SUSTAINABLE MATERIALS

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Renewable Bioproducts Institute, Georgia Tech

HTMAA, RECITATION, OCTOBER 26, 2023

1. **Why Care?**

   Discussion

2. **Commercially Available Options**
   - 3D printing
   - Molding & Casting
   - CNC Machining

   Discussion

3. **DIY Ideas**

   Discussion

4. **The Materiom platform for regenerative materials**

   Discussion

WHY WE CARE ABOUT SUSTAINABLE MATERIALS?

Humanity & Materials: An Inseparable Relationship

Adapted from "Materials That Changed History", Robert Friedel, 2010

21st Century: The Plastic Age

Revolutionary & fundamental material: Versatile, durable & cheap

Plastic production

- 1950s: 500,000 tons/yr.
- 2020: 500 million tons/yr.
- 2050: 1 billion tons/yr.

Sources:
- *www.plasticseurope.org*
- *Fernandez & Dritsas, Matter, 2020*

Plastic: A Blessing

Used in almost every sector

- Packaging
- Building & Construction
- Textiles
- Electronics
- Transportation
- ….

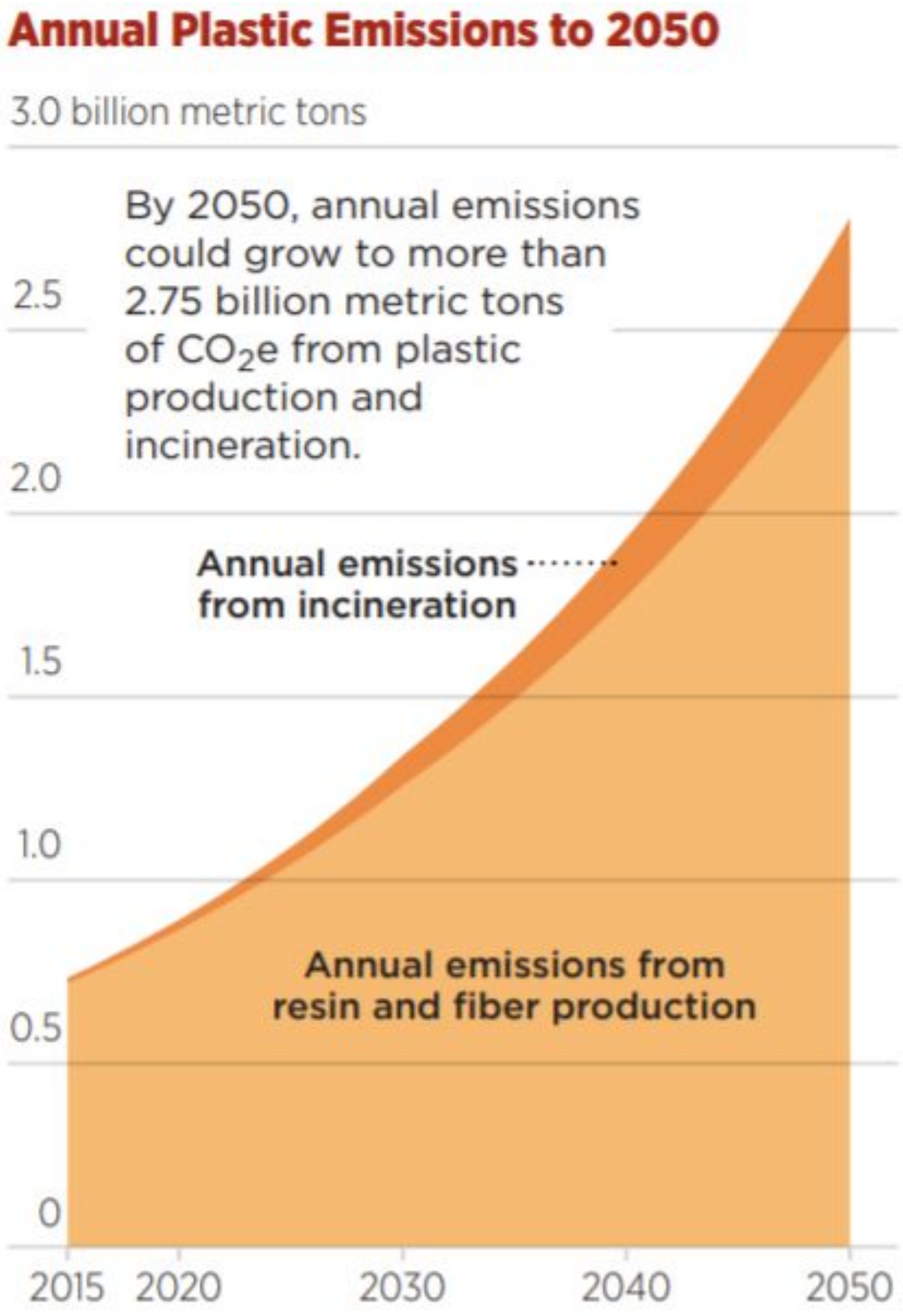
Apollo’s heat shield made of epoxy phenolic novolac resin in a fiberglass honeycomb

… & A Curse

… & A Curse

Environmental Impacts of **Plastic Production**

- GHG emissions from extraction, transportation & manufacturing
  - **~1 billion tons of $CO_{2\text{-}eq}$ annually**



Source: CIEL, 2019

Environmental Impacts of **Plastic Waste**

- **~1 million tons/day**
- **COVID-19: 1.6 million tons/day**
- **80% in landfills, dumps & natural environment**
  - Too long to biodegrade ~450 yrs
- **150 million tons polluting oceans**

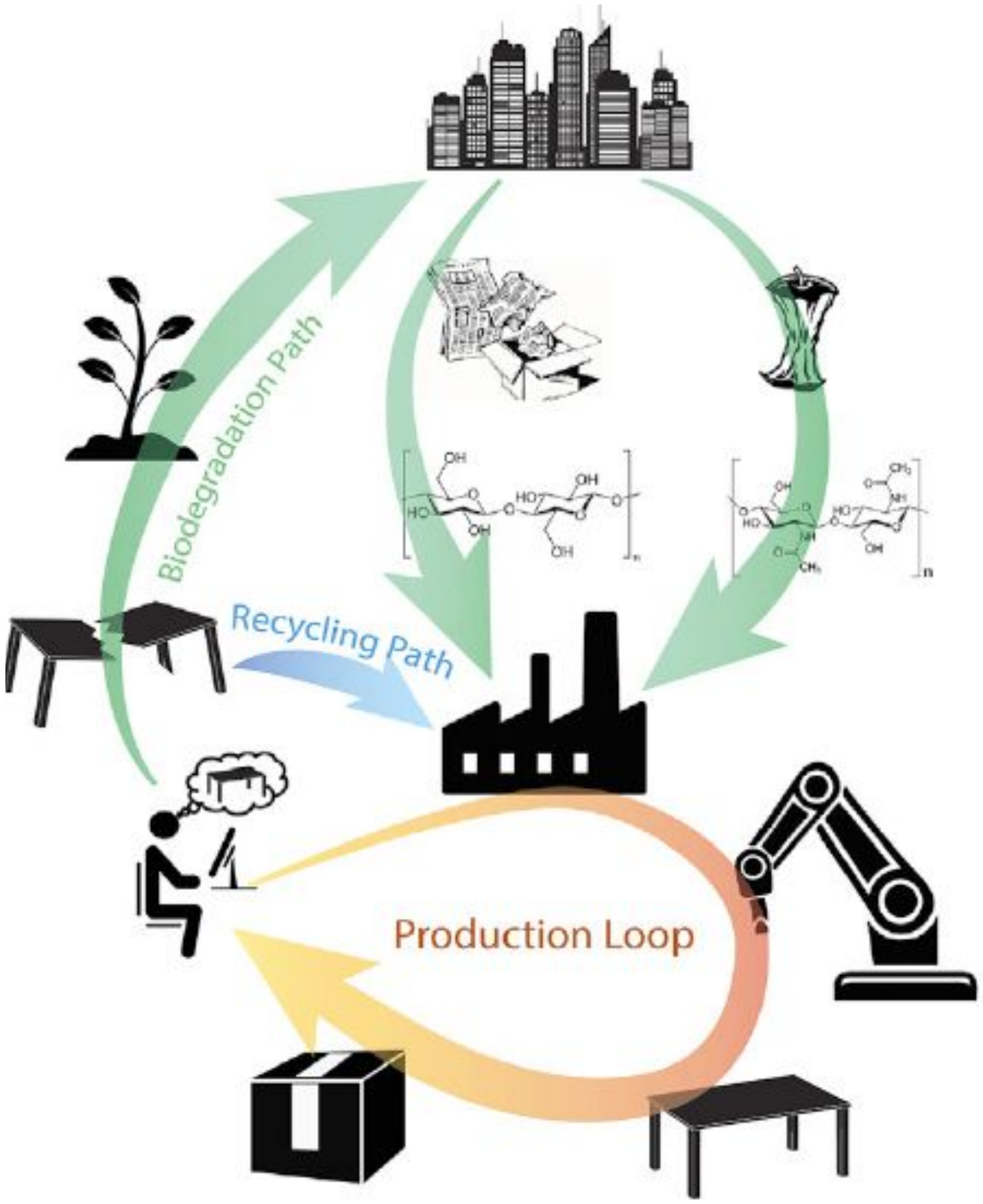
"Plastics will outweigh fish by 2050"

