# Historical Perspective of Material Innovation

Presented by Dr. Lauren Blake

September 9th, 2024 3-4:15pm

Sustainable Materials Course


Where is this?

# Housekeeping items

- Don't forget Assignment #1 due on Wednesday! ***Envisioning Sustainability Through Art***
- Logan to describe **semester project** on Wednesday- stay tuned!
- Please **watch video posted on Canvas** and let us know your thoughts!
- Bring a **sealable tupperware** in on Wednesday for Kombucha leather homework assignment (Chinese takeout containers work great!)

# Lecture 2-3

**Introduction**
- Overview
- Historical Perspective

**Challenges**
- Human Health
- Environment
- Opportunities

**Solutions**
- Old Polymers
- Attempts w/Impact
- Emerging Concepts

**Applications**
- Food and Ag
- Electronics and Optics
- Healthcare

**Future**
- What do we need?
- How do we get there?

# Learning Outcomes

1. Understand the unique challenges of materials today compared to centuries ago
2. Know the advantages and disadvantages of plastic production
3. Discuss futuristic solutions to the world's material problems

# **Stone Age:** lasted from 30,000 BCE to 3,000 BCE- material innovation for weapons, shelter, and jewelry

Stone

Feathers

Bone

Clay

Wood

Fibers

Animal skin

Shells

# Bronze Age: Bronze gradually replaced stone from 2000 BCE to 700 BCE

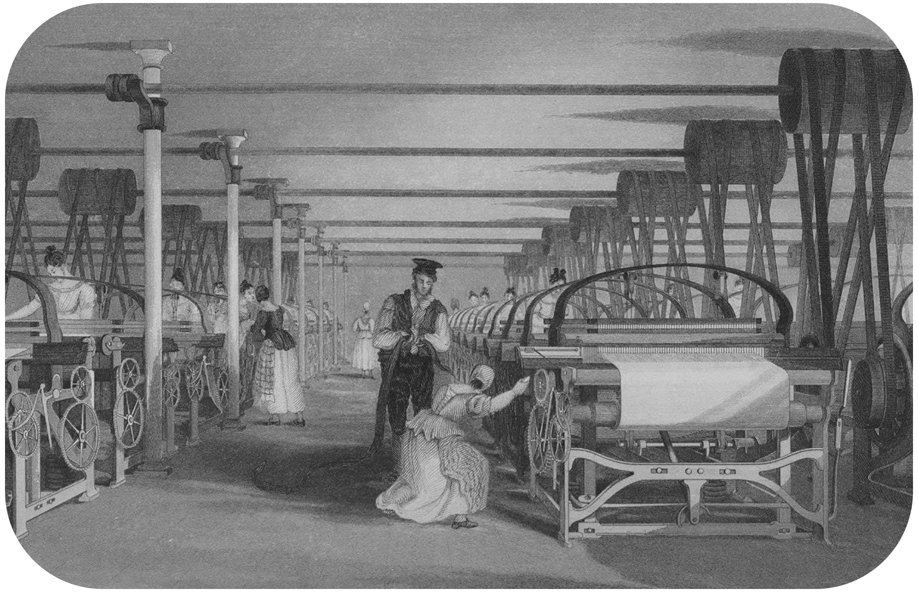
- Bronze made by melting tin and copper and mixing together
- Tin and copper have lower melting points than iron- easier to process
- Stronger, more durable material that can be more easily shaped

# Iron Age: transition from bronze to iron tools from 1200 BCE to 550 BCE

- Specially designed **furnaces** allowed for easier melting of iron
- Iron even stronger than bronze
- Breakthrough in warfare, sturdier buildings, improved farming techniques, better quality of life
- Iron ends up being the key driver of the **Industrial Revolution** later

# First Industrial Revolution: transitioned society from creating goods by hand to using machines

- The FIRST Industrial Revolution (~1760 to 1840) involved the implementation of **mechanical production** instead using steam and water power
- Textiles: mechanized **cotton spinning** powered by water and steam
- Larger quantities of iron making enabled by steam engine
- Invention of machine tools such **as lathes and mills** to shape and cut more specific parts

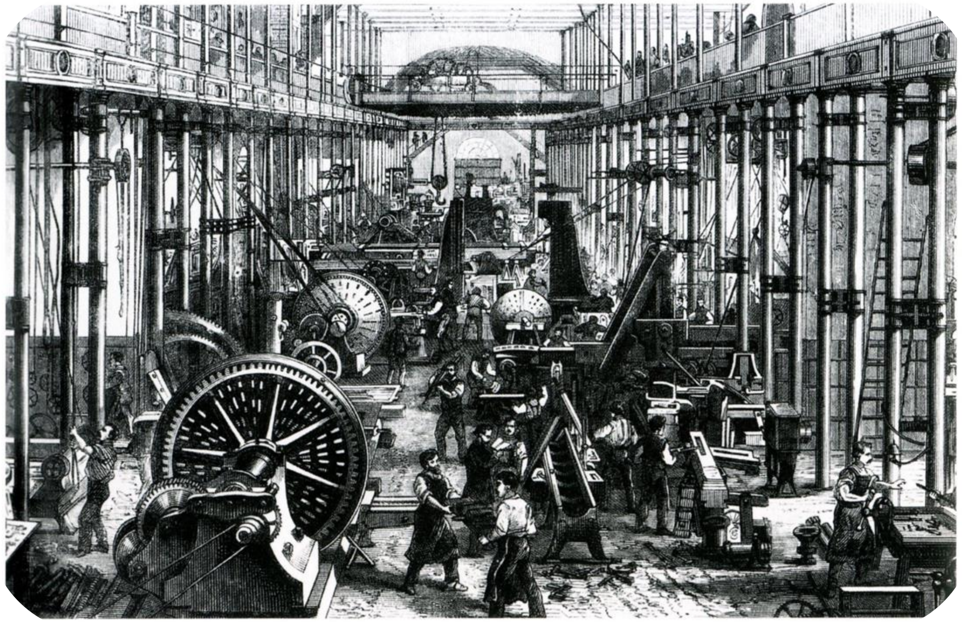


The textile industry took off during the first industrial revolution with the invention of power looms.

