Sustainable Materials

Fall, 2024

- overview
- team
- schedule
- logistics

Teaching Team:

David Kaplan, David.kaplan@tufts.edu

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Artem Arkhangelskiy, Artem.arkhangelskiy@tufts.edu

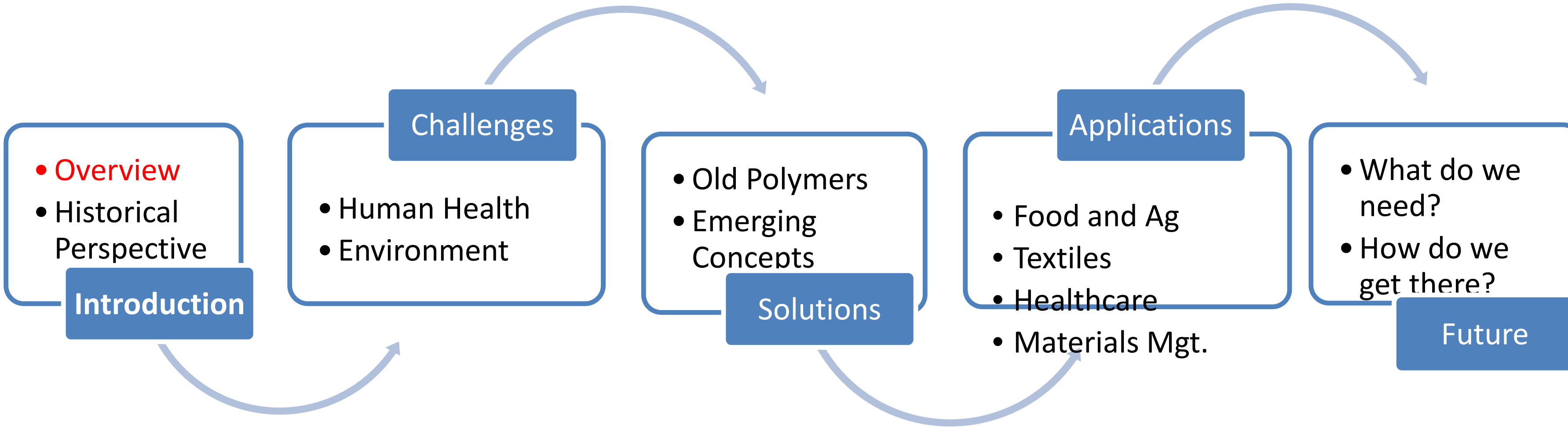
Reddhy Mahle, reddhy.mahle@tufts.edu

Monday and Wednesdays, 3:00pm-4:15pm

Syllabus Schedule *(subject to change)*

Sep 4- Overview - definitions, coverage, topics, rationale, the future *(David Kaplan)*
Sep 9, 11 - Historical perspective *(Logan Morton and Lauren Blake)*
Sep 11: Assignment #1: Envisioning Sustainability Through AI-Generated Art
Sep 16, 18 - Challenges and opportunities – *(Logan Morton and Lauren Blake)*
Sep 18: Project checkpoint #1: Pick your groups and pick your problem
Sep 23, 25 - Old polymers with new perspectives and approaches *(Logan Morton and Sanjana Gopalakrishnan)*
Sep 25: Assignment #2: Exploring Emerging Polymers for Sustainable Materials
Sep 30 - Emerging concepts part 1 (*Sanjana Gopalakrishnan)*
Oct 2 – Sustainable materials for textiles guest lecture *(Sydney Gladman)*
Oct 2: Project checkpoint #2: Send one slide introduction to your project
Oct 7 - Emerging concepts part 2 *(Lauren Blake)*
Oct 9, 16 - Attempts with impact *(Reddhy Mahle and Sanjana Gopalakrishnan)*
Oct 9: Assignment #3: Creative Applications of SCOBY: Designing Sustainable Products
Oct 16: Project checkpoint #3: Written portion of the midterm presentation (1-2 Pages)
Oct 21, 23 - Case studies + midterm *(Logan Morton and students)*
Oct 23: Assignment #4: Surface Modification for Sustainable Materials: Enhancing Functionality and Performance
Oct 28 - Sustainable materials for food and agriculture *(Lauren Blake)*
Oct 30: Project checkpoint #4: Literature review(minimum 5 articles)
Nov 4, 6 - Sustainable Materials Management *(Artem Arkhangelskiy)*
Nov 6: Assignment #5: Materials Management and Life Cycle Analysis of Emerging Polymer
Nov 13 - Sustainable materials for healthcare *(Sanjana Gopalakrishnan)*
Nov 13: Project checkpoint #5: Materials management and life cycle analysis for your proposed project
Nov 18 – State of the Kaplan lab – *where you can get involved in sustainable materials right here at Tufts*
Nov 20, 25 - **What we need, how do we get there, circular approaches** *(David Kaplan)*
Nov 20: Assignment #6: Journal Club: Critical Review of Sustainable Materials Research
Nov 27, Dec 2, 4, 9 - final presentations (students)

Course Overview



Sustainable Materials

Introduction

- **Definitions**
- **Course coverage – topics**
- **Overview of materials, examples**
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- **News and views – hot topics**

First …the life of a tree

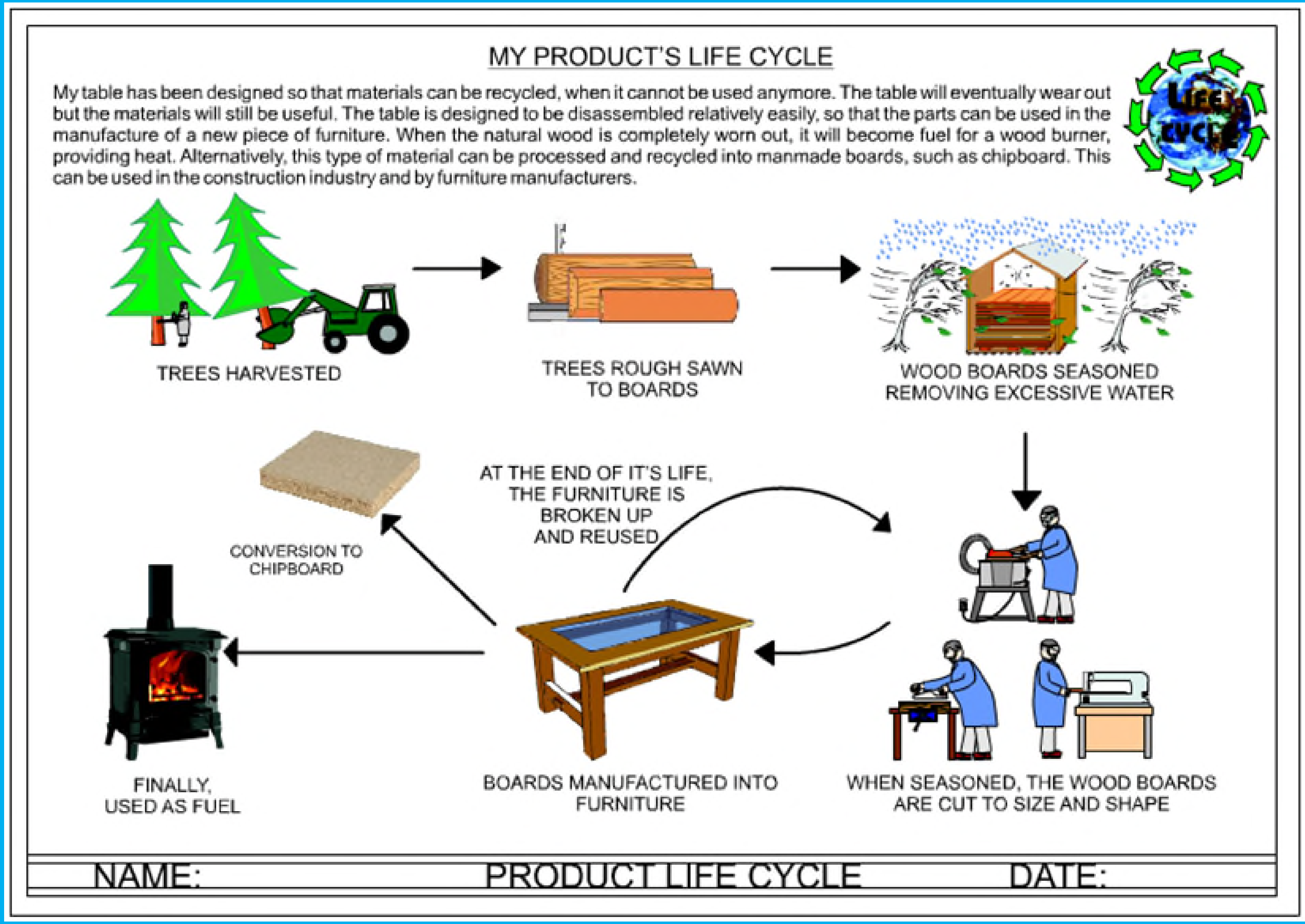
Trees – wood and wood products

Utility: construction materials, paper manufacturing, consumer products, fuel, resins, fragrances …..

Trees – wood and wood products

Functions: renewable, fix carbon dioxide, replenish soil, clean the air…..

Concept: Lifecycle Considerations – sustainability….



Why Show This ?

Direct Processing

Reduced resource use
Reduced energy for manufacturing
Reduced waste
Improved sustainability
….


FULL GROWN
Salix reclinatoria - 'The Nelson Armchair'
Using ancient rural techniques combined with modern technology, this is one of our First Edition Grown Armchairs. Started in 2012 using Salix viminalis - Common osier - it will take 5-6 years of nurturing and training into shape before harvest with an additional year to season and dry the wood, the piece is hand-finished using both modern and pre-industrial tools. Each piece is unique, epitomising an elegant cooperation between Nature and Humanity that could last for hundreds of years. We've called this chair 'The Nelson', as the field identification number is Unit 111 - a 'Nelson' is the cricketing term for 111 runs. Cricket bats are also made from willow. Manufacturing our everyday objects this way needs much less energy, even at this early stage, encouraging tree-planting and a constantly developing relationship with our Flora and Fauna.
Leaves and catkins of Salix viminalis
Chair design by Gavin Munro
Artwork by Geoff Diego Litherland
Finishing details - the rings on the slightly raised entry branch above show the tree's age
Once harvested and turned upside down, the 'entry branch' will show both the age of the piece and evidence of the years' weather over the chair's growth cycle.
Spring 2012
Summer 2012
Spring 2013
Summer 2013
Summer 2014
Summer 2015


Genesis 2002
Genesis 2000
Photographed 2017

Death of a Tree

why show this?

Concept: programed utility and reuse…..