Jim Leape
Stanford Center for Ocean Solutions

Looking Beyond the Plastic Horizon

Renewable biomass sources

- Locally-sourced materials
- Abundant biopolymers
  - Chitosan, starch, gelatin, agar
- Lignocellulosic biomass



Source: Fernandez & Dritsas, 2021

Looking Beyond the Plastic Horizon

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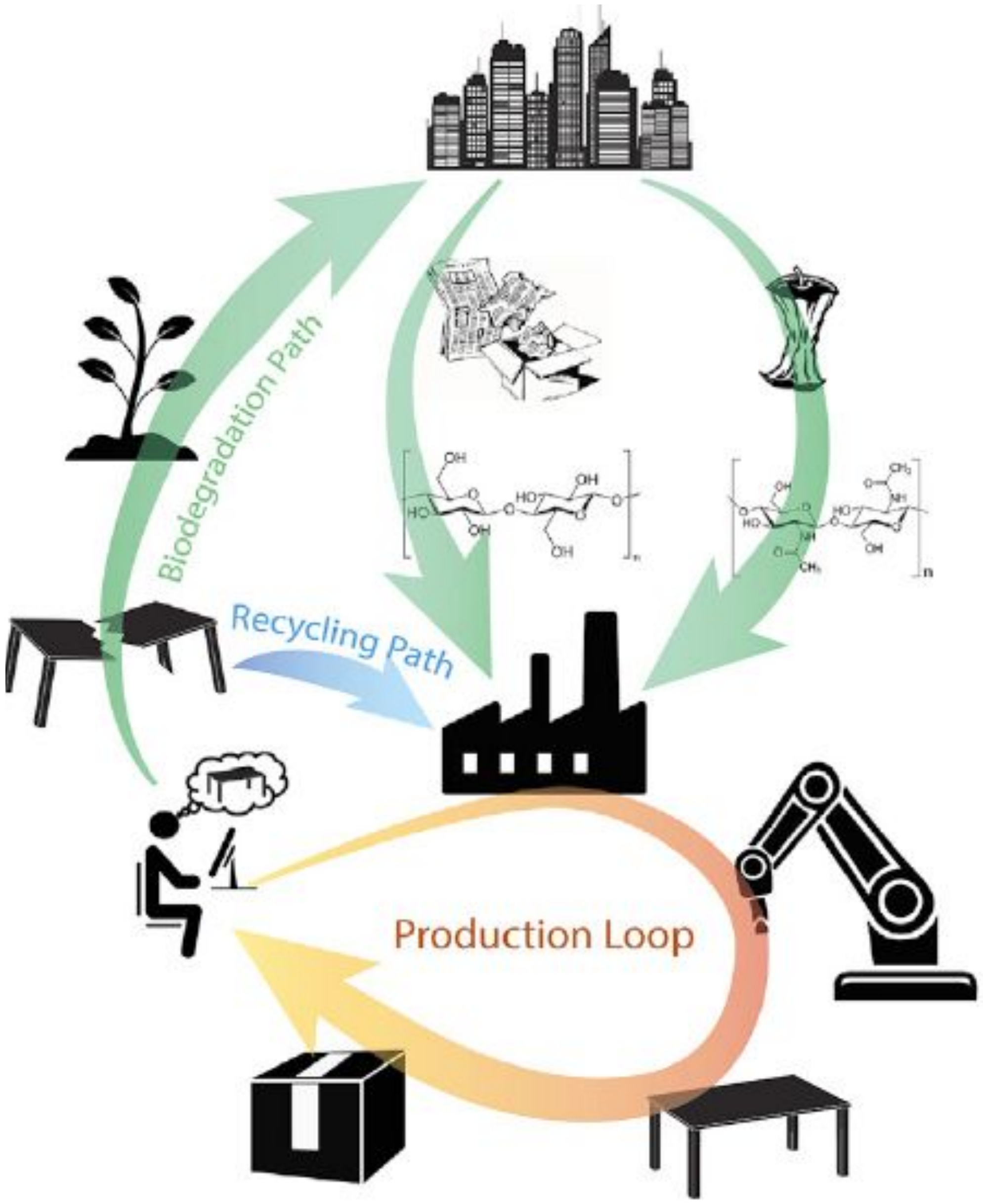
Circular systems

- Inspired by nature
- Recycling
- Biodegradability



Source: Fernandez & Dritsas, 2021

Looking Beyond the Plastic Horizon

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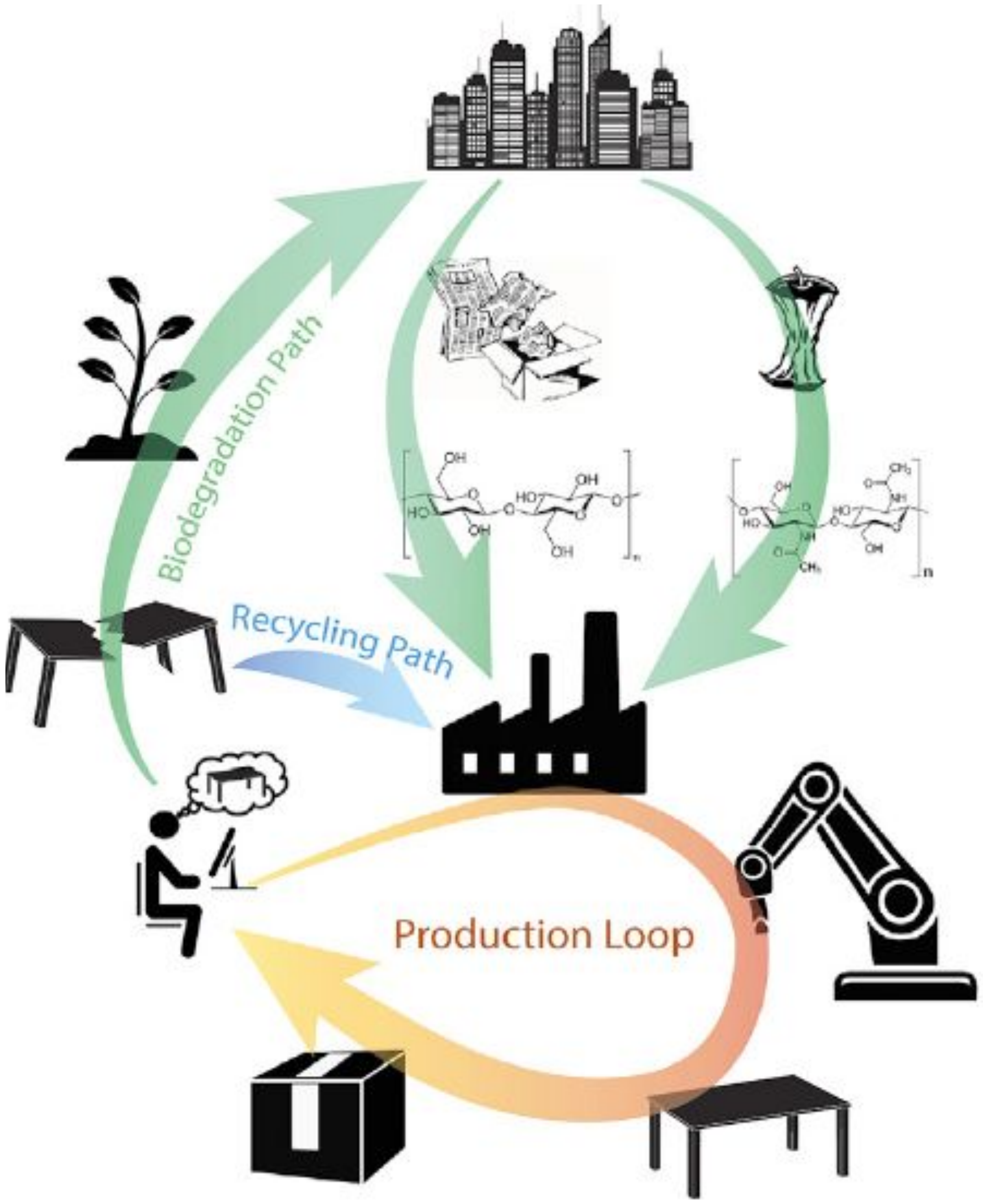
Digital fabrication