Source: Unknown

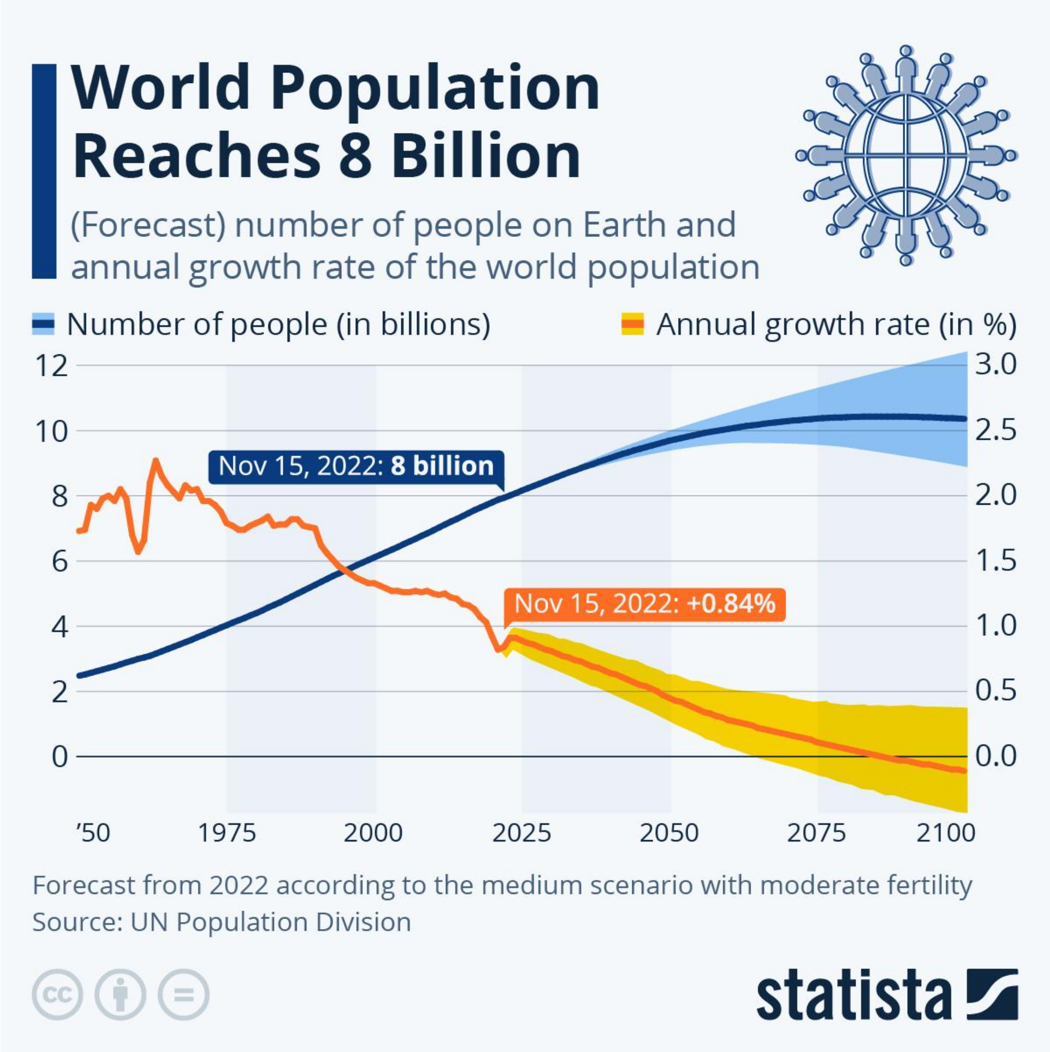
# Second Industrial Revolution: transitioned society from creating goods using machines on a larger scale

- The SECOND Industrial Revolution (also known as the Technological Revolution, 1870-1914) marked a transition towards **mass production**
- Utilization of electricity, petroleum, steel, assembly lines, and the railroad
- **Common theme:** Both industrial revolutions were in response to a need for more manufacturing as a result of **population growth**



Assembly lines allowed for mass production.
Source: Unknown

# Population is continuously increasing, though the growth rate is slowing down

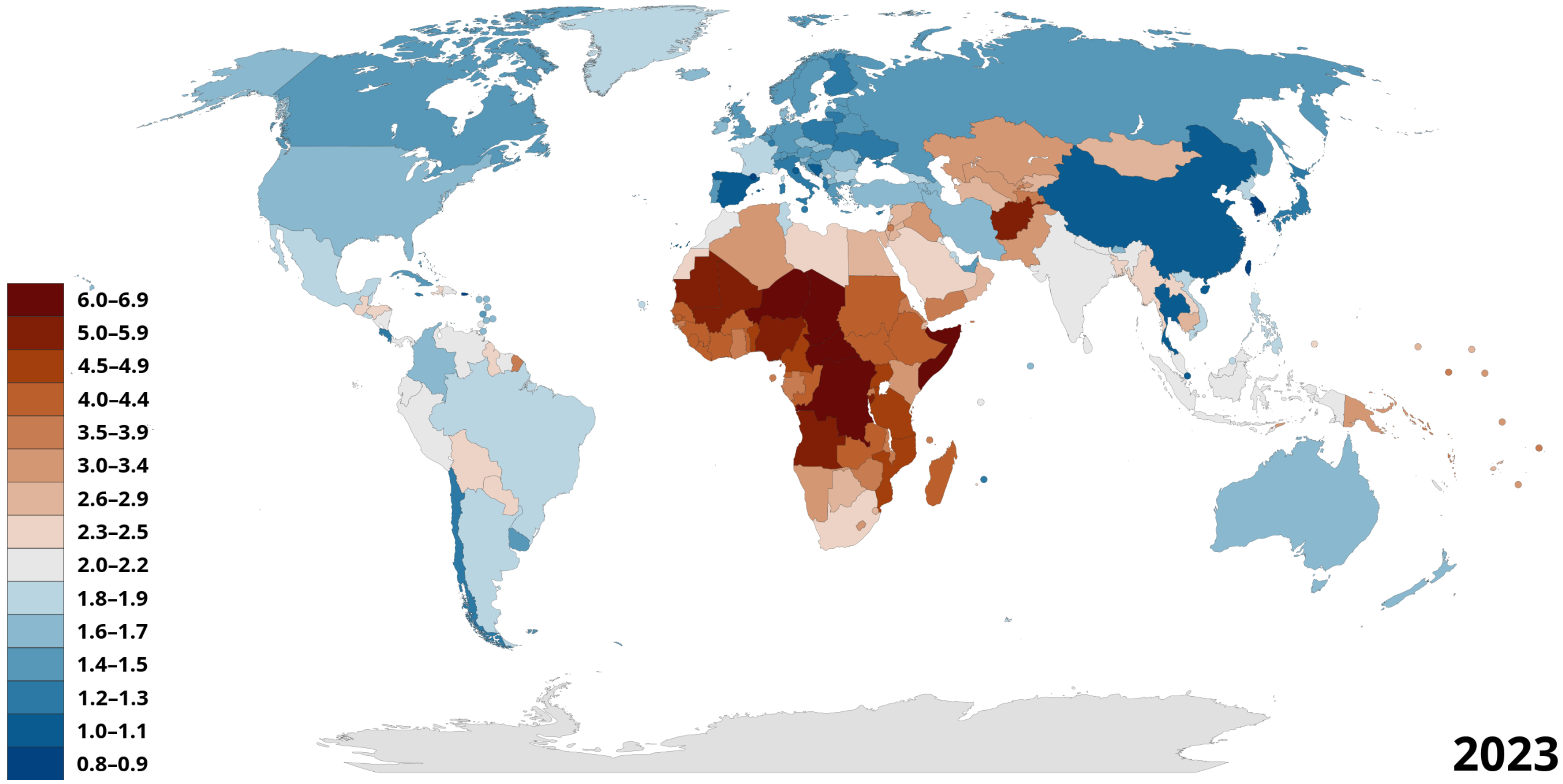



- **Carrying Capacity** = the maximum population size of a biological species that can be sustained by that environment, given the food, habitat, water, and other available resources