Death of a Tree

‘’designed to degrade’ or ‘degrade-on-demand’

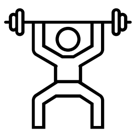
Metabolomics, Kinetics, Mass balance, Short- vs. long-term

Concept: The Lorax

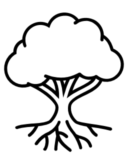
Sustainable Materials
→ trees as inspiration

simple building blocks → remarkable structures & functions
[cellulose, hemicellulose, lignin]

Structure



- Structural hierarchy – mechanics
  porous to dense (balsa to ironwood), soft to hard…



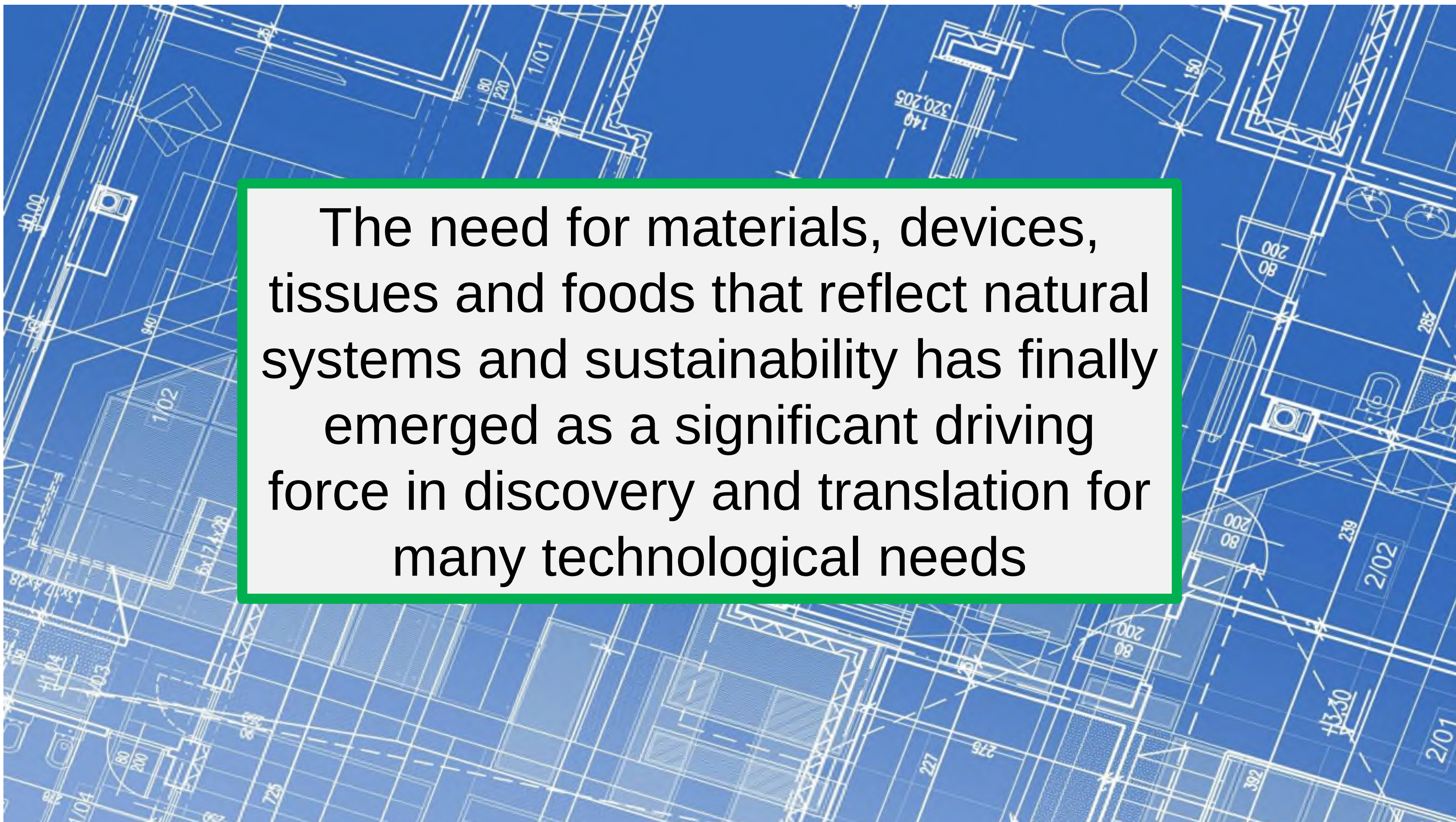
- Vascular networks, transport

Sustainable Materials
→ trees as inspiration

Functions

- Carbon Fixation/Sequestration, biomass production
- Enzymatic Processes – protection from infections, metabolism…
- Longevity – short to long (annuals to >1,000s of years)
- Regenerative capacity – regrow limbs, turnover in soil
- Sustainability, all aqueous, ambient – nothing wasted

Sustainable Materials → trees as a blueprint



The need for materials, devices, tissues and foods that reflect natural systems and sustainability has finally emerged as a significant driving force in discovery and translation for many technological needs

Extremes & Adaptability in Sustainable Biomaterials

Tress: wood/cellulose

Both:
- semi-crystalline
- H-bonding
- no chemical crosslinking
- water is a key

Spider Webs:

Nature offers an incredible starting point for biomaterials designed for sustainability - remarkable mechanical roles, degradability, designed to last as long as needed

Extremes & Adaptability in Sustainable Biomaterials

Tress: wood/cellulose

- simple building blocks, ~no nitrogen
- longest living things on earth?
- withstand forces of gravity, use sunlight
- some trees need fire to reproduce

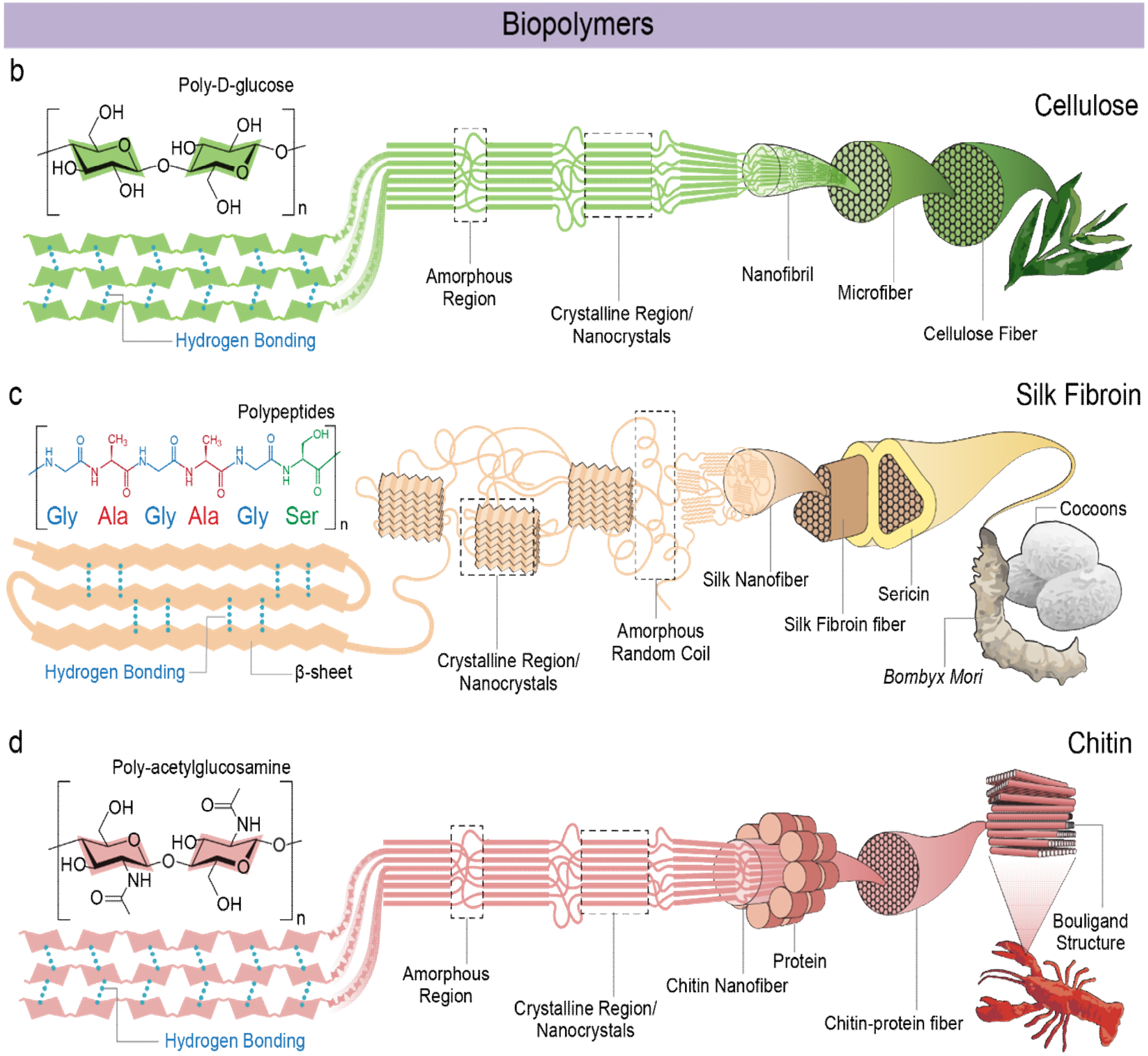
Spider Webs:

- 20 building blocks, nitrogen rich
- ultra-lightweight material & sensor
- amazing mechanical properties
- some recycled daily, others not

Both:

- semi-crystalline
- H-bonding
- no chemical crosslinking
- water is a key

Nature offers an incredible starting point for biomaterials designed for sustainability - remarkable mechanical roles, degradability, designed to last as long as needed