- On-demand production
- Reduced waste & emissions



Source: Fernandez & Dritsas, 2021

COMMERCIALLY AVAILABLE OPTIONS

3D PRINTING

Polylactic acid - PLA

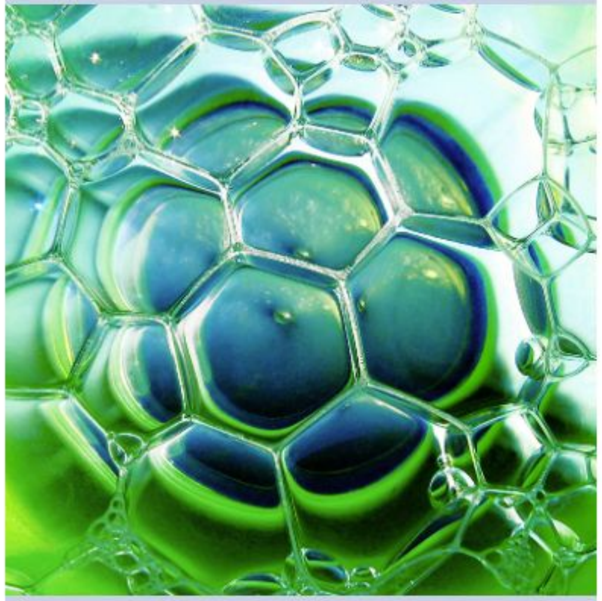
TODAY

Dextrose and sucrose from cassava, corn starch, sugar cane, or beets.

INDUSTRY DEVELOPING

Lignocellulosics: Sugars from bagasse, wood chips, switch grass or straw.

NOW ASSESSING



CO_2 to lactic acid technology

CH_4 to lactic acid technology

PLA Filaments

- Biobased
- Industrially compostable
  - Few months
  - In nature needs 80+ yr. to biodegrade
- Recyclable

- Virgin
  - NatureWorks - Ingeo PLA
  - PolyTerra PLA
    - Plants a tree for every spool near the region of purchase
- Recycled
  - Prusament PLA Recycled
  - 3D Jake
  - Reflow

Polyhydroxyalkanoates - PHAs

- Biobased
  - Fermentation of glucose, sugar or lipids by bacteria
- Microbial polymerization - Biodegradable
  - 1 yr. in nature
  - < 10 yr. in seawater

- 100% PHA filaments
  - [colorFabb]
- PLA/PHA blends
  - [colorFabb]

Recycled Filaments

- Re-PETG - chemical resistance, durability
  - Prusament
  - Reflow
  - GreenGate 3D
    - Made in the US
- Re-PET
  - Re-pet3D
    - Recycled PET bottles
- Re-TPU
  - Kimya

Sustainable Composite Filaments

- Filamentive – Wood PLA
    - 40% re wood fibers
    - 60% re PLA

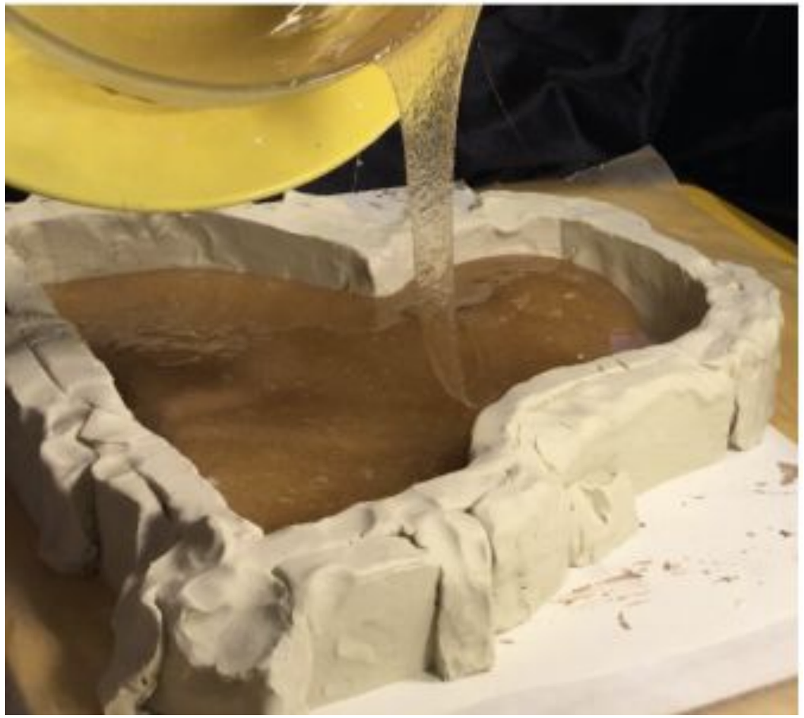
- Filamentive – Carbon Fiber PETg
    - 15% re carbon fibers
    - 85% re PLA

- 3D Jake options
- Filament2print options

MOLDING & CASTING

Sustainable Mold Making

- Glycerol / Gelatin Mold
- Natural Latex Mold
- Alginate Mold



Sustainable Epoxy Options

- 20-50% biobased content
  - vegetable oils, lignin from wood products, tannins

- Entropy resins
- GreenPoxy
- Ecopoxy

COMPUTER-CONTROLLED MACHINING

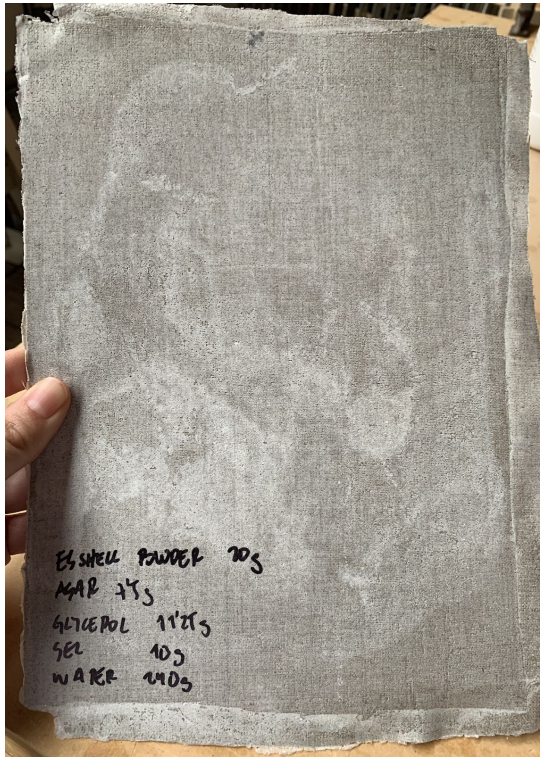
- [Sustainable Plywood]

