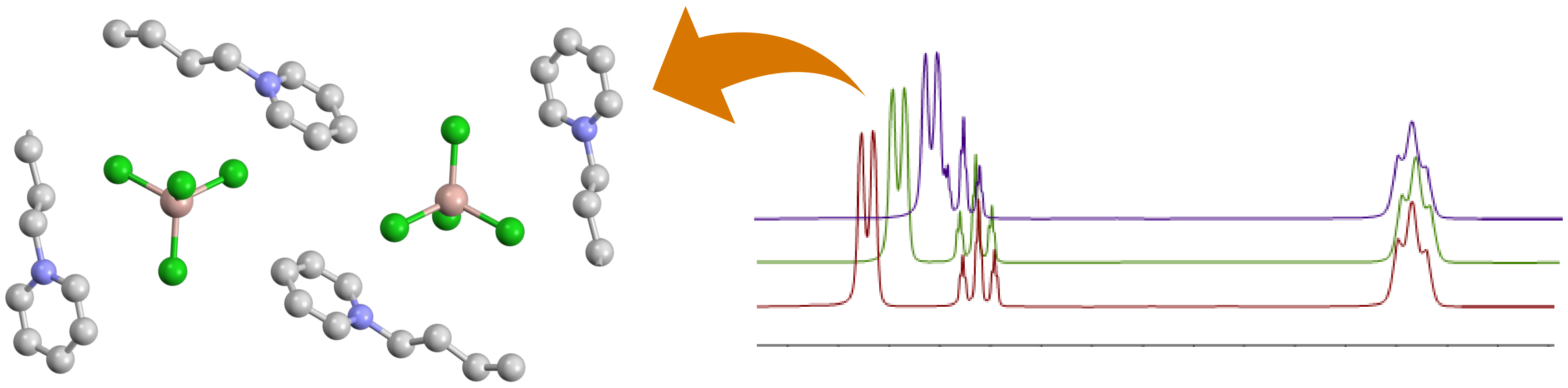




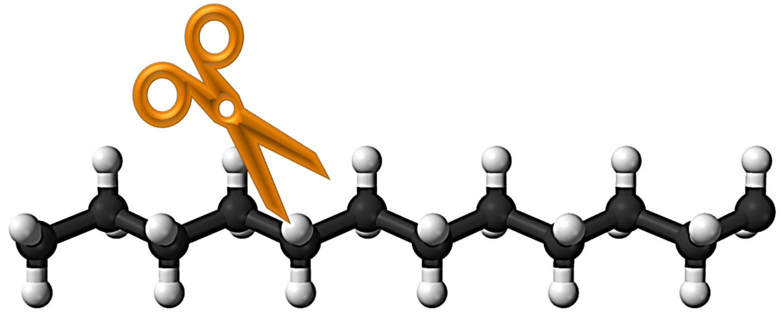
- Our catalyst works at temperatures 3x lower than current catalytic technologies
- The catalyst can be recycled up to 7x
- Selective product distribution

# My job is to understand how the catalyst works

**What does it look like?**



**How does it bind to plastics and break the chemical bonds?**



**How fast does it go under various conditions?**

# What does this mean for you?

**If we can understand, improve, and build on the chemistry behind plastic upcycling catalysis we will help to:**

- **Take plastic waste out of the landfill and out of the ocean**
- **Decouple the production of plastics with the use of fossil fuels**
- **Recover the material value lost from single-use packaging by creating higher value products**

# Solving big problems starts with a great team

Sungmin Kim, Wenda Hu, Jian Zhi Hu // PNNL

Wei Zhang, Yue Liu, Lennart Wahl // TUM

Advisors: Johannes Lercher, Abhi Karkamkar, Oliver Gutierrez

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U.S. DEPARTMENT OF ENERGY

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

EMSL

# Thank you

Pacific Northwest
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# Questions?


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Post Doctorate Researcher

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