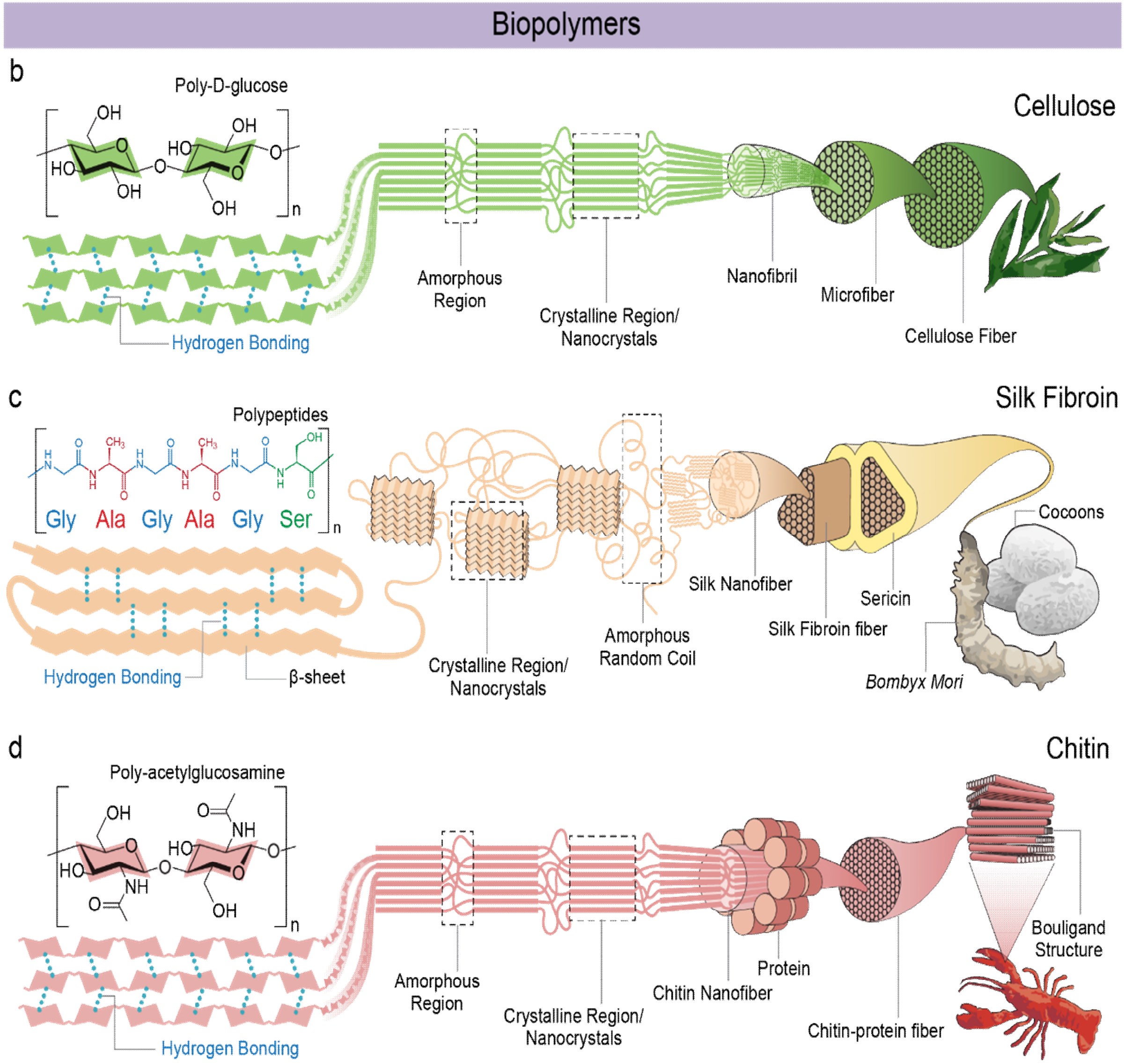


Sustainability

synthetic vs. biopolymer structures

Concept: hierarchical assembly – structure/function

Ling et al., ***Nature Reviews Materials***, 2019; Li et al., ***Advanced Matls***., 2021



Sustainability

Some of the most dominant biopolymers on earth

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no glues

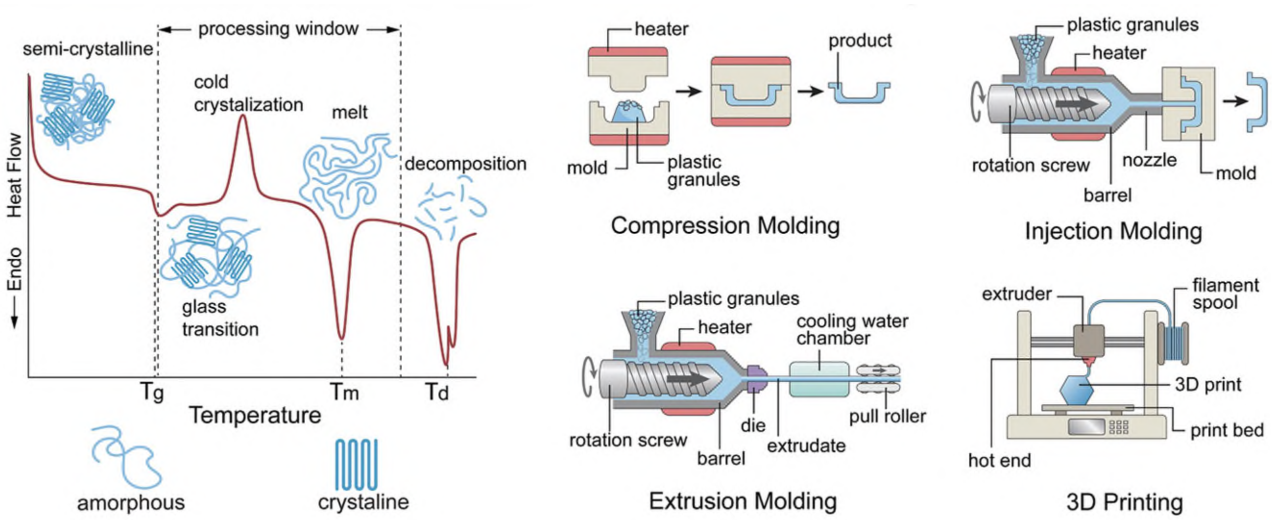
no covalent bonds

no chemical crosslinkers

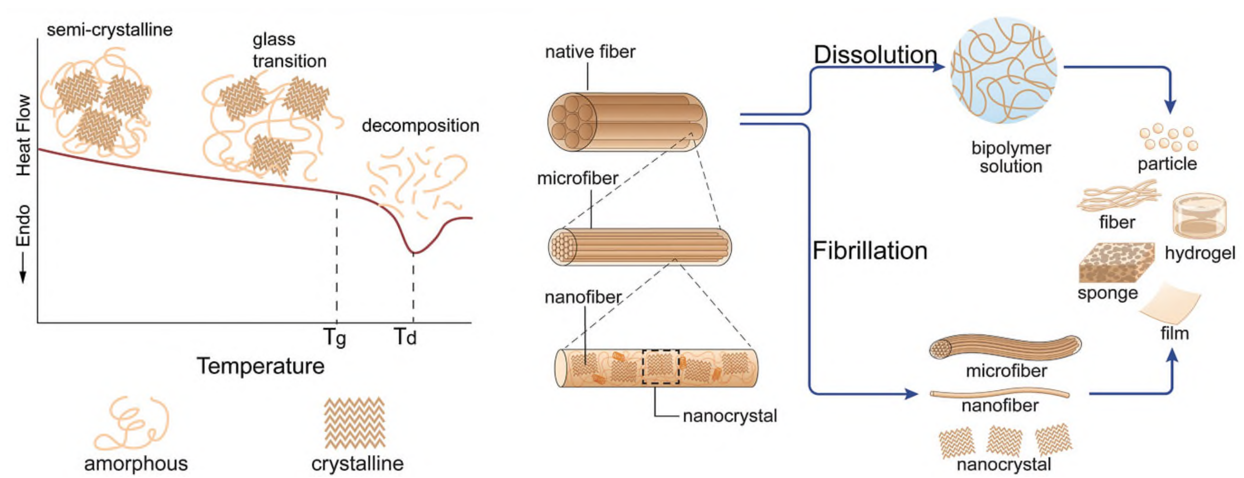
Ling et al., ***Nature Reviews Materials***, 2019; Li et al., ***Advanced Matls***., 2021

Processing - thermoplastic molding of biopolymers vs. synthetics

Synthetic polymers



Biopolymers: chitin, cellulose, silk

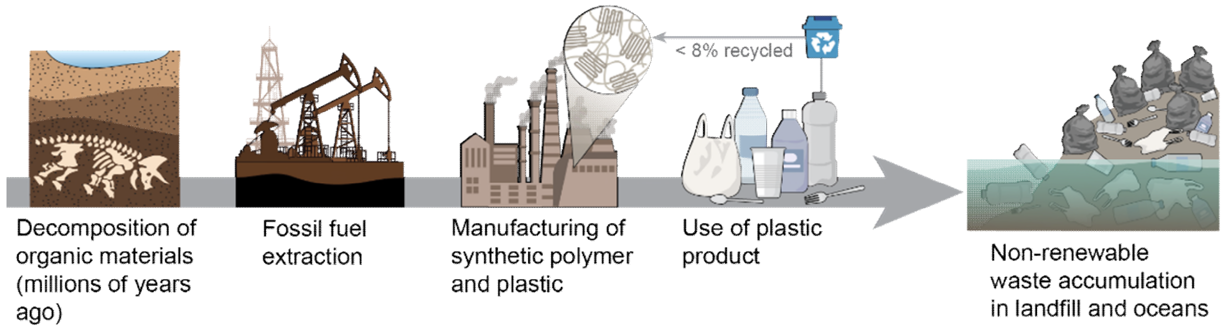


Li et al., ***Advanced Materials*** 2021

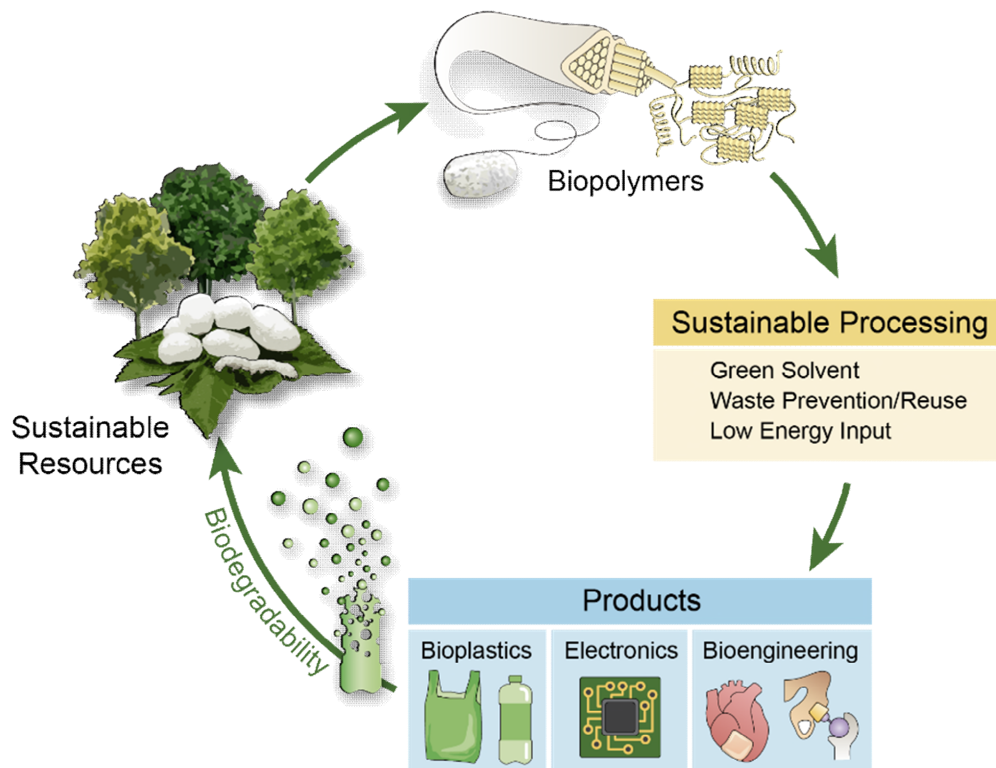
Sustainability

linear lifecycle of synthetic polymers vs. circular lifecycle of biopolymers

<u>Linear</u> –
fossil fuels



<u>Circular</u> –
silk protein



Li et al., ***Advanced Matls,*** 2021

Sustainable Materials

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What is Sustainability?