- [Recycled Acrylic Sheets]

DIY IDEAS

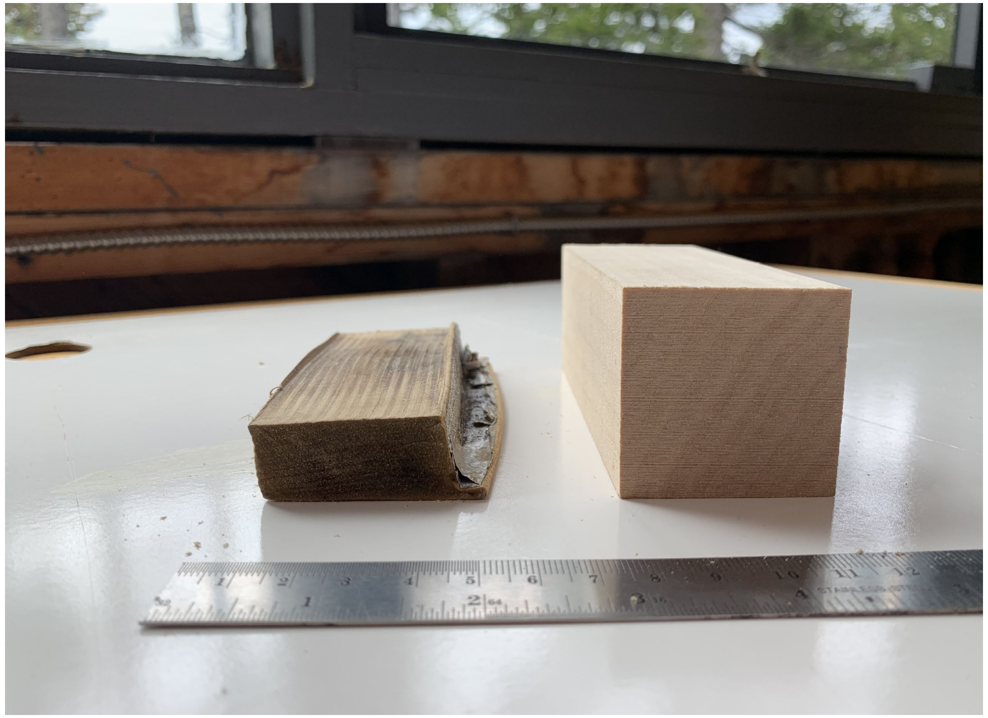
Wet lay-up biocomposites

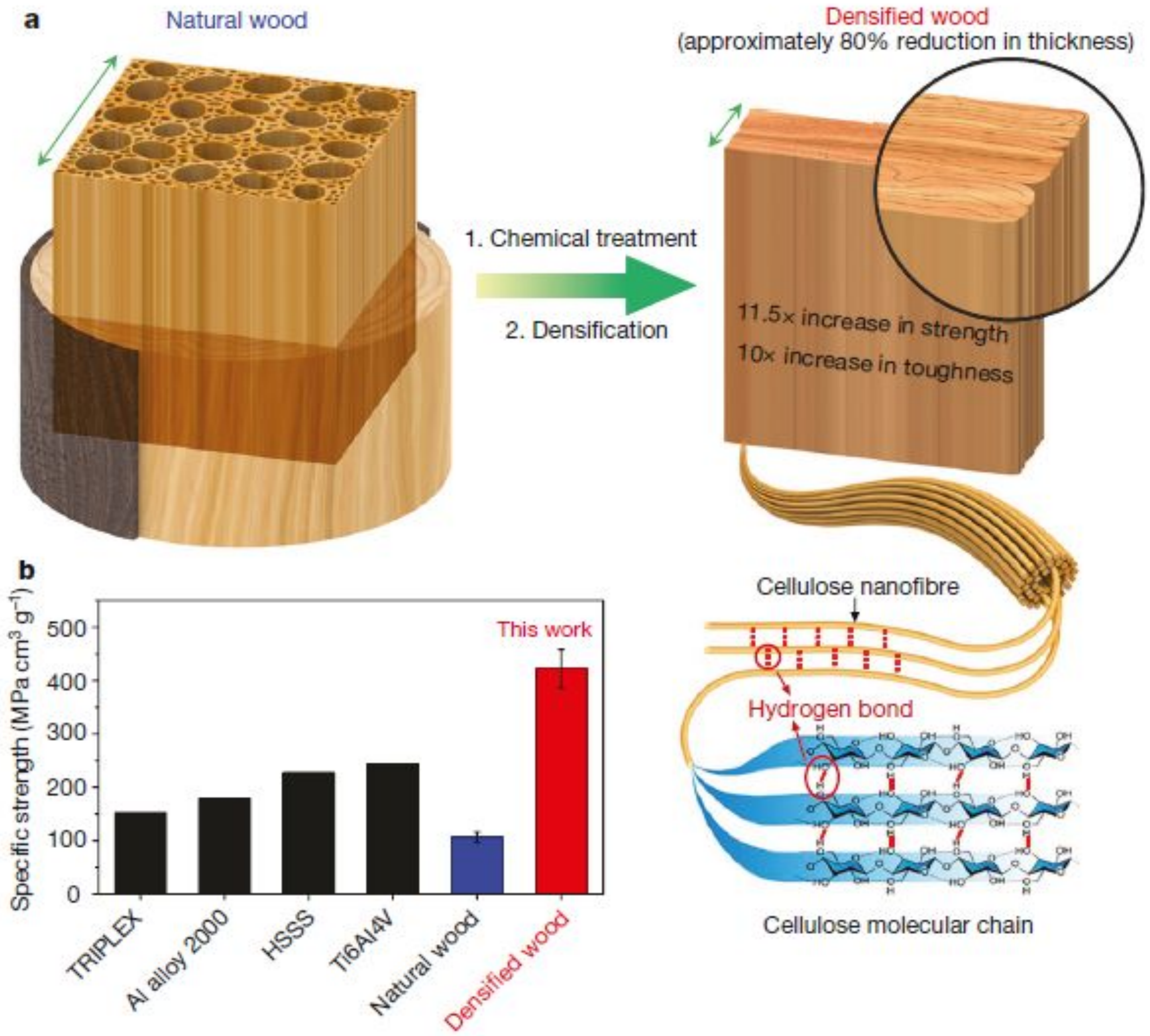
- Organic fabrics + Biopolymers



SuperWood

- Song et al., 2018
- SuperWood making





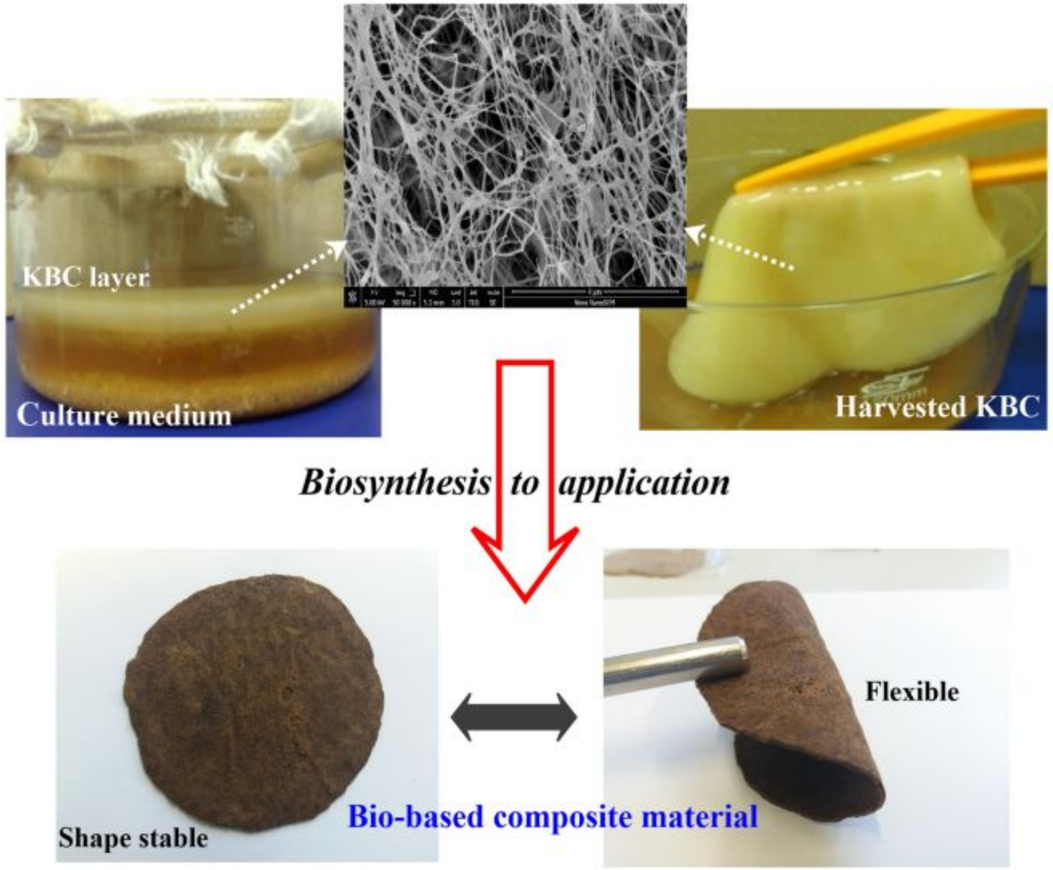
Lignocellulosic bioplastic

- [Xia et al., 2021]

Bacterial Cellulose Fibers

- [Kombucha Scoby Recipes]

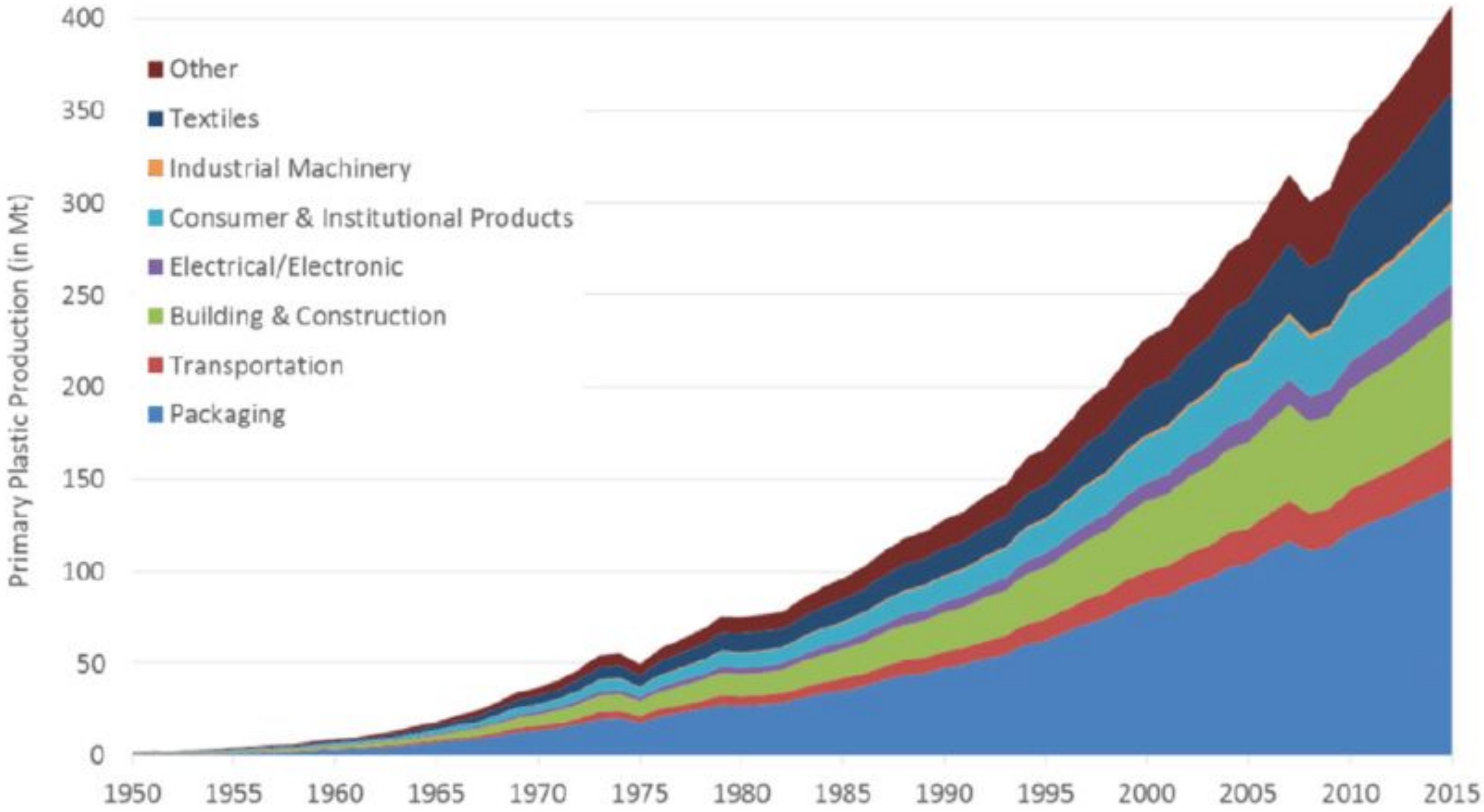
	1 Litre	2 Litres	3 Litres	4 Litres