- Human carrying capacity estimates = **2 - 4 billion** for higher standard of living

Lianos, T. P., & Pseiridis, A. (2016). Sustainable welfare and optimum population size. *Environment, Development and Sustainability*,

# Population growth rate is slowing down due to less overall fertility rate globally




- People are having less children per person overall
- A declining population will pose **difficult economic** challenges, but **positive ecological** benefits

Map of countries by fertility rate (2023), according to the Population Reference Bureau

# The **circular economy** dominated prior to the Industrial Revolution (and we need to return to it!)


Materials amenable to circular economy:

- **Buildings:** wood, stone
- **Textiles:** cotton, linen, wool, silk
- **Packaging:** glass, paper, wax, aluminum

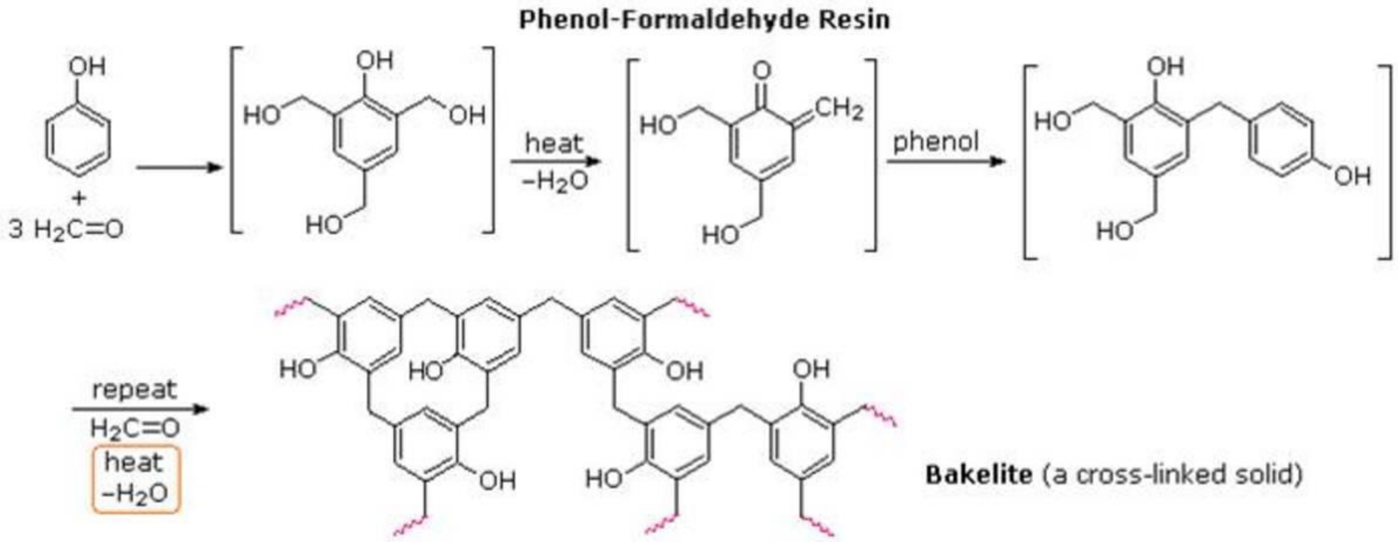
# The **linear economy** "take-make-waste" model dominated in the late 1800s

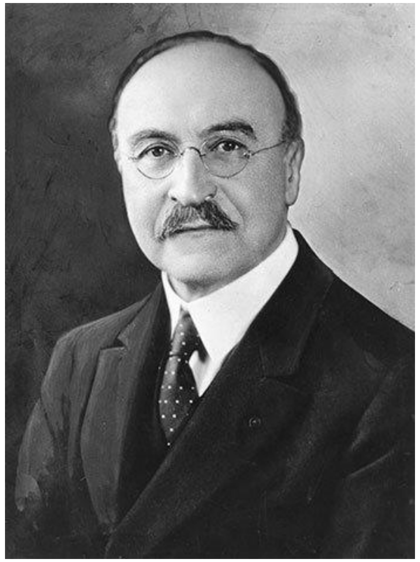
- Became popular during a time of plentiful resources
- Recycling infrastructure is overwhelmed
- Linear systems cannot be upheld on a finite planet indefinitely


Credit: Elnur - stock.adobe.com

# Plastic was invented in 1907 as a substitute for natural products like ivory and shellac

- Bakelite was invented by Belgian-American chemist Leo Baekeland.
- Bakelite was made by combining phenol and formaldehyde under heat and pressure





Bakelite inventor Leo Baekeland


Bakelite Type 232 telephone made in the 1930s.


Ekco radio receiver in Bakelite case, 1935.

Photos from Science Museum Group Collection

# Plastic began to be mass-produced after the Second World War and then again during the 1960's and 1970's

Consumers loved plastics instead of traditional materials because of their:

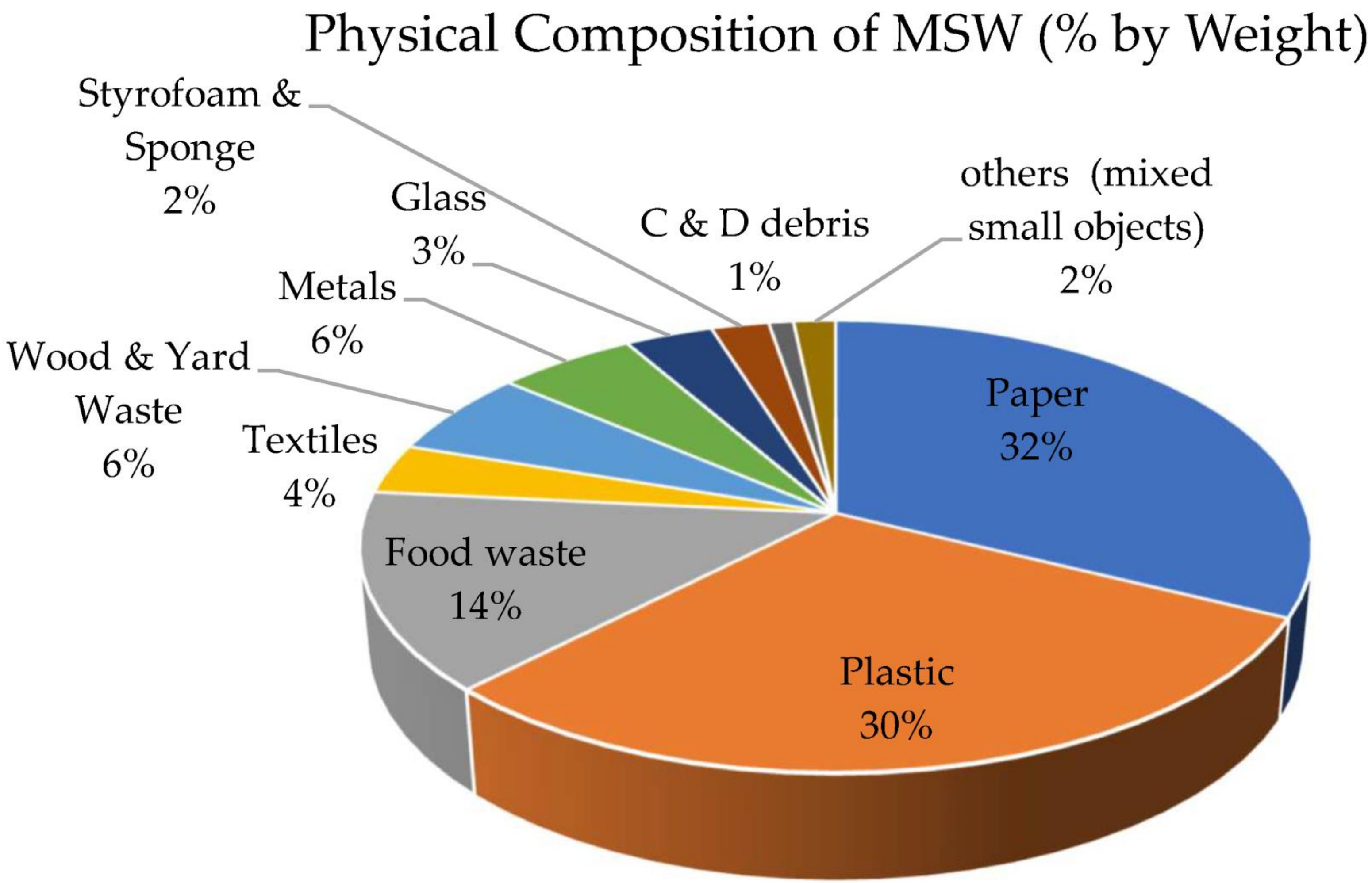
- Low cost
- Versatility from ease of manufacturing into a variety of forms (films, fibers, molds, etc)
- Versatility of mechanical properties (strength, elasticity, flexibility)
- Sanitary nature
- Durability