Sustainable Materials

items produced and used by humans in an environmentally-responsible way, and without depleting non-renewable resources in order to maintain natural resource systems' in established steady-state balance.

Sustainable materials are sourced from low environmental impact or renewable resources, have a longer lifecycle and smaller environmental footprint to manufacture or use, or be easier to break down at end of life.

Confluence of sourcing, utility, environment, society, economic, lifecycle considerations

What Makes a Material Sustainable?

Sustainability - using resources responsibly and efficiently to preserve their availability → sourced sustainably, use less energy in production, last longer with minimal upkeep, easy to repair and/or recycle when needed, have low embodied energy (energy required to produce them), and have minimal negative environmental impact

Selecting Sustainable Materials

Making the 'right' material choice is no longer based purely on structural efficiency but a balance across a number of different factors, including:

- Efficient design
- Fitness for purpose
- Environmental impact/ recycled content
- Local context
- Responsible sourcing
- Fabrication process
- End of life/deconstruction

What are green materials?

green materials - based on how they intrinsically affect the environment. Naturally occurring materials (such as wood), ceramics, glass and composite materials are common examples of green materials.

Green materials include:

- High recycled content and/or high recyclability
- Made from rapidly renewable sources
- Very low emissions that contribute to global warming and ozone depletion
- Minimal to zero pollution to the environment

The requirements for green materials are relatively easy to comply with compared with sustainable materials

Green	**Sustainable**
Hinged on only one pillar: **environment**	Hinged on three pillars: **environment, economy and social equity**
Concerned with **individual parts** and their constitution alone, including their recyclability, toxicity, etc.	Considers the **relationship** between individual parts and the entire system as a whole, including upcycling, recycling, production processes, the constitution of the product, etc.
Does not inherently curb the rate of production as long as the materials used are "green"	Questions human **need** for new products
Has an approach of **small incremental** reform to individual human habits to limit human impact on the environment	Has an approach of a complete **overhaul** of the status quo to design and implement a self-sustainable system
Positive change is effected by addressing **individual** products and manufacturing practices on a relatively small scale.	Demands positive change on a larger scale, usually by **policy changes** from the government at a city level, at least, for it to be effective

where do sustainable materials fit ?

Sustainable Materials

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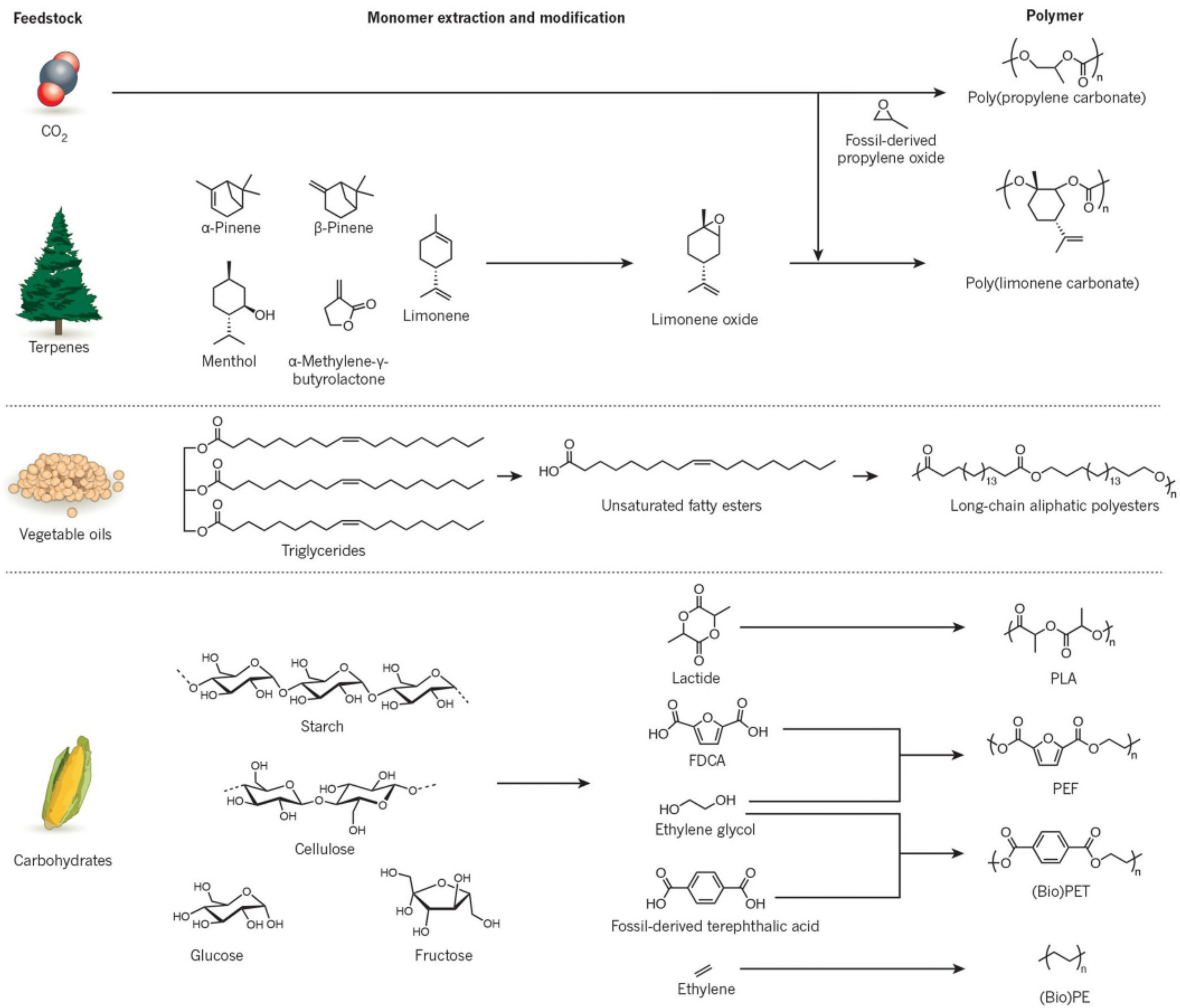
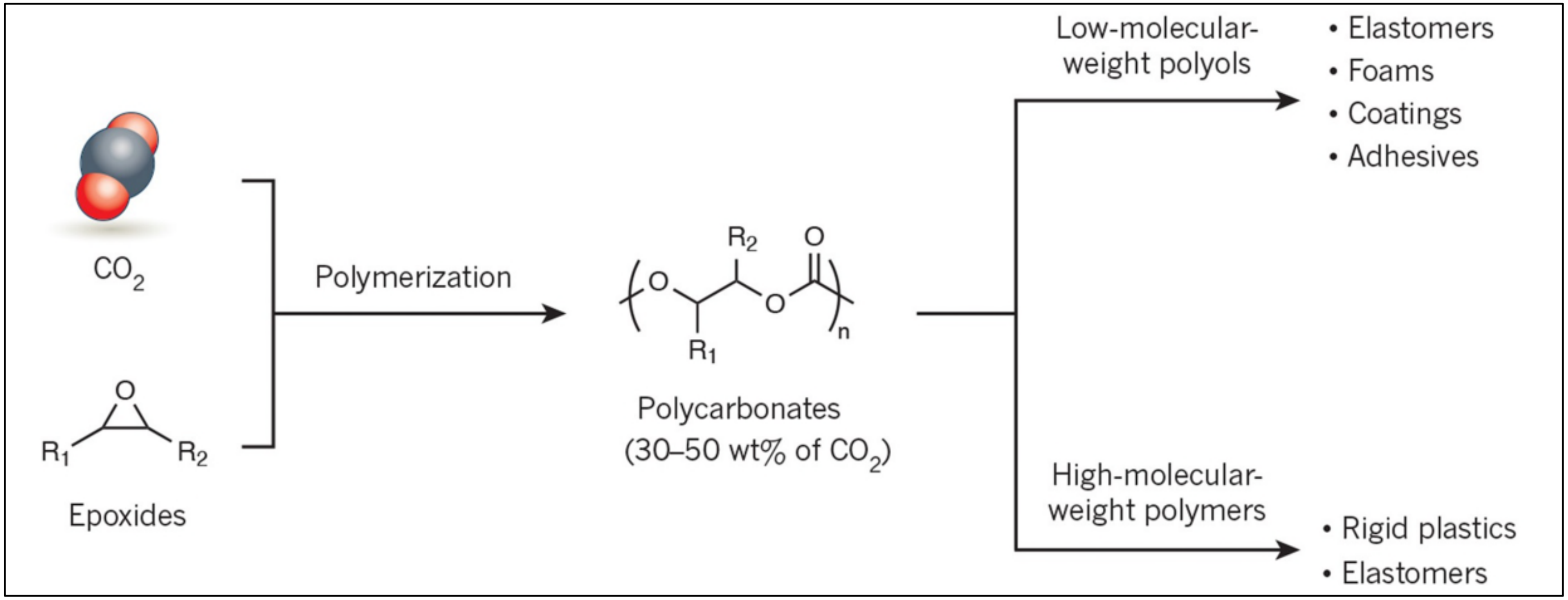
Options for replacing petrochemicals as raw materials in the manufacture of polymers

Sustainable polymers from renewable resources



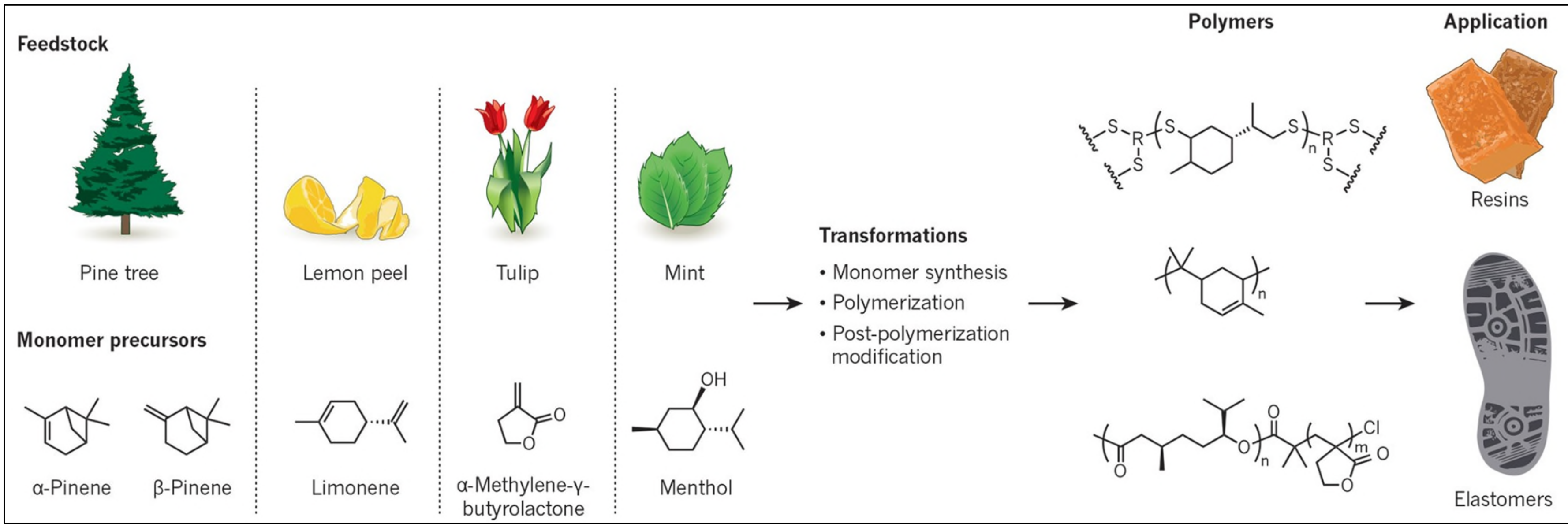
Upcycling carbon dioxide into sustainable polymers of high value

carbon dioxide copolymerized with propylene oxide to generate propylene carbonate polyols