Boiled Water	250ml	500ml	750ml	1 litre
De-chlorinated water	750ml	1.5 litre	2.25 litre	3 litre
Sugar	50 - 100g	100 – 200g	200 – 300g	300 - 400g
Tea (either teabags or teaspoons of loose tea. All black, or a mixture with green, white or other)	1	2	3	4
Scoby	1 small	1 medium	1 large	1 large
Starter Liquid	100ml	200ml	300ml	400ml



Backup Slides

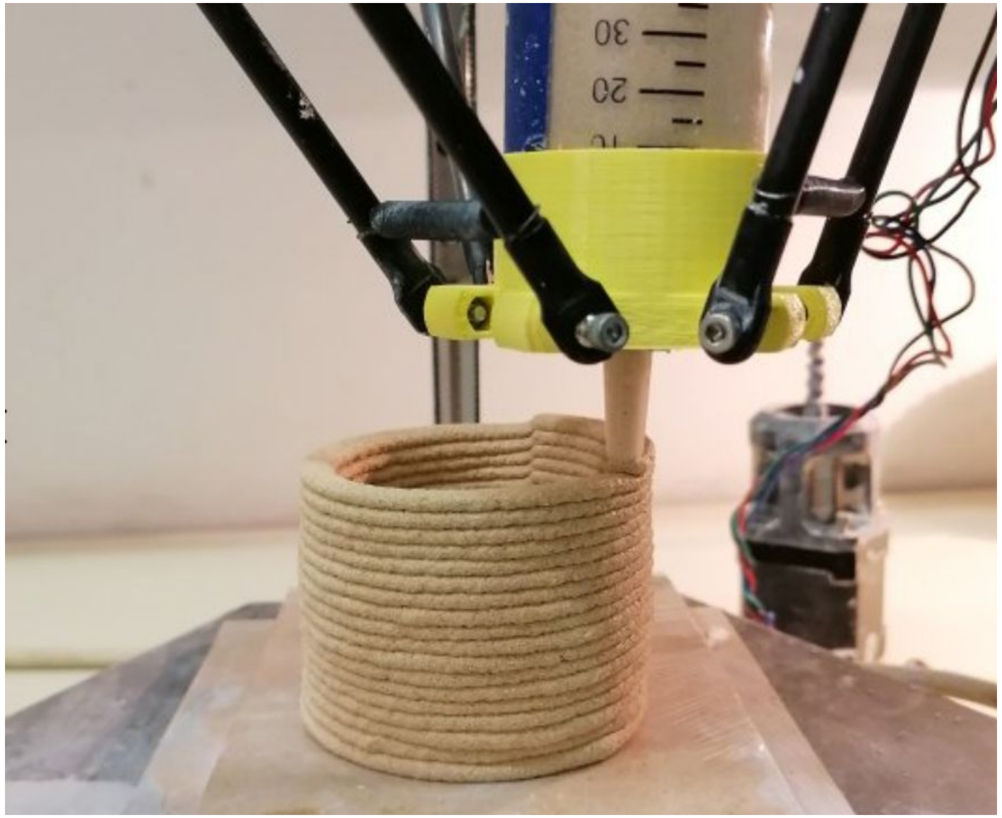
Global primary plastics production according to industrial use sector from 1950 to 2015 (*million metric tons*)