# Environmental and Health Hazards of Plastics

These problems are **unique to the 21st century**

# Plastic is the fastest growing segment in landfills

- MSW = Municipal Solid Waste (aka community trash)
- COVID-19 pandemic sparked reliance on single-use items to prevent spread of diseases
- Plastics went from 18.5 % of landfills before COVID-19 to 30% of landfills after

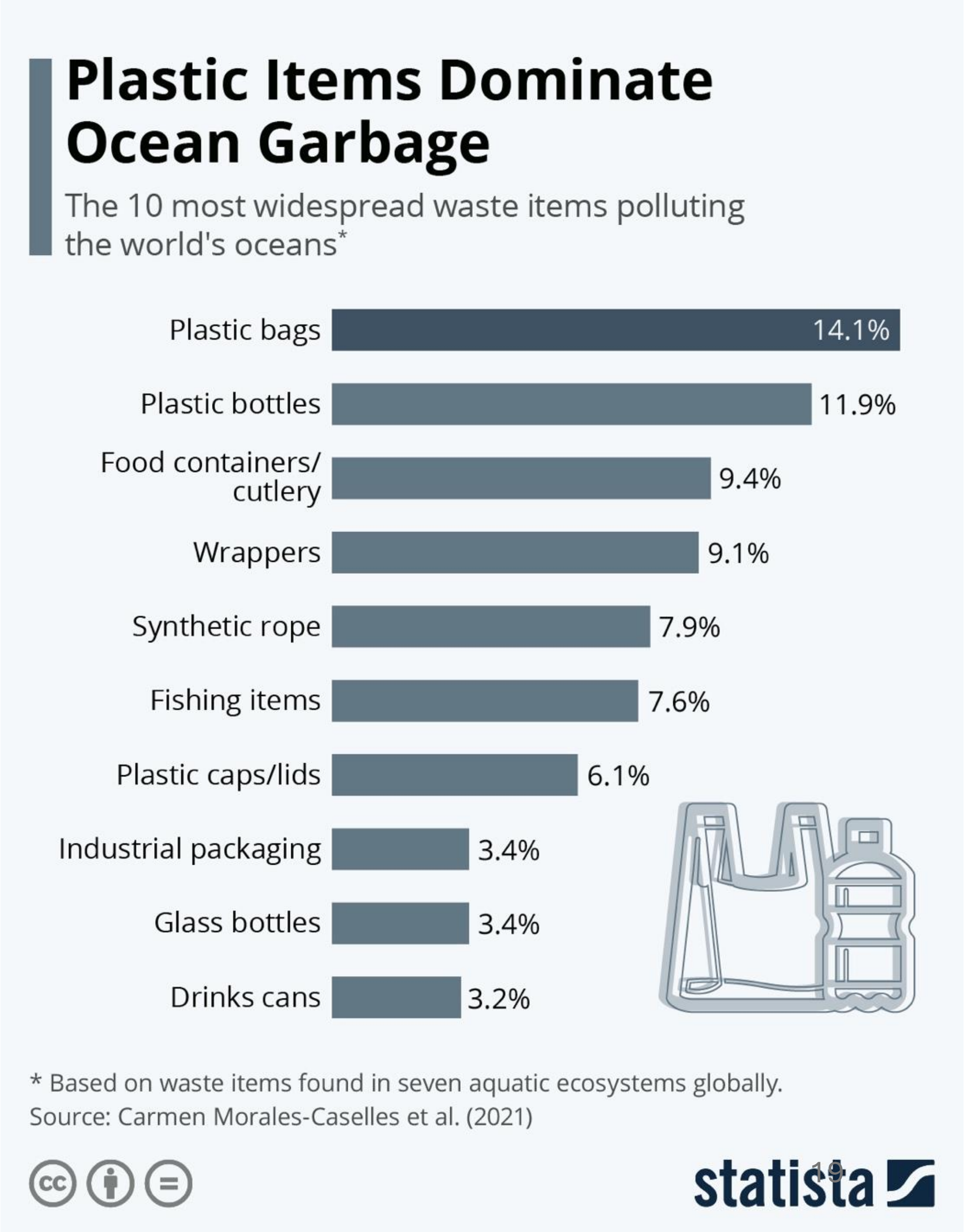





**Sources:** Aurpa et al. Effect of Plastic Waste on Volume Consumption of Landfill during the COVID-19 Pandemic. Sustainability 2022.