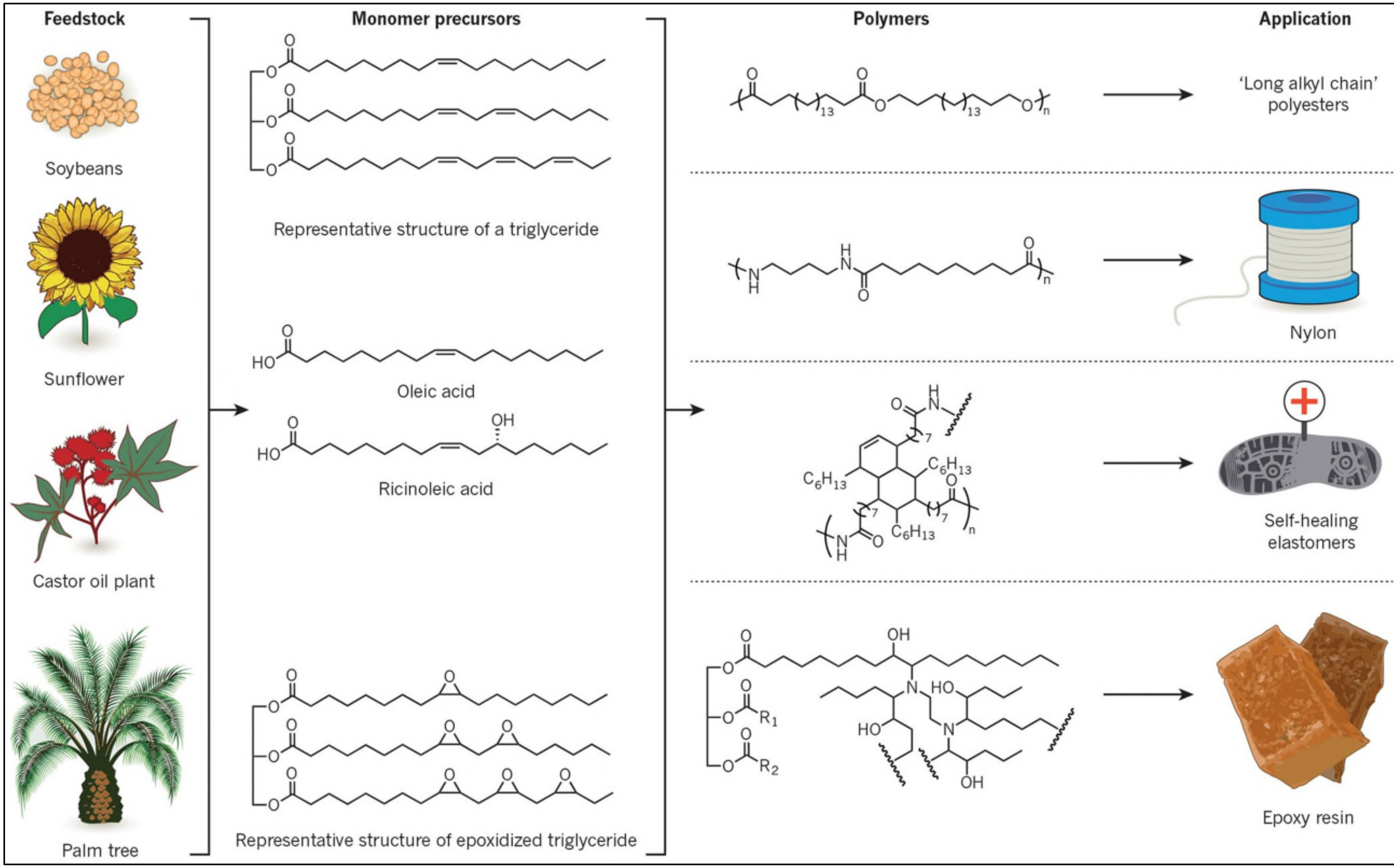
Carbon dioxide and epoxides can be copolymerized to deliver aliphatic polycarbonates. Polycarbonate polyols of low molecular weight suitable to prepare foams, coatings and adhesives, whereas high-molecular-weight polycarbonates may be used as rigid plastics or elastomers.

Sustainable polymers produced from terpenes and terpenoids



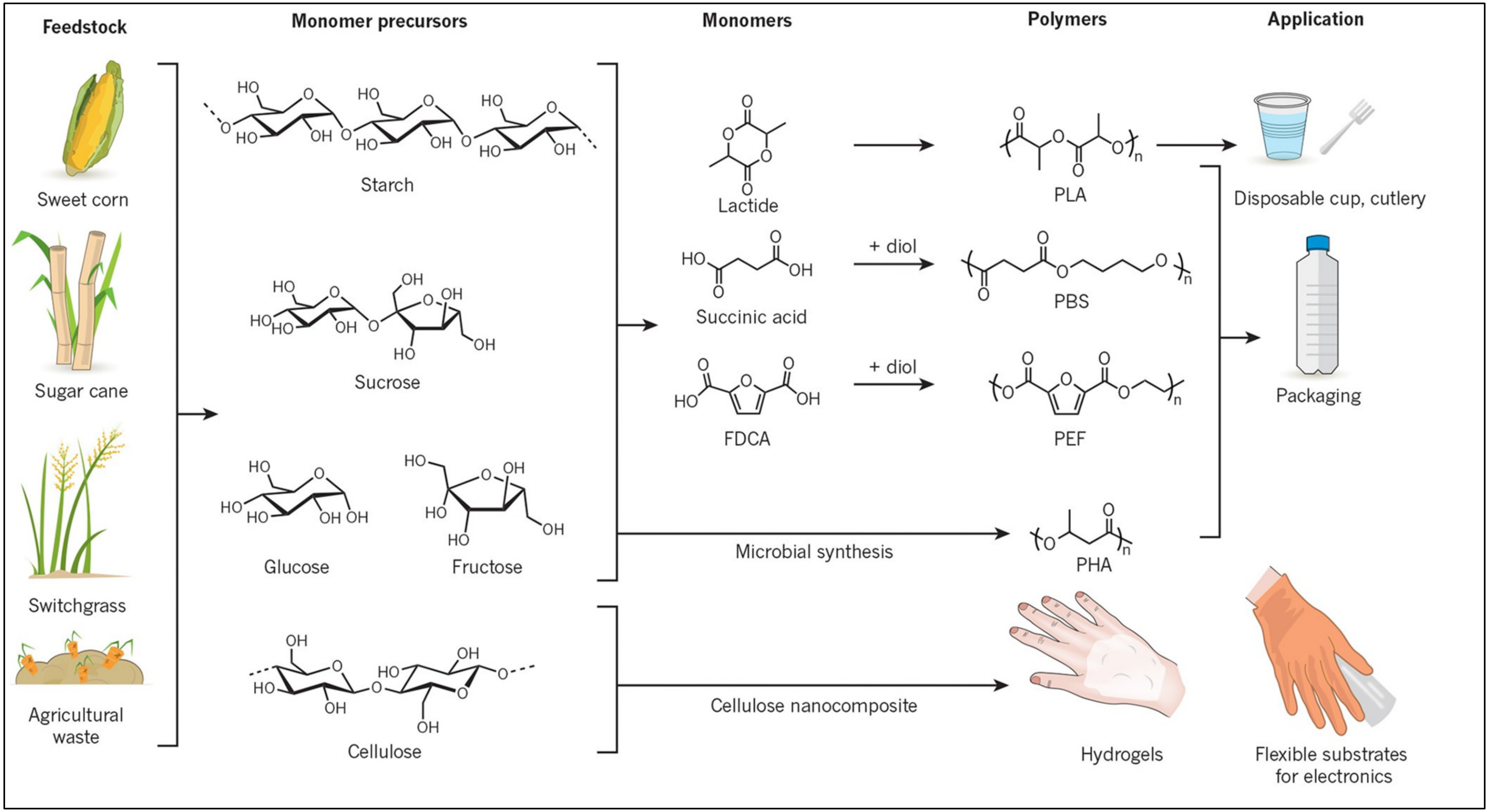
Terpenes such as pinene and menthol are extracted from plants such as pine or mint - transformed into polymer resins or elastomers

