

Sustainable Plastics: Biopolymer Lab Module



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BACKGROUND

With 8 million tons of plastic waste entering our oceans, a move towards recycling and reuse has been implemented. Alongside these efforts, a movement to create biodegradable plastics is also underway. They are often seen as good alternatives to [traditional plastics](#) and are advertised as being more sustainable and biodegradable (See link to shift [Healthy Materials Lab Video BV](#)). But what does it mean to be a bio-based polymer? Commercially, if a plastic contains 20% renewable material it is considered to be “[bio-based](#).” This 20% is usually made of shrimp shells, wood, coconut, wheat, corn or other renewable materials, but the remaining 80% can be made from traditional fossil fuel-based polymers. More recently, researchers are designing biopolymers by looking to those in nature, as some can be constructed to be easily degraded, and thus, an alternative to fossil fuel-based plastics.

Currently, many of the plastics used on a daily basis are processed from crude oil/petroleum. The origin of current plastics came out of [WWII when plastic was used as substitute](#) material for those that were unavailable during wartime. The Society for Plastics Industry foresaw that need and then built a campaign around plastic use during peacetime. These traditional plastics are polystyrene, polyethylene, and polypropylene-based products, used for one-time use food packaging and plastic bottles.

After being discarded, these plastics can end up in a [landfill](#), a recycling plant, or in the ocean. It's estimated that 35,500 tons of microplastics are floating in the ocean, most of which can be attributed to microfiber waste. Once in the ocean, plastics can take hundreds of years to degrade and during this time they often break into smaller and smaller pieces, which, when under 5 millimeters, are considered to be microplastics. These small plastics often leach hydrophobic organic pollutants and can be ingested by marine organisms, including organisms meant for human consumption. It's also important to note that much microplastic pollution can be attributed to the production and washing of synthetic fabrics like fleece, nylon, and polyester. In [2019](#), the World Health Organization published a report stating that microplastics 150 micrometers in size and smaller were not likely to be absorbed by the human body, but the report highlights the limited data, and recommends more research and a reduction in plastic to maintain ecosystem health. The report also mentioned that 90% of microplastics can be filtered out by large drinking water facilities.

Many plastic products contain plasticizers which have repeatedly been proven to act as endocrine disruptors in animals. Bisphenol A (BPA), and some of its substitutes are plasticizers that have been shown to leach and act as an endocrine disruptor. In studies using human placental cells, BPA was shown to inhibit or limit the activity of aromatase, an important enzyme in the process of estrogen biosynthesis, which when disrupted can impact sexual and reproductive characteristics. In [2020](#), the chemical acting on placenta cells was found to influence the production of serotonin in future generations of mice. Currently, the European Food Safety Authority has set tolerable daily limits for the ingestion of BPAs, phthalates, and other plasticizers. They have also banned the use of BPAs in plastic intended for use by infants. Some municipalities have also [banned BPA](#) in the United States or creating programs to [minimize plastic bag use](#).

Many industries are researching and looking into biopolymers as additives or [alternatives to traditional plastics](#) to limit pollution and possible toxicity. Currently, PLA (polylactic acid) and PHA (polyhydroxyalkanoates) are widely used as alternatives and as co-polymers. PLA is synthesized from the

fermentation of plant sugars while PHA is isolated from reserve energy deposits of bacteria and yeast. Both are considered to be biopolymers because their starting materials are bio-based and both are considered to be fully biodegradable when processed alone. That said the PLA is not compostable at ambient temperatures and requires an industrialized composting facility that can maintain high temperatures and aeration for microbial digestion.

Additionally, there has been some pushback on plant-based bioplastics, as few companies have considered the life cycle analysis in a comprehensive manner. For instance, an [initiative to use cassava based bags](#), used the edible part of the plant and not the waste, cutting in food resources. Whereas, [Coca Cola's Plantbottle](#) exploits the industry's use of sugar cane, by incorporating sugar cane waste into the bottle. Still, biopolymers can produce challenges in recycling, should they be mixed in with traditional plastics, and their lower melting point will not work for some products.

On the front end, the synthesis of some plant-based polymers uses more energy, land, and water than petroleum based plastics. So some [researchers are looking for new innovations in chemistry to tackle two problems at once: waste and plastics](#). For instance, shellfish chitin is incredibly durable and usually requires acid and other toxic chemicals to be broken down into its monomeric form. But in the last few years, [researchers have identified ionic liquids](#) that are non-toxic and capable of disrupting the biopolymer chains, allowing for chitin to be used as a biopolymer- addressing two problems- shellfish waste and biopolymer synthesis. Other researchers are using biomimicry to explore how nature designs molecular structures without using harsh chemicals (see [Shriik](#)). Because chitin is the second most abundant biopolymer on the planet its supply is virtually limitless as it can be harnessed from zooplankton, which is highly regenerative.