# Plastic is most popular garbage in oceans

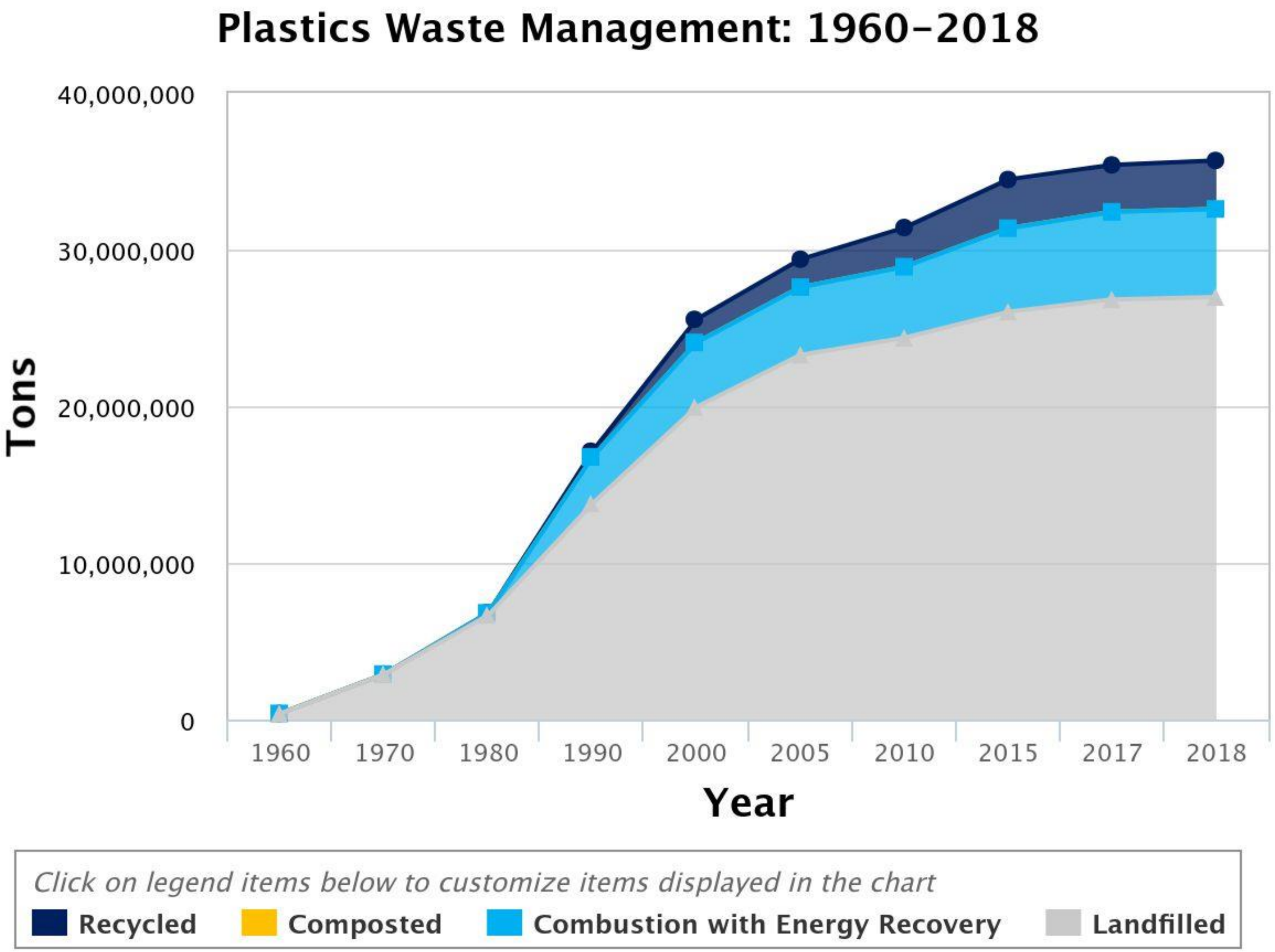
Photo source: Himanshu Bhatt/NurPhoto via Getty Images



# Modern day material innovation is focused on the **process** and **design**, not necessarily raw materials

- Using **less material**
  - Thinner packaging
  - Reinforced design structures
- Designing for **recovery** (improving recyclability)
  - Avoiding black/dark dyes (interferes with recycling sorting equipment)
  - Not combining with unremovable materials (e.g. gluing paper on plastic, making it nonrecyclable)
- Optimizing for **less energy usage** during production
  - e.g. more efficient chambers to melt plastic resin