Sustainable polymers produced from vegetable oils



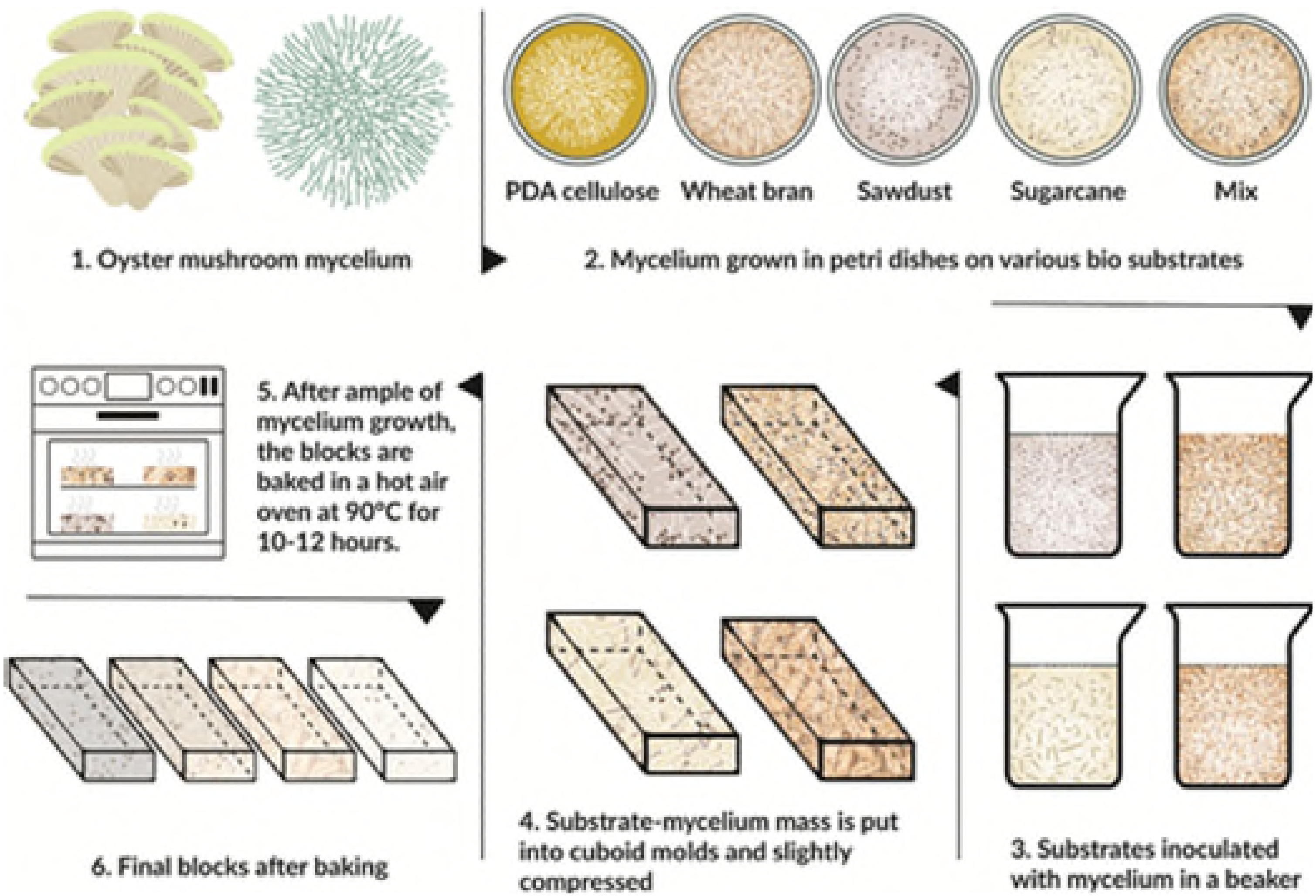
Plants such as soybean, sunflower, castor oil or palm tree are good sources of triglycerides - triglycerides transformed to polymers such as polyesters or nylons and are subsequently applied as elastomers or resins

Sustainable polymers produced from polysaccharides



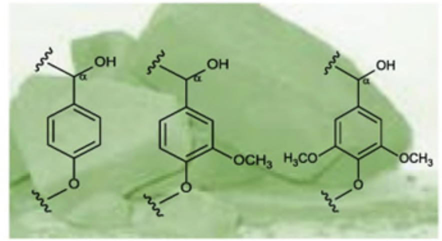
Plants such as sugar cane and maize are good sources of sucrose or starch, transformed to monomers, including lactide, succinic acid, 2,5-furandicarboxylic acid (FDCA) - monomers polymerized to polylactide (PLA), poly(butylene succinate), poly(ethylene furanoate) (PEF). Poly(hydroxyalkanoate) (PHA) produced directly from glucose by biosynthesis. Cellulose fibers to reinforce composites for hydrogels or flexible substrates for electronics.

Schematic - growing mycelium blocks from agricultural waste substrates



Fungal (mycelium) furniture & architecture

applications of lignins



Chemicals:

- Vanillin and vanillic acid
- Phenolic compounds
- Fuels
- Catechol
- Aldehydes
- DMSO
- Benzene, toluene, and xylene

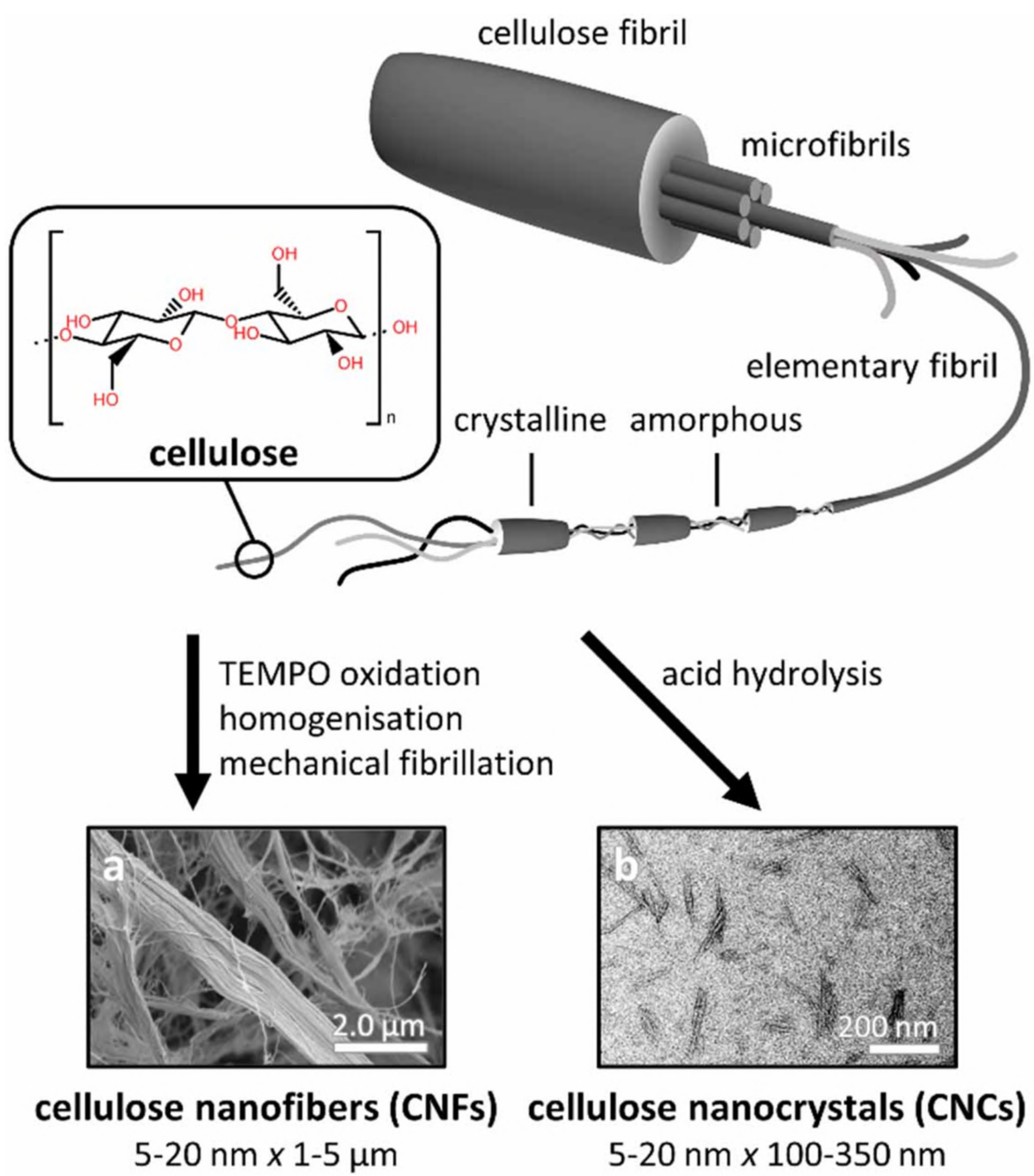
Polymers/materials:

- Thermoplastics (filler or copolymer)
- Thermosets such as phenolic, epoxy, and urethane resins
- Dispersants
- Adsorbents
- Binders
- Fire retardant
- Cement
- Asphalt
- Biomedical

Carbons:

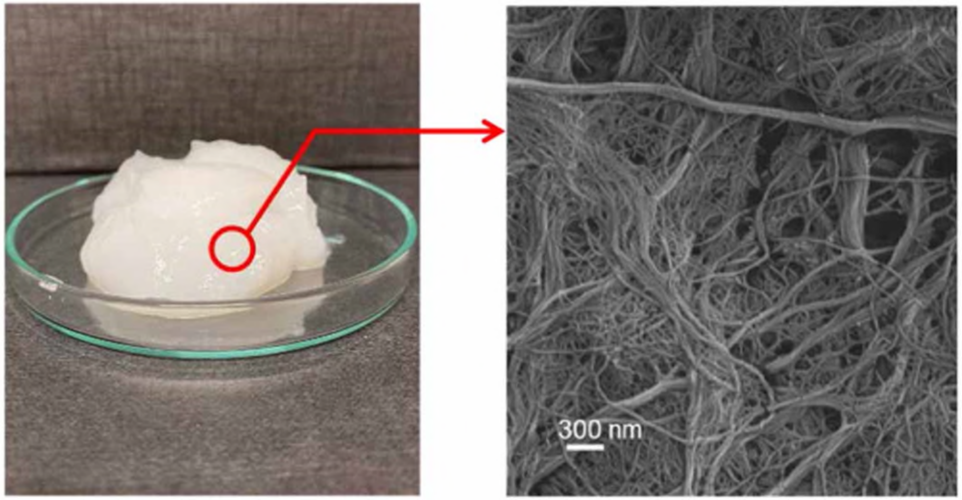
- Carbon fibers
- Biochar
- Activated carbon
- Carbon foam
- Carbon black
- Graphite/graphene
- Catalyst support
- Carbon electrodes
- Filters
- Lubricants

cellulose fibrils -
hierarchical structure
(high aspect ratio CNFs,
colloidally stable CNCs)



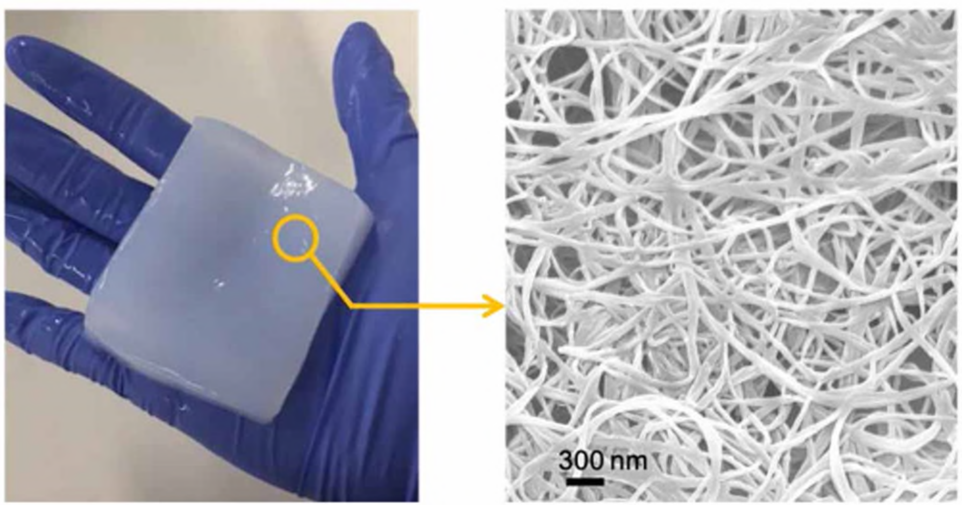
Bacterial cellulose fibrils

a



aqueous gel of nanocellulose 98 wt.-% water, scanning electron microscopy (SEM) image – morphology