In this lab module we will touch on various aspects of plastics: ([food webs/bioaccumulation](#)); biology (estrogen disruption and reproductive health); chemistry (polymerization and chemical bonding); and epistemology (how science is done, and the role of variables such as time, space, and scale). You will have the opportunity to make a starch-based plastic and explore the variables that can influence its characteristics.

CONTEXT

Fashion and Sustainability: We are able to contextualize this for sustainability through exploring the production of modern plastics and their impact on environments. Particularly, we can explore microplastic accumulation through the use of synthetic fibers. It's estimated that 35,500 tons of microplastics are floating in the ocean, most of which can be attributed to microfiber waste. Exploring biopolymers as alternatives for creating synthetic threads is a possibility through collaboration with fashion or textile faculty.

Genetic Modification for Sustainability: Biopolymers, particularly PHA can be produced through the insertion of plasmid DNA into both bacteria and yeast. This extra DNA allows microbes to act as factories or bioreactors for the production of secreted biopolymers. Once the initial experiment has been completed, we can use selective growth media containing and antibiotic (ampicillin) to isolate those microbes that have taken up the DNA that allows them to code for enzymes necessary to build polymers. By exposing these genetically modified microbes to specific chemical environments we can stimulate the production of PHA.

Chemistry, Environment and Sustainability: Plastic synthesis is based in chemistry. Hydrocarbon monomers are processed through the use of catalyzers (enzymes or chemicals) to produce aliphatic polymers which eventually become plastics. Currently crude oil is used as a raw material and the energy source to power the plastics industry. There are both industrial and product contributions to greenhouse gases.

Design, Biomimicry and Closed Loop (Waste → Polymer). Research on designs that exist in nature is being done to mimic that design outside these living organisms for a more sustainable polymers.

RESOURCES

Vocabulary List on Biopolymers

Student Lab Worksheet on Biopolymers

Slide Set on Sustainable Plastic: Biopolymers Lecture PreLab 75 minutes (1-20) Lab (20-42)

- Slide 1-3 Plastics history and why plastics are a problem
- Slides 4-5 Proximate Solutions: Reuse, Recycle, Refuse/ Bans and Upcycling
- Slides 6-7 Ultimate Solutions: Systemic Policy Change/Regenerative Approaches (Indigenous Practice)
- Slide 8 Bioplastics (PLA) challenges (Land, Water, Energy, etc)
- Slides 9-10 What is a polymer
- Slide 11-16 Scale of the problem, debris, microplastics, plasticizers, degradation estrogen disruption,
- Slides 17-18 Biopolymers in nature
- Slide 19 Biomimicry, biodesign, and new generation of biopolymers (Shrilk)
- Slides 20 The Lab
- Slide 21-25 Starch polymers
- Slide 26-28 Natural plasticizers and their effect on morphology
- Slide 29-31 Lab set Up and Scientific Method and Handout
- Slide 32-33 Lab safety
- Slide 34-35 Lab Protocol and tips
- Slide 37 Marcus Banks MFA Project on Starch Based Incubator
- Slide 38 Searching for alternatives using biodesign, biomimicry, and biology
- Slide 39 Shellworks - Imperial College Video as a Future Design Application
- Slide 40 Assessment
- Slide 41-42 Courses and Additional Workshop Opportunities

Short Suggested Bibliography * items used in the slide set, # selected by instructors

Videos on Making

1. **Short 5' Youtube Green Plastics:** Process and Ingredients (Tapioca Starch) and variable output with gauze impregnated. https://www.youtube.com/watch?v=5M_eDLyfzp8
2. **Longer 20' How to Make Everything** with history of polymers (milk and how to extract potato starch) <https://www.youtube.com/watch?v=kjvQMMQWNGE> (NSF Center for Sustainable Polymers, corn, sugars, high tech lab etc) 1) Dehydration stir bar to make smaller chains, 2) cyclization with catalyst making the monomer 3) polymerization for longer chains all under high vacuum and liquid nitrogen or high heat 3.5) precipitation like nylon extraction with molding challenges and companion podcast Simply Complex: Plastics <https://makeeverything.tv/simplycomplex/2019/01/plastic>

Traditional Polymers History and Alternatives

1. ***History Of Polymers:** Knight, L. May 17, 2014. A brief history of plastics, natural and synthetic.”*BBC News*, BBC. [LINK](#). (3 pages; DNA, rubber, Parkesine, Bakelite)
2. **Book Chapter:** Voyles, T. "Hot Spots: Justice Power and Gender in the Radioactive Present" In *Wastelanding: Legacies of Uranium Mining in Navajo Country*. Minneapolis:University of Minnesota Press, 2015. Project MUSE, Chapter 4:117-150. [Link to Google Books](#).