# Only ~8% of plastic is actually recycled



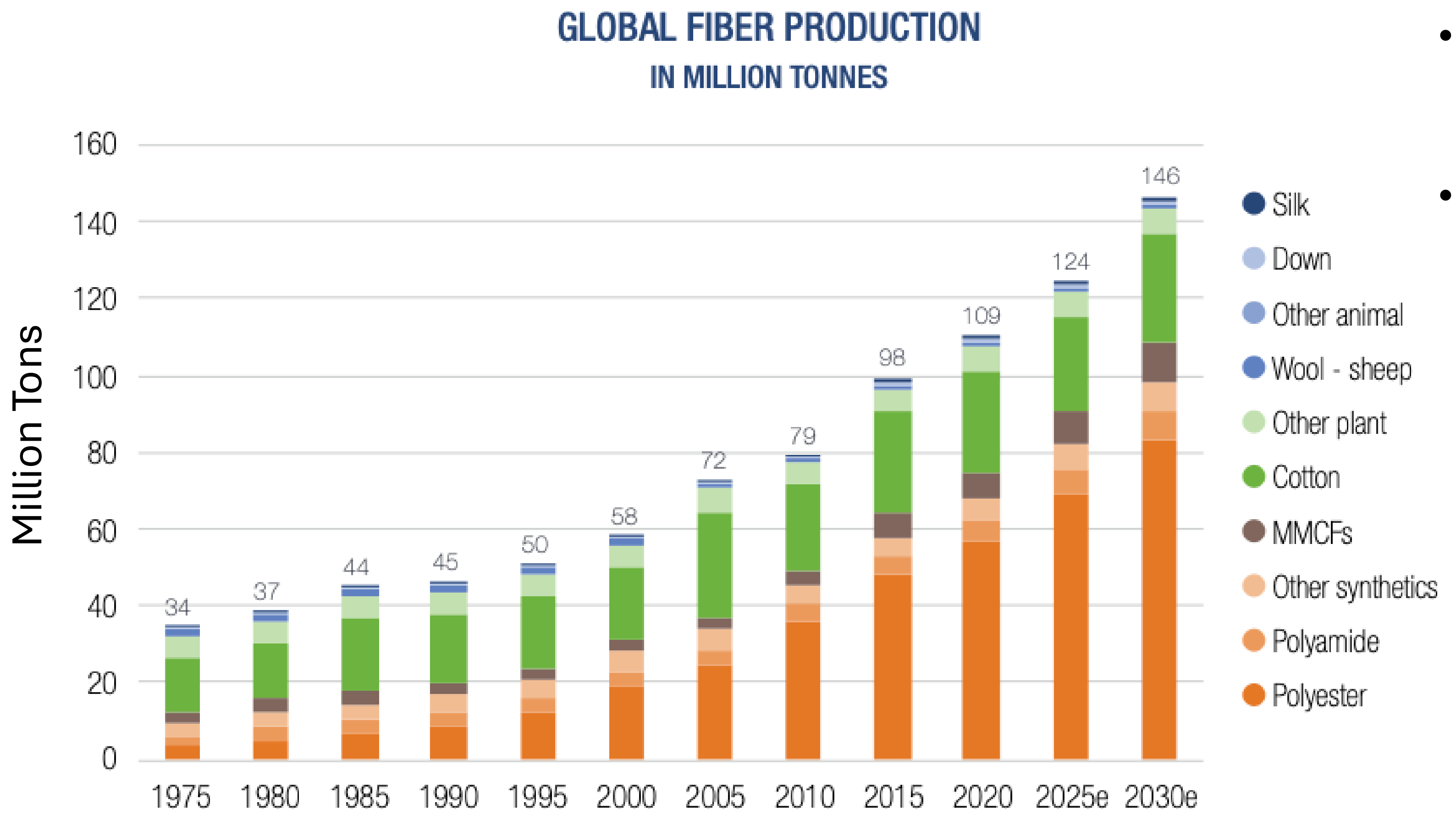

* Data is not available for composted items



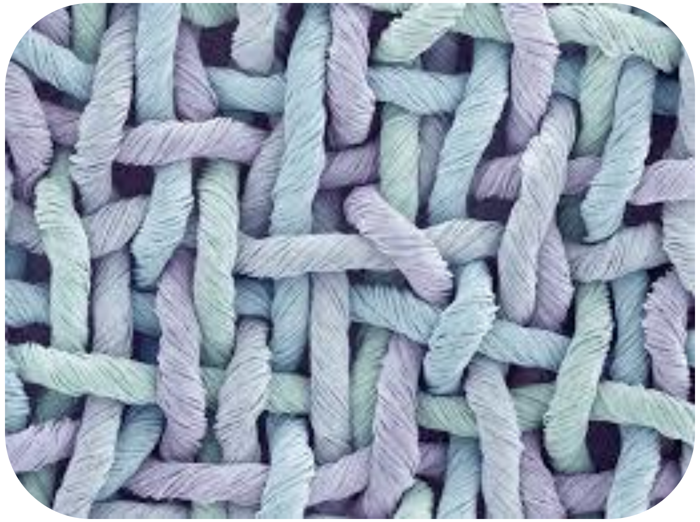
**Sources:** Plastics information is from the American Chemistry Council, the National Association for PET Container Resources and The Association of Plastic Recyclers.

# Is recycling a myth?

# Plastic (synthetic) textiles have dominated the textile industry since early 2000s




- Increase in population and individual consumption responsible for growth
- Synthetics tend to be more durable, longer lasting, more reliable supply, and CHEAPER!



Textile Exchange, Preferred Fiber & Materials Market Report 2021

# Microplastics may be linked to some health concerns but current research is inconclusive


- Microplastics themselves MAY not be harmful
- BUT potential **transfer of toxic chemicals** using microplastics is a known concern

# Some call the rise of ***biomanufacturing*** the **Third Industrial Revolution** or the **"BioRevolution"**

(others say that the "Third Industrial Revolution" is the rise in digital technologies or renewable energy)

Biomanufacturing = Using **Bio**logical systems for **manufacturing**

**Question:** Why are biological systems being explored as a manufacturing platform?

**Possible answers:**

- Need for **renewable inputs** (e.g. sugars and amino acids instead of fossil fuels and metals)
- Need for **biodegradable outputs** (e.g. protein materials, cellulosic materials)
- **Less geographic restrictions**, as bioreactors can control manufacturing conditions
- More **tunable properties** using protein engineering, metabolic engineering
- Easier **quality control** compared to agricultural farming

Solar Plunk depiction of manufacturing facilities of the future. Credit: Albert Anis

# Biomanufacturing typically involves expressing recombinant genes exogenously in host microbes

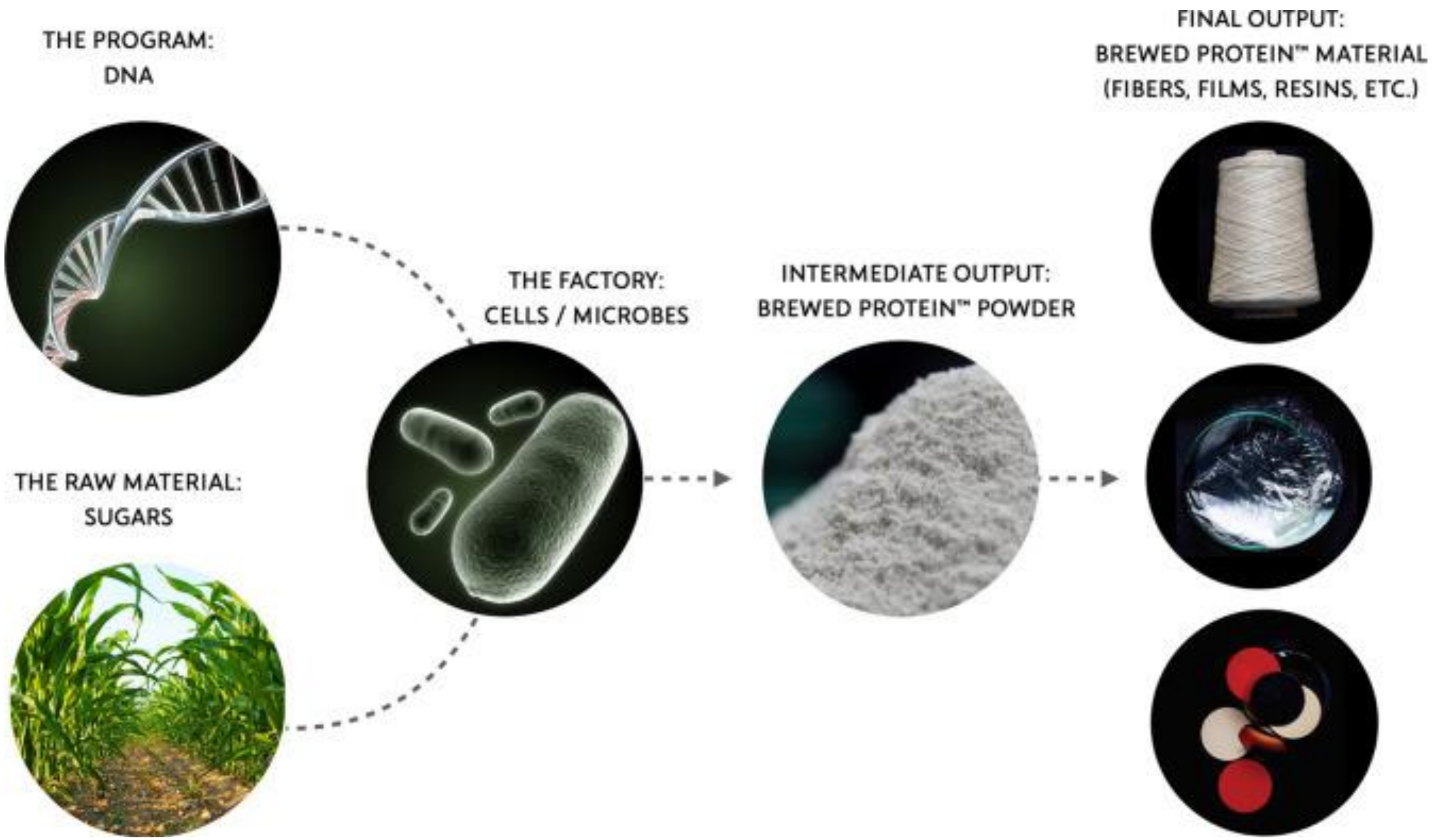
# Biomanufacturing has been happening for ~ 4 decades