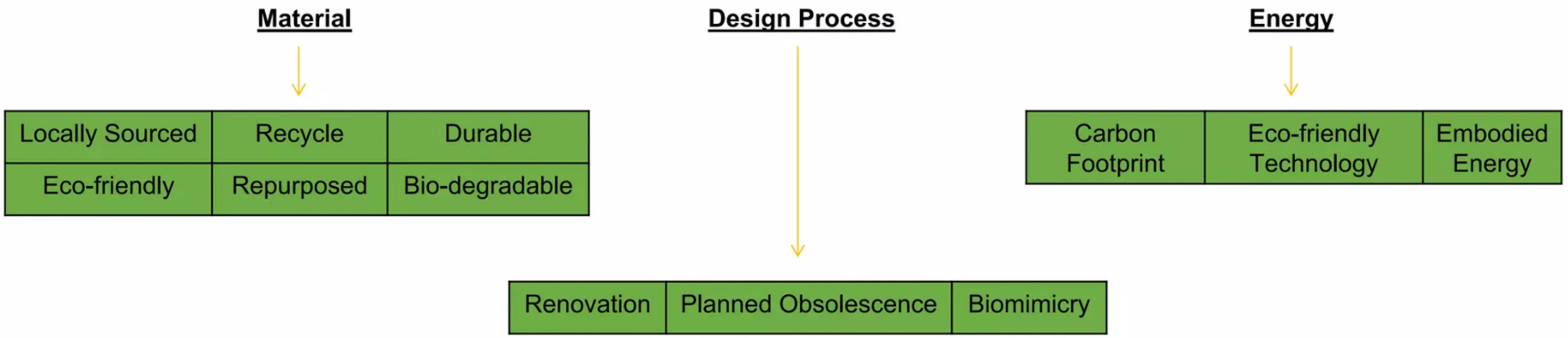
b



Bacterial cellulose pellicle 99 wt.-%, SEM showing the morphology

Approaches to Sustainability

SUSTAINABILITY PARAMETER



SUSTAINABILITY PARAMETER

Material

Locally Sourced	Recycle	Durable	Eco-friendly	Repurposed	Bio-degradable

Local materials are the resources that can be found readily in large quantity at a particular location or area at a certain time.

Recycling is the process of converting waste materials into new materials and objects.

Durability is the ability of a material to remain serviceable in the surrounding environment during the useful life without damage or unexpected maintenance.

Eco- friendly products do not harm the environment whether in their production, use or disposal. Such products can be made from scratch, or from recycled materials.

Repurposing is the process of using the item without breaking it down into its core components and using it again as a whole with new use.

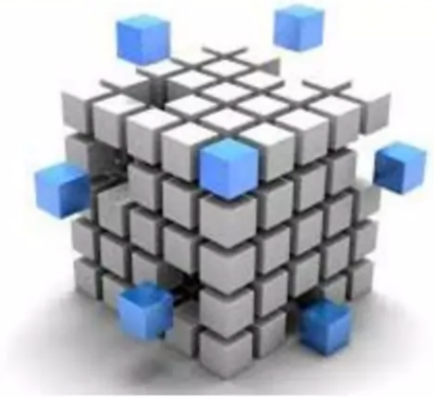
Bio-degrading is the process of decomposing of a material 100% organically, leaving behind no residual waste.

SUSTAINABILITY PARAMETER

Design Process

Renovation	Planned Obsolescence	Biomimicry

Renovation is a way to reduce the embodied energy by re-doing the interiors of a space without having to damage the built structure.



Planned Obsolescence is a policy of producing consumer goods that rapidly become obsolete and so require replacing, achieved by frequent changes in design, termination of the supply of spare parts, and the use of non-durable materials.

Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies.
The core idea is that nature has already solved many of the problems we are grappling with. Animals, plants, and microbes are the consummate engineers

SUSTAINABILITY PARAMETER

Energy

Carbon Footprint	Embodied Energy	Eco-friendly Technology

Carbon Footprint is the amount of carbon dioxide released into the atmosphere as a result of the activities of a particular individual, organization, or community.

Embodied Energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery.

An eco-friendly technology is a technology that has no adverse effect on the environment and uses a sustainable source of energy.


Sustainable Materials

SUSTAINABLE MATERIALS

Naturally Occurring	Recycle and Composite	Man-Made
Timber	Silica	Recycled Fabric
Metal	Latex	Repurposed Concrete
Stone	Wood Chips and Dust	E – Plastic
Leather	Reclaimed Wood	
Earth	Metal Alloys	
Plant Fibre	Reclaimed Metal	
Animal Fibre	Crete Composites	
Natural Extracts	Stone Chips and Dust	

Sustainable Materials - Naturally Occurring - Timber

Why is Timber a Sustainable Material?

- Renewable resource
- Grows naturally, and modern forestry standards harvest wood in a sustainable way to preserve the environment of the forest
- Be sourced locally
- Long life – provides strength and durability
- Requires less energy for processing
- Repairable, recyclable and re-purposing properties

Examples of Sustainable Indian Timber


FSC Certified Wood


Rubber Wood


Mango


Palm


Babul


Benteak

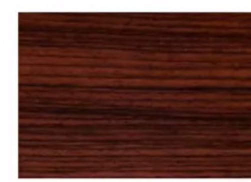

Red Sanders


Ebony Wood


Himalayan Fir


Indian Mahagony


Neem


Indian Rosewood

Sustainable Materials - Naturally Occurring – Plant Fibre

Why is Plant Fibre a Sustainable Material?

- Renewable resource
- Fast growth rate
- Grows naturally, and is a replacement for hardwood.
- Be sourced locally
- Requires less energy for processing
- Recyclable and re-purposing properties
- Durable and high tensile strength

Examples of Sustainable Indian Plant Fibre


Bamboo


Jute


Coir


Sisal


Banana


Palm Thatch


Reed Thatch


Pina Fibre


Hemp


Strawbale


Cotton


Linen

Sustainable Materials - Naturally Occurring – Animal Fibre

Why is Animal Fibre a Sustainable Material?

- By-product of another industry
- Can be bred
- Be sourced locally
- Recyclable and re-purposing properties
- Requires less energy for processing
- Low on maintenance

Examples of Sustainable Indian Animal Fibre


Tussar Silk


Mulberry Silk


Sheep Wool


Goat Wool


Peacock Feather

Sustainable Materials - Naturally Occurring – Natural Extracts

Why is Natural Extracts a Sustainable Material?

- By-product of another industry
- Can be bred
- Be sourced locally
- Recyclable and re-purposing properties
- Requires less energy for processing

Examples of Sustainable Indian Natural Extracts

Linseed Oil

Dammar Resin

Bees Wax

Latex

Acacia Adhesive

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Why the Urgency?

•Global natural resource consumption is forecast to rise 60% by 2060, compared with 2020 levels (United Nations)

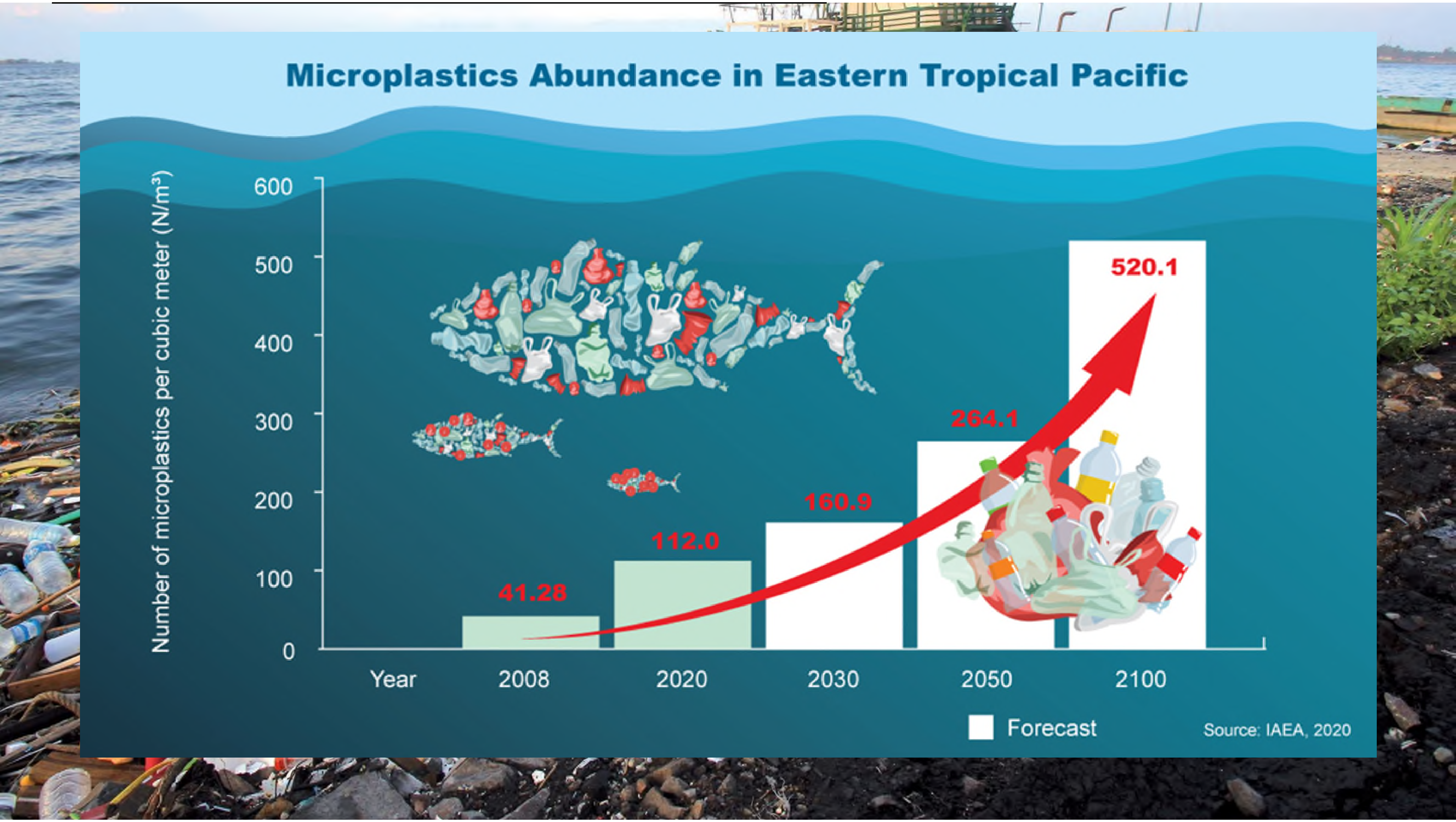
•Increasing demand for resources due to **urbanization, industrialization and a growing population**, leading to severe consequences such as biodiversity loss, water stress, climate change and air pollution

•Disrupted supply chains for critical goods and resources among the top risks identified in the World Economic Forum's *Global Risks Report 2024*

micro- and nano-plastics in marine environments

physical & chemical impact on wildlife: chemical carriers, nondegradable, accumulation…..