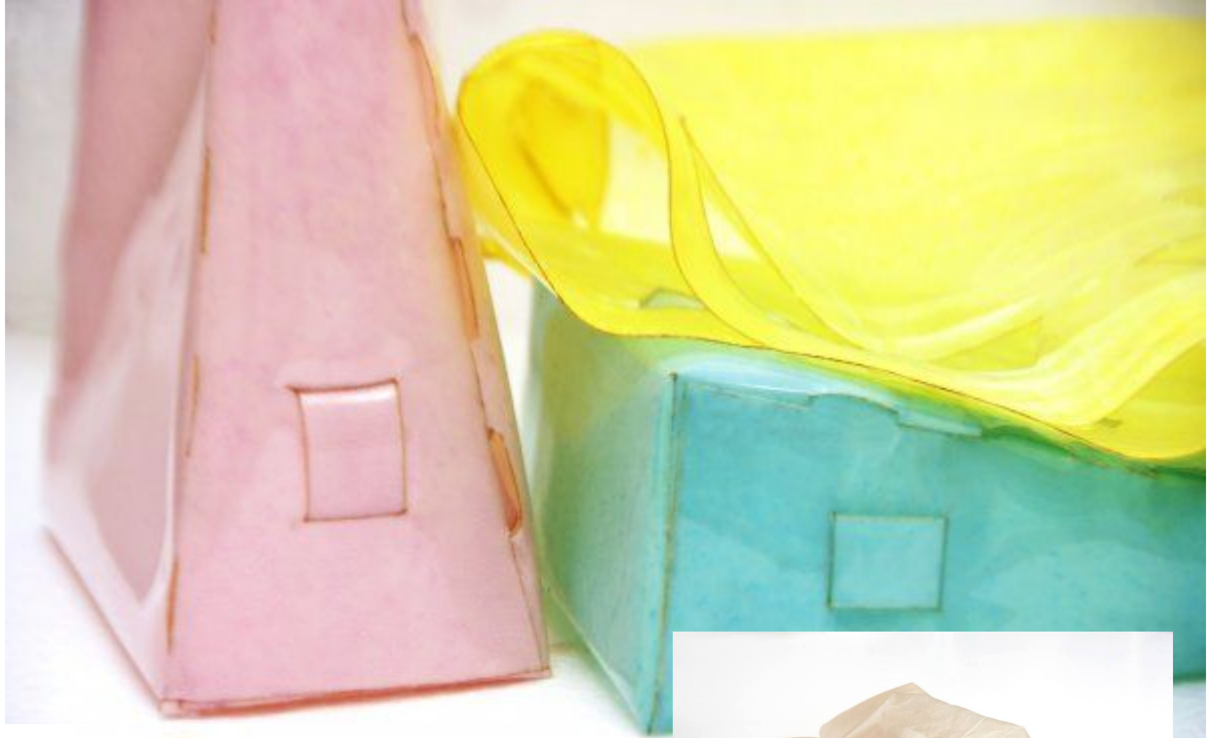
Source: US Department of Agriculture, https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us.aspx



Materiom recipes

- [Eggshell biocomposite]
- [Oyster Alginate Composite]





Materiom

26th October 2023

materiom

Imagine a world where plastics are plant food.

It's 2050 and the world no longer relies on fossil fuels. The materials revolution brought with it a new set of tools and materials to make the products we need, while enriching rather than harming the world around us.

Regenerative materials are 100% biobased, 100% biodegradable, and sourced from biomass that does not compete with food security. At the end-of-life these materials transform into compost - regenerating soils and natural ecosystems.

Biomaterials can be **converted into soil amendment & compost**

20x

Seaweed sequesters **20x more** carbon dioxide than trees

CO_2

Food waste diverted from landfill avoids CO_2 and methane emissions

Agricultural waste

Leaves, stalks, husks, stems

Glucose / Dextrose / Glycerol

Industry byproducts

Shellfish waste, nut shells

Chitin / Chitosan / Starch

Non-competitive biomass

Seaweed, mycelium

Agar agar / Alginate / Carageenan

Unavoidable food waste

Coffee grounds, peels, pits

Pectin / Cellulose / Gelatin

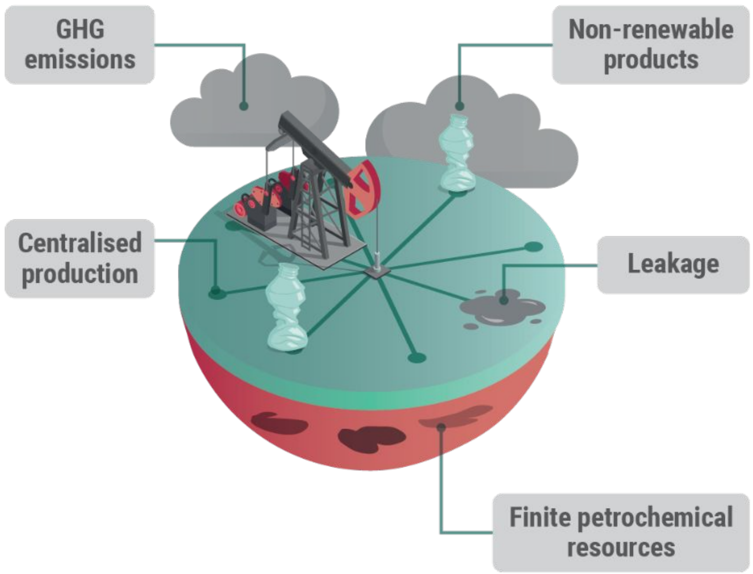
Municipal green waste

Mown grass, culled trees

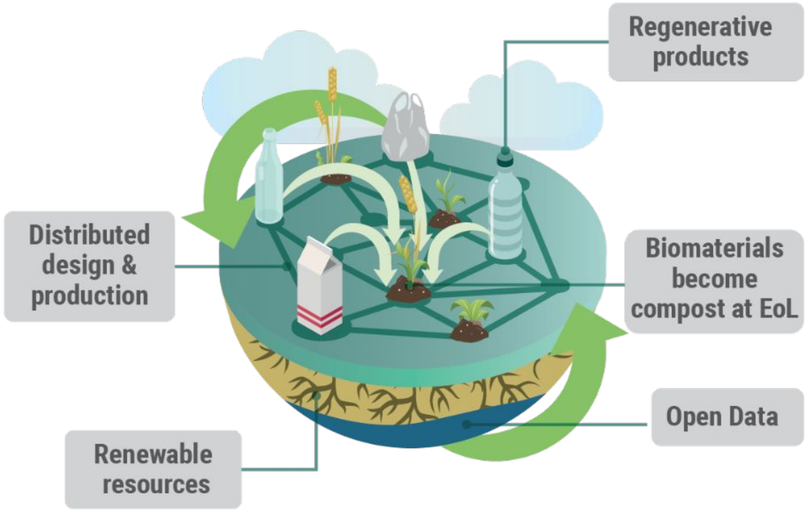
Cellulose / Glycerol / Starch

BIOPOLYMERS

From a centralized, fossil-based economy



To a decentralized, renewables-based economy



To tackle climate change and create a waste-free world, we must transform how materials and products are made. Biomaterials made of renewable sources can not only replace petrochemical plastics, but regenerate our planet by becoming compost at end-of-life.

Materiom is an innovation platform specialising in biomaterials R&D. We provide open data and AI software to help scientists, producers, and brands design, make, and use materials that positively impact the planet.