- Insulin is a protein that helps control the level of glucose in the blood.
- As a treatment for diabetes, it was initially isolated from the pancreas of pigs and cows
- One of the first examples of biomanufacturing was when scientists modified E. coli bacteria to produce insulin in 1982

Pile of pig and cow pancreases at Eli Lilly collected from a slaughterhouse in the 1930s


Insulin Manufacturing Facility at NECI

# Example of biomanufacturing now: spider silk gene grown in bacteria can produce many protein-based products



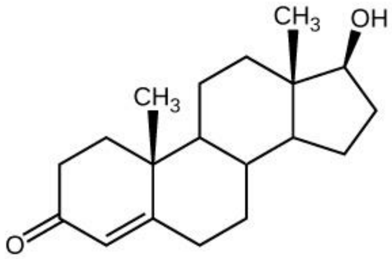

Photos of Spiber Inc's Brewed Protein™

# Biomanufacturing can be used to produce many types of polymers, ingredients, and materials

Proteins

Sugars

Hormones




Lipids

Biofuels

Bioplastics

# President Biden issued an Executive Order to promote biomanufacturing initiative in 2022

Administration Priorities The Record Brie

SEPTEMBER 12, 2022

## Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy

BRIEFING ROOM › PRESIDENTIAL ACTIONS

MARCH 22, 2023

## FACT SHEET: Biden-Harris Administration Announces New Bold Goals and Priorities to Advance American Biotechnology and Biomanufacturing

OSTP › NEWS & UPDATES › PRESS RELEASES

**TL;DR**

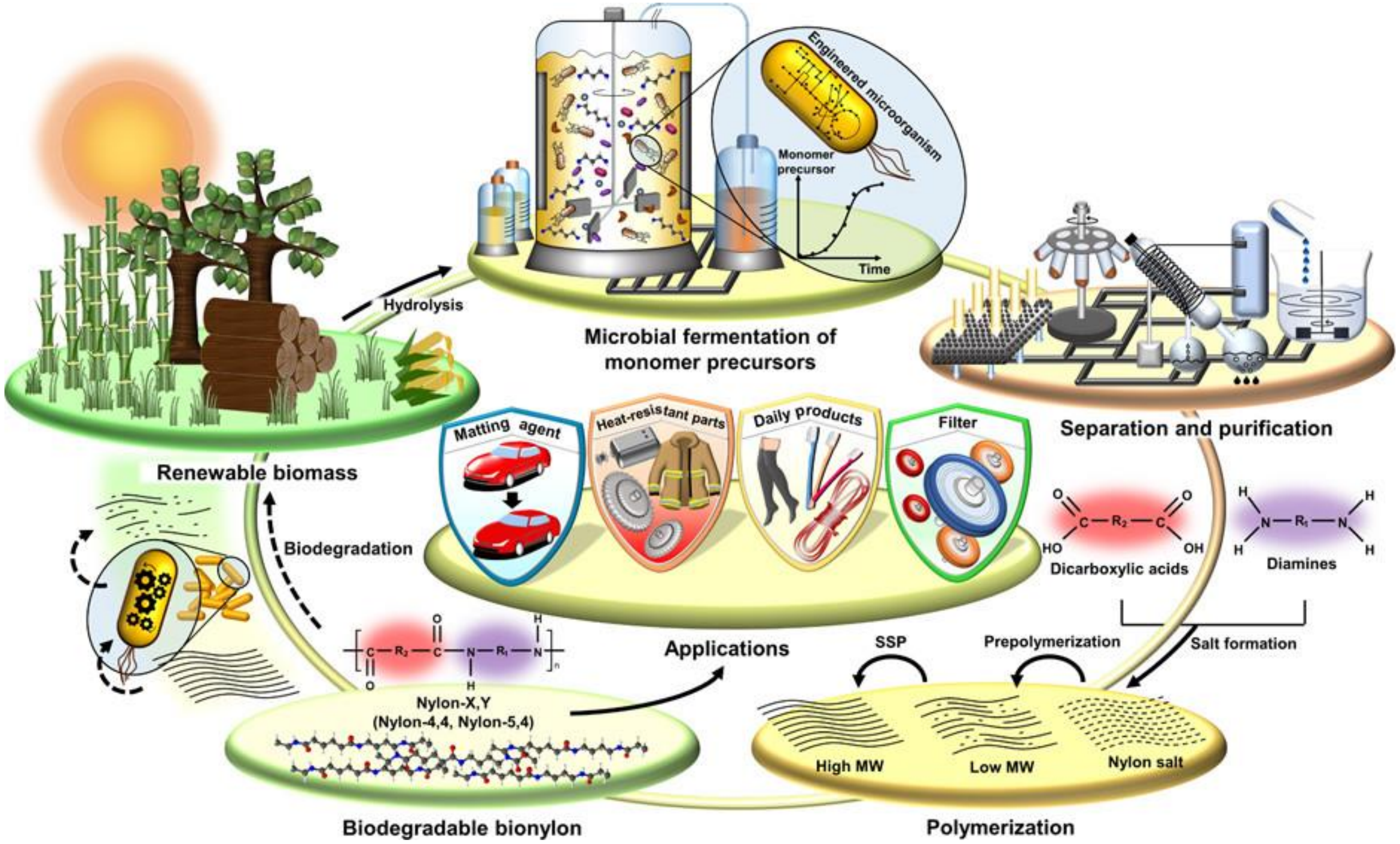
**Key takeaways:**

- The Biden Administration has set a target of producing "at least **30% of the US chemical demand** via sustainable and cost-effective **biomanufacturing pathways**" within 20 years
- The U.S. Department of Defense announced an **investment of $1.2 billion in bioindustrial domestic manufacturing** infrastructure to catalyze R&D accessibility to innovators.