Traditional Synthetic Plasticizers and Estrogen Disruption

3. * **Short Science News on BPA substitutes:** Service, R. Sept 13, 2018. BPA substitutes may be just as

bad as the popular consumer plastic. Science. (This is the work of Patricia Hunt on cages and petri dishes) [Link](#)

4. **Review Article on Soy and Estrogen Disruption:** Patisual, H. May 2017. Endocrine disruption by dietary phyto-oestrogens: impact on dimorphic sexual systems and behaviours. *Proc Nutr Soc* 76(2): 130–144. [Link](#)

Chemistry of Plastics and Alternatives: Pros and Cons

5. *** Sustainability Science Review Article:** Gerngross, T. and Slater, S. 2000. How Green are Green Plastics? *Scientific American*. 36-41. [Link](#)
6. ***Press Article PHA Basic Information:** van der Hoeven, D. Aug 21, 2016. PHA: promising, versatile, biodegradable. *Bio Based Press*. [LINK](#).
7. ***Blog: Greendot Bioplastics Blog:** explaining the biodegradable v. Bioplastic etc.
8. **TEDxTalks.** Sheriden, K. Aug 26, 2016. Bioplastic Fantastic: Why we don't need oil for plastics. *YouTube*, [Link](#)
9. **Video:** Virtualschooluk. Dec 7, 2015. Problems with Plastics and Biodegradable Plastics. Chemistry for All. The Fuse School. *YouTube*. [LINK](#).

Policies Around Plastic (exporting waste, managing ecosystems, bans on plastic, removing microplastics)

1. ***Video:** 60 Minutes Australia/Plastic Forest (6:15-8:00, 16-16:50) [Link](#)
2. ***Video:** AJ+. Untold America. The Indigenous Town that Banned Plastics (San Pedro La Laguna, Guatemala). Facebook Watch. [Link](#)
3. ***Video:** Mar 29, 2019. Plastic Bag Ban Approved, In Effect For NY Next March. CBS NY. [Link](#)
4. **News;** Talvitie and Vahala. June 20, 2019. Are Microplastics a Challenge for Water Treatment Facilities? . [Link](#)

Research Innovations

1. **#Video and News Chitosan:** Wyss Institute. Manufacturing a Solution to Planet Clogging Plastics. March 3, 2014. [Link](#) (9:38' - 14 minutes)
2. **#Video:** 2014. Replacing Plastics with Shrilk with Javier Gomez Fernandez. Science for the Public. YouTube. [Link](#) (43 minutes)
3. **#Video:** 2014. Replacing Plastics with Shrilk. Fox News shorter video. [Link](#) (6 min)
4. **News:** Entomology Today. Got Shrilk ? Bioinspired plastic. [Link](#)
5. ***Video:** May. 16, 2014. Pollution solution: Plastic made from shrimp shells?(6:45) - Javier Fernandez from Harvard's Wyss Institute discusses new bioplastic made from chitosan. [Link](#)
6. ***Website for Close the Loop Challenge: Shrilk.** [Link](#)
7. **SciArt Magazine Interview:** October 2018. Spanning the Divide. Don Ingbar. [Link](#)
8. **# Research Review Article:** Drahl, C. June 22, 2019. How Seafood Shells Could Solve the Plastic Waste Problem. *Science News*. 195 (11):18-22. [Link](#)
9. **#Science Review:** Gerngross, T. and Slater, S. 2000. How Green are Green Plastics? *Scientific American*. 36-41. [Link](#)

Feminist/ Decolonialist/ Citizen Science Approaches to Microplastic Research

1. **Video:** Liboiron, M. Tools, Practices, and Ethics for Monitoring Marine Plastic Pollution Developed in a Feminist Lab. YouTube. [Max Liboiron Video \(20 min\)](#)
2. **Documentary Short:** Documentary Short: Noah Hutton. and Taylor Hess. GUTS: Plastic Pollution Recycling is Like a Band-Aid on Gangrene. The Atlantic/YouTube. A short film about Dr. Max Liboiron and CLEAR, a feminist, anti-colonial marine plastics lab in Newfoundland. [Link \(13 min\)](#)

Industry Innovations

1. **Companies trying to find alternatives:** McKenna, P. August 5, 2015 Meet the companies trying to break our plastic addiction.”*GreenBiz*, GreenBiz Group Inc., 6, [LINK](#).
2. **News:** Dec 1, 2017. Bioplastics are Making the Difference. *Packaging Europe*, [LINK](#).

[Full Bibliography for Further Learning](#)