Our **open-access database** of biomaterials - the world's largest - acts as a commons: democratising R&D and seeding a groundswell of innovators to develop bio-based alternatives to plastics.

Our **AI Software** uses our database to create novel biomaterials that meet the needs of market leaders and targets of policy makers - accelerating R&D by 10x.

We convene and support an **extensive network of leaders** across the value chain: from manufacturers and brands seeking solutions to municipalities and communities looking to create value from waste.

Generative AI: Users and needs

Materiom's GenAI is designed to use the information generated by our database to provide novel biomaterial for our community.

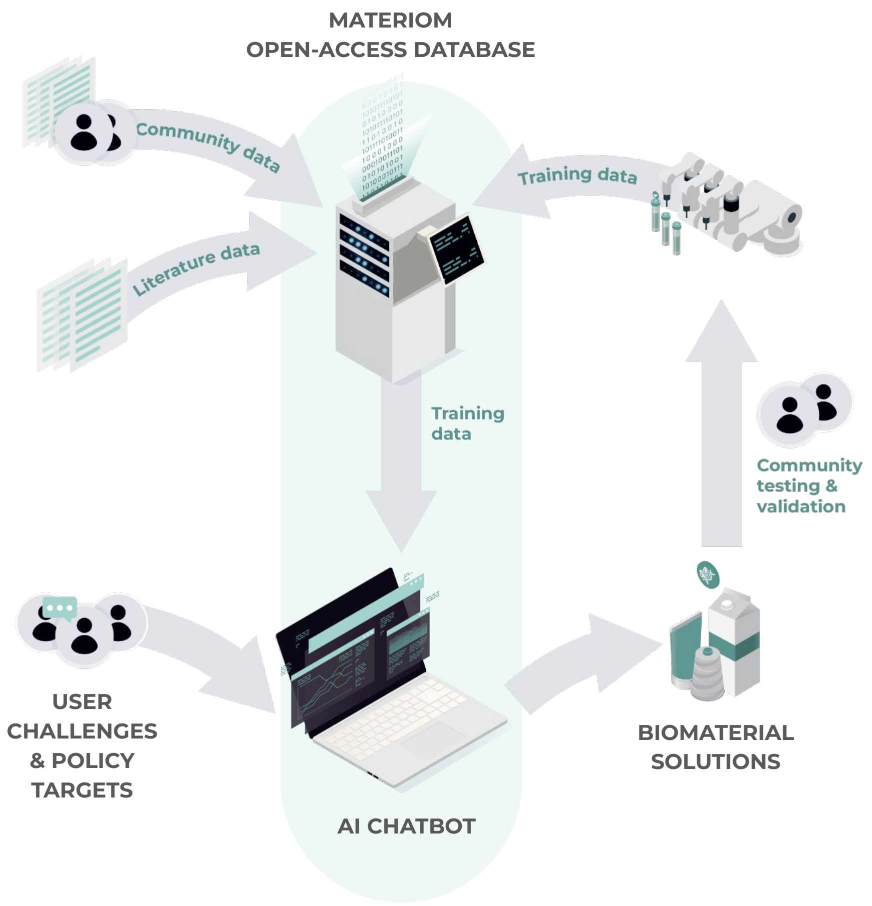
Impact-driven material SMEs & brands
Meeting performance and impact targets

Scientists & educators
Generating novel materials for cutting edge research

Generative AI: Learning over time with the Materiom community

Combining the power of generative AI with Materiom's community-driven platform, we can radically accelerate the ability for anyone, anywhere to develop net-positive materials.

Recipes generated by the chatbot will be tested by our community. Once validated, they can be added to our database, helping the AI improve over time.



Generative AI use case: Accelerating R&D for biomaterial entrepreneurs

Can you help me find a recipe for a 100% biobased leather for fashion that uses banana fibers, minimizes carbon emissions and water consumption?

Sure, here is a recipe that meets your desired performance:
Ingredients:

- 70% banana fibers
- 25% chitosan
- 5% glycerol

You can extract starch from potato waste instead of primary crops. Here is an extraction technique that minimizes energy and water use...

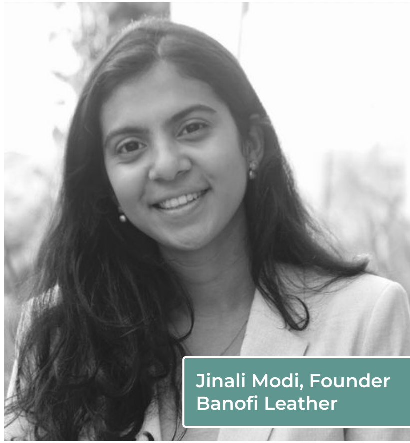
Can this material be used as compost to enhance soil fertility in banana plantations and drawdown carbon?

The soil in banana plantations in Southern India are poor in nitrogen. I suggest adding some collagen to your recipe to make it higher value for soil amendment. Here is a new recipe:

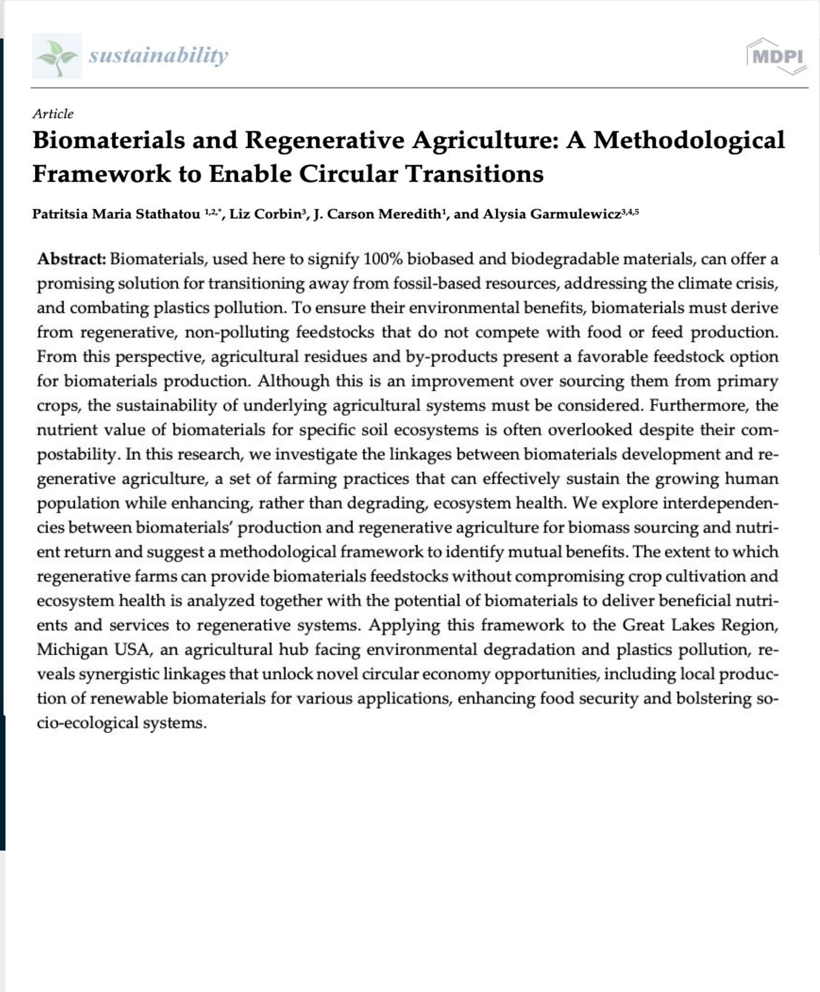
Ingredients:

- 60% banana fibers
- 30% starch
- 10% collagen

Enter a prompt here



Jinali Modi, Founder
Banofi Leather



sustainability

MDPI

Article

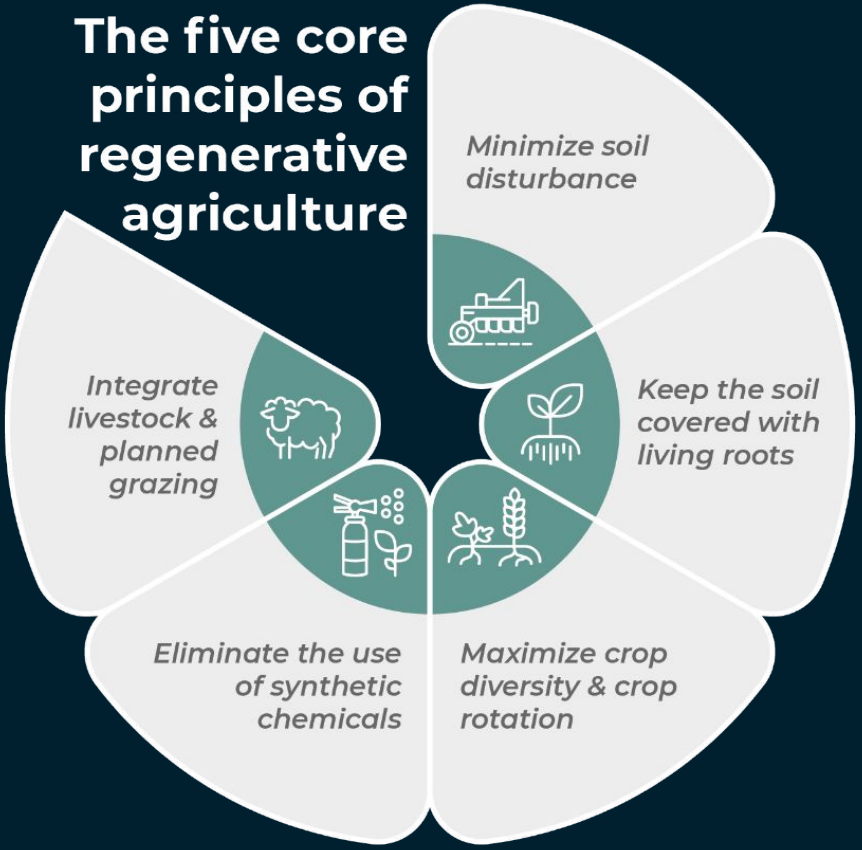
Biomaterials and Regenerative Agriculture: A Methodological Framework to Enable Circular Transitions

Patritsia Maria Stathatou [1,2,*], Liz Corbin[3], J. Carson Meredith[1], and Alysia Garmulewicz[3,4,5]

Abstract: Biomaterials, used here to signify 100% biobased and biodegradable materials, can offer a promising solution for transitioning away from fossil-based resources, addressing the climate crisis, and combating plastics pollution. To ensure their environmental benefits, biomaterials must derive from regenerative, non-polluting feedstocks that do not compete with food or feed production. From this perspective, agricultural residues and by-products present a favorable feedstock option for biomaterials production. Although this is an improvement over sourcing them from primary crops, the sustainability of underlying agricultural systems must be considered. Furthermore, the nutrient value of biomaterials for specific soil ecosystems is often overlooked despite their compostability. In this research, we investigate the linkages between biomaterials development and regenerative agriculture, a set of farming practices that can effectively sustain the growing human population while enhancing, rather than degrading, ecosystem health. We explore interdependencies between biomaterials' production and regenerative agriculture for biomass sourcing and nutrient return and suggest a methodological framework to identify mutual benefits. The extent to which regenerative farms can provide biomaterials feedstocks without compromising crop cultivation and ecosystem health is analyzed together with the potential of biomaterials to deliver beneficial nutrients and services to regenerative systems. Applying this framework to the Great Lakes Region, Michigan USA, an agricultural hub facing environmental degradation and plastics pollution, reveals synergistic linkages that unlock novel circular economy opportunities, including local production of renewable biomaterials for various applications, enhancing food security and bolstering socio-ecological systems.

The GLR generates $14.5 bn in annual agricultural sales, yet is facing critical environmental challenges - water quality, loss of essential wildlife habitats, and rising pollution - due to agricultural intensification and climate change.

The five core principles of regenerative agriculture



Environmental benefits:

- Enriched soils and resilient land areas;
- Enhanced biodiversity/ecosystem services;
- Improved water quality;
- Increase the capacity of soil to capture carbon & reverse global warming.

Socio-economic benefits:

- Improved farmer profitability and increased income;
- Reduced exposure of farmers to harmful agricultural chemicals;
- Reduced exposure to extreme weather events and climate change impacts;
- Climate-resilient and food-secure communities.

Rodale Institute. (2014). Regenerative Organic Agriculture and Climate Change: A Down-to-Earth Solution to Global Warming. / Rodale Institute. (n.d.). Regenerative Organic Agriculture. / General Mills. (n.d.). Regenerative agriculture. / Newton, P., et al. (2020). What is regenerative agriculture? A review of scholar and practitioner definitions based on processes and outcomes; *Frontiers in Sustainable Food Systems*, p194.

TABLE 3: MEAN DRY WEIGHT OF EXTRACTIVES & LIGNOCELLULOSIC COMPONENTS OF COVER CROPS

	Dry weight (%)			
Cover Crops	Extractive	Hemicellulose	Cellulose	Lignin
Abruzzi rye	46.30	25.17	25.26	2.56
Black oat	52.17	20.82	25.17	1.77
Crimson clover	62.22	9.53	25.58	3.35
Hairy vetch	53.71	14.29	27.24	4.86
Winter barley	53.40	20.88	19.36	1.42

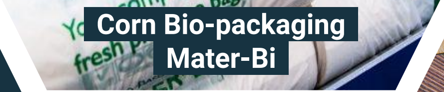
Cellulose: abundant, renewable, and biodegradable.

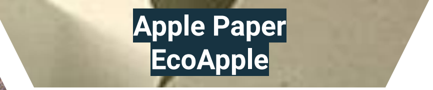
Cellulosic monomers, derivatives, fibers, & nanocellulose is used for the production of advanced biocomposites, films, & nanomaterials.

In the GLR, an average of 20-30% of cover crop residues can be removed for use as feedstock for biomaterials production.

Shahi, N., et al. (2020). Potential sustainable biomaterials derived from cover crops. BioResources, 15(3), 5641-5652.
Shaghaleh, H., et al. (2018). Current progress in production of biopolymeric materials based on cellulose, cellulose nanofibers, and cellulose derivatives. RSC advances, 8(2), 825842.

The potential of residues derived from main and functional crops in polycultural systems





Project Syntropia

Syntropic Materials

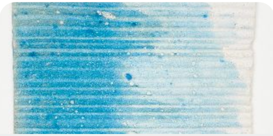
ESSENTIAL CROP NUTRIENTS

7 N Nitrogen	20 Ca Calcium	5 B Boron	26 Fe Iron
19 K Potassium	12 Mg Magnesium	17 Cl Chlorine	25 Mn Manganese
15 P Phosphorus	16 S Sulfur	29 Cu Copper	42 Mo Molybdenum
	6 C Carbon	28 Ni Nickel	30 Zn Zinc

BIOPOLYMERS & INGREDIENTS WITH HIGH NUTRIENT CONTENT
Chitin, Chitosan, Sodium Alginate, Iota-Carrageenan, Kappa-Carrageenan, Gelatin, Keratin, Casein, Collagen, Whey Protein, Calcium Carbonate, Egg Shells, Mussel Shells, Oyster Shells, Silk Fibroin Protein

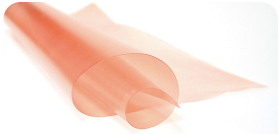
RECIPES IN MATERIOM'S COMMONS

Walnut Shell & Mycelium Composite
Lab FADEU



Eggshell & Chitosan Biomaterial
Big Circle Studios

Walnut Shell & Keratin Composite
Valentian Dipietro



Gelatin Bioplastic
Margarita Talep Follert

Carrageenan Film
Lugae

Gelatin Bioplastic
FabTextiles

Carrageenan & Avocado Bioplastic
Zoë Powell

Sodium Alginate & Sage Bioplastic
Zoë Powell

Chitosan & Methylcellulose Film
Materiom


Thank you
26th October 2023
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