Source: whitehouse.gov, EO Fact Sheet and Full EO

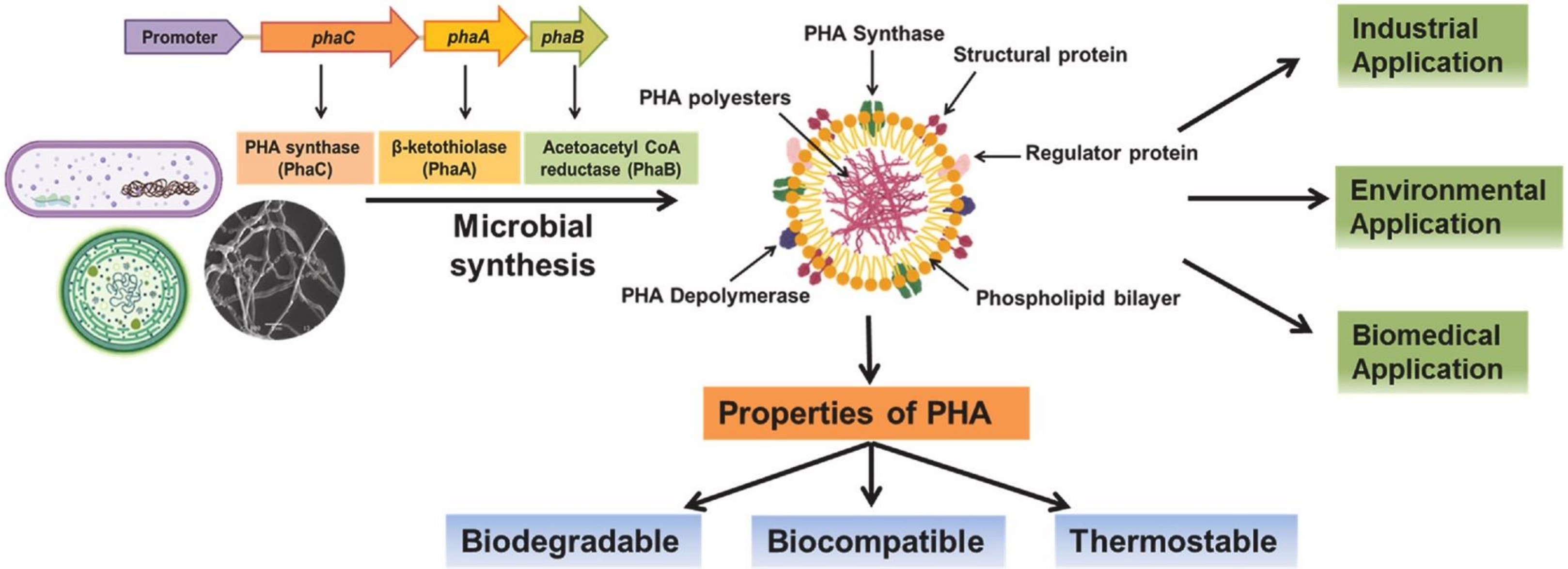
# Possible renewability solution: Bio-nylon made from renewable inputs

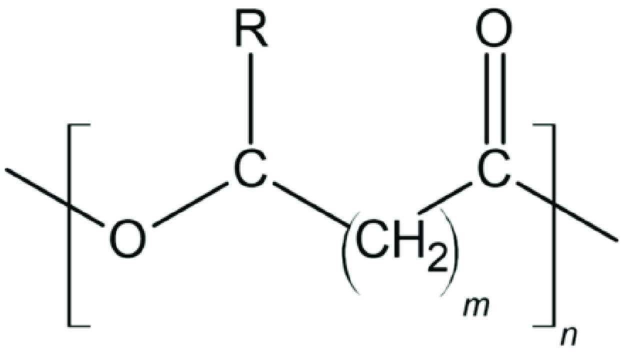
- Nylon monomer precursors (dicarboxylic acids and diamines) are produced by fermentation
- Monomers are then separated, purified, and polymerized to synthesize fully biobased nylons.
- Upon disposal, bionylons can be biodegraded




Lee et al. Synthesis, Characterization, and Application of Fully Biobased and Biodegradable Nylon-4,4 and -5,4. 2020 ACS SCE

# Poly-hydroxy-alkanoates (PHAs) are a biodegradable + renewable + biocompatible alternative to plastics



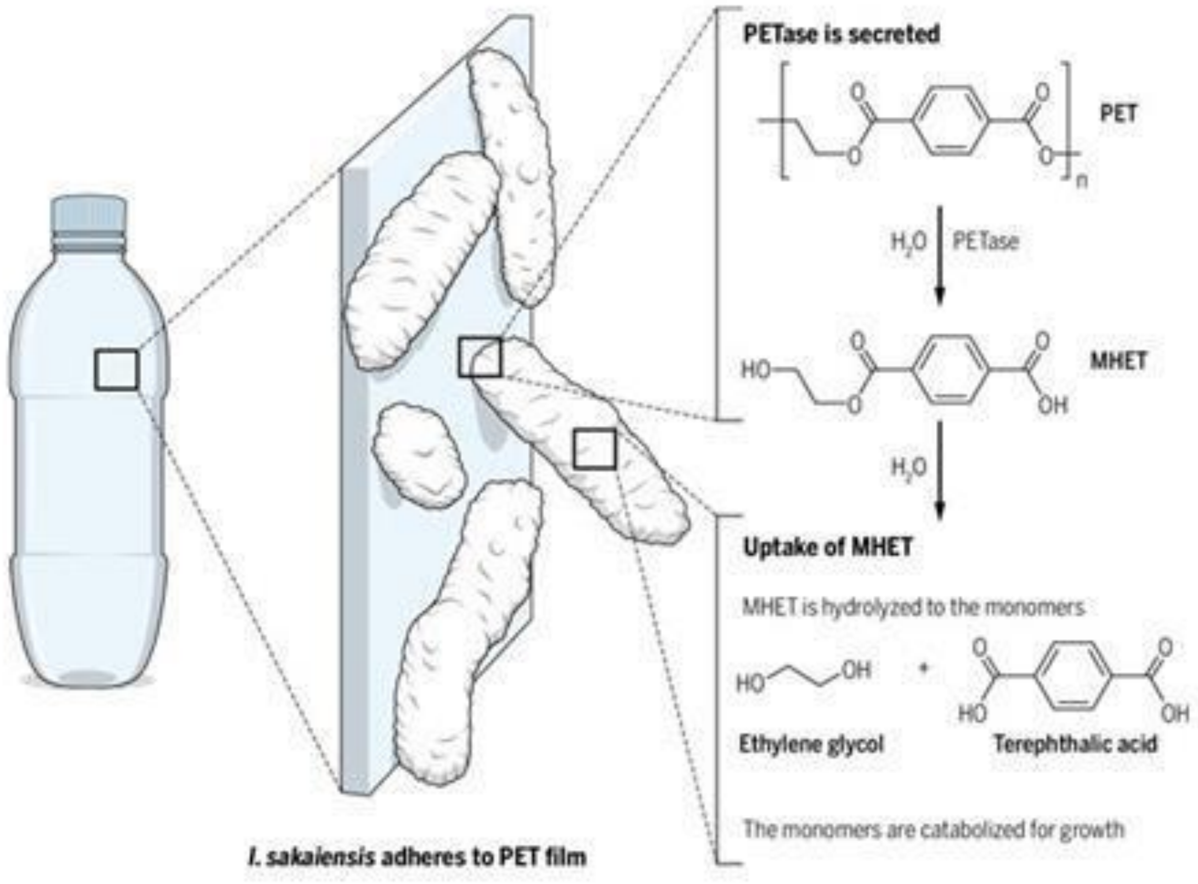

**Question: Why haven't PHAs taken off yet?**

**Possible answers:**

- Expensive production (media especially)
- Companies resistant to change
- Instability on thermo-mechanical properties
- Changing molecular weights

Besera et al. Polyhydroxyalkanoates, the bioplastics of microbial origin… 2022 Chemosphere

# Possible degradation solution: design microbes to degrade plastic into individual components




- Sifting through debris at a plastic bottle recycling plant has led to the discovery of microorganism that can break down polyethylene terephthalate (PET)

**Question: Why haven't PETases taken off yet?**

**Possible answers:**

- Inefficient PETase enzyme- need improved kinetics
- Requires particular temperature, humidity, in order to grow
- Expensive production

Yoshida et al. A bacterium that degrades and assimilates poly(ethylene terephthalate). Science 2016