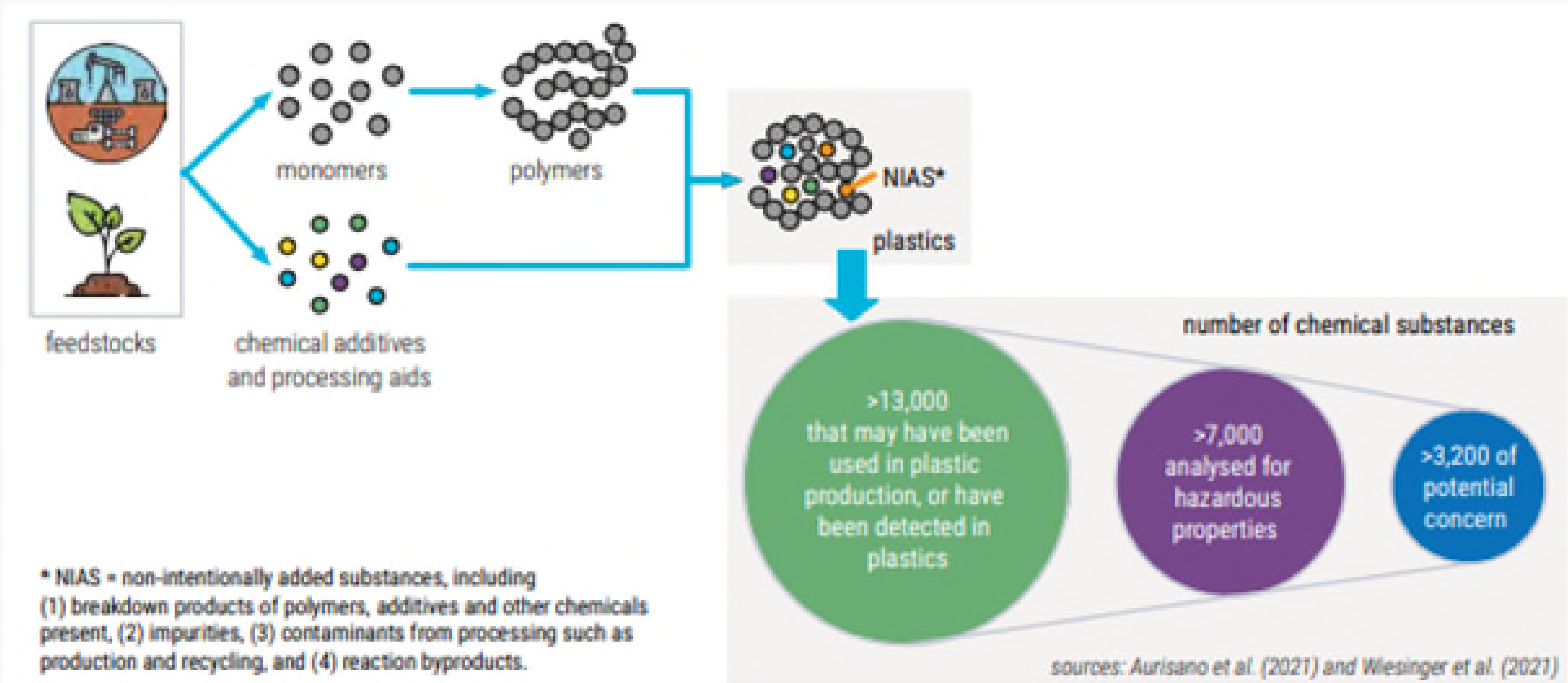
micro- and nano-plastics in marine environments



physical & chemical impact on wildlife: chemical carriers, nondegradable, accumulation…..

Its Not Just the Plastic !

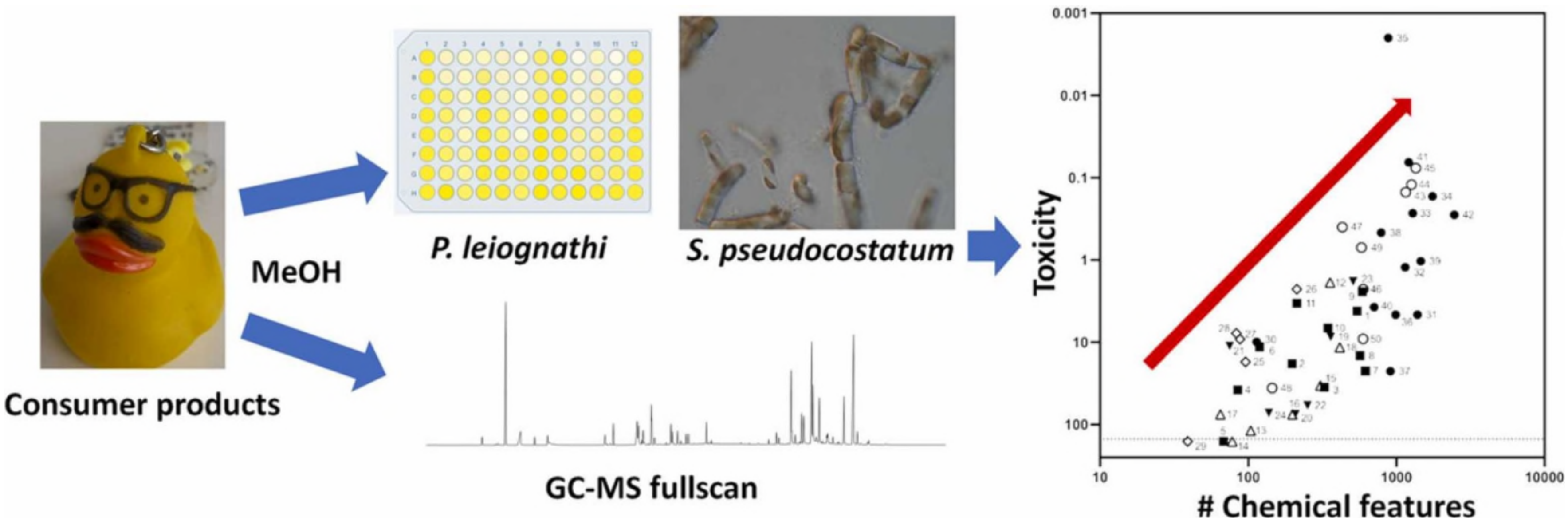
Figure 3.3: Overview of chemicals in plastics (adapted from UNEP and the Secretariat of the Basel, Rotterdam and Stockholm Conventions 2023).



Examples of common contaminants?

Micro- and Nano-Plastics – associated chemicals

chemical complexity of fifty plastic (36) and elastomer/rubber (14) methanol extracts from consumer products, toxicity in bacteria and marine microalgae

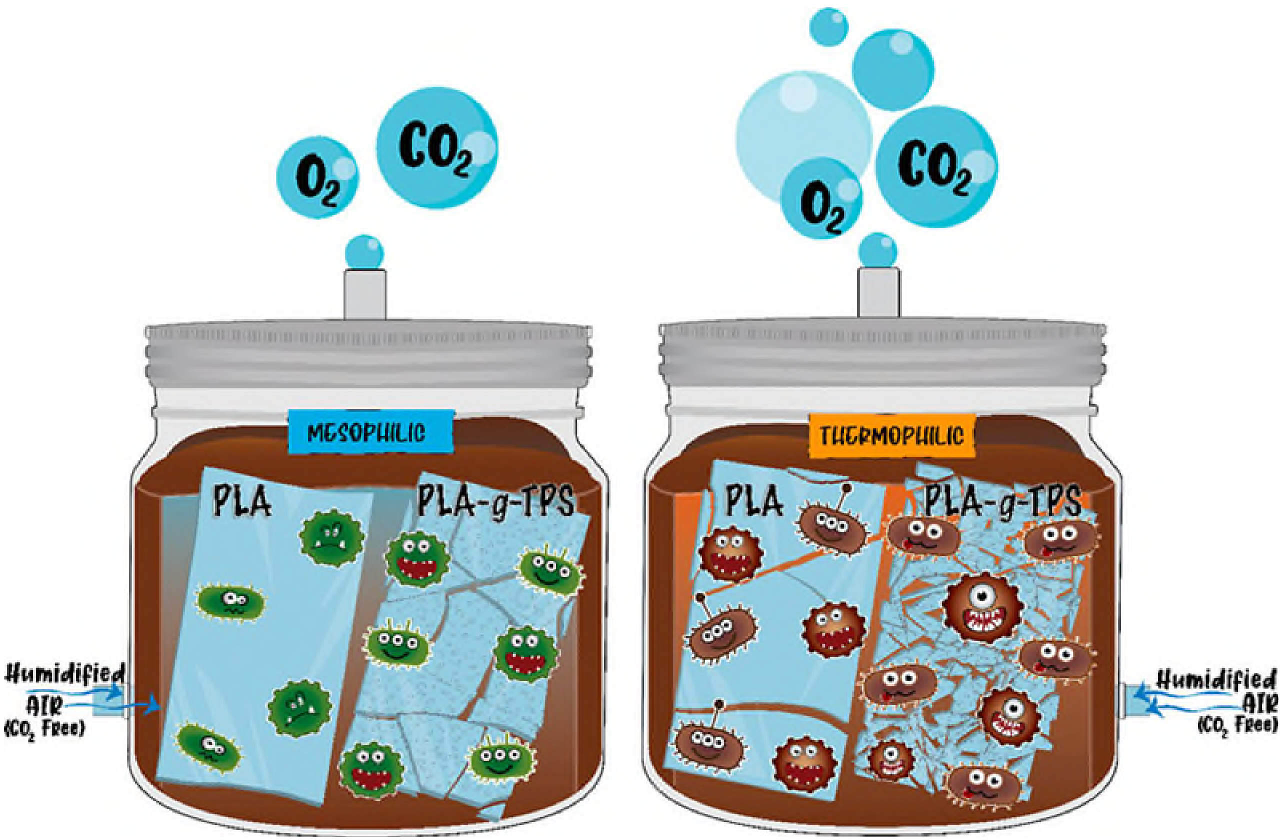


- Chemical features in products determined by GC-MS ranged from 39 to 2456
- Only 26 % of chemical features across all products could be identified
- Chemical complexity and abundance correlated with toxicity to marine species
- Elastomer product chemicals were generally more toxic than thermoplastic products
- Most complex sample (car tire rubber) contained 2456 chemicals, least (disposable water bottle) 39
- differences in toxicity between plastic and elastomer extracts: 86–93 % of the 14 elastomer extracts and 33–36% of other polymer extracts were more toxic than the median.

Journal of Hazardous Materials Volume 458, 15 September 2023, 131810
https://doi.org/10.1016/j.jhazmat.2023.131810

Solution - Plastics that Degrade ?

Thermoplastic Starch Enhances Poly(lactic acid) Biodegradation in Compost



Poly(lactic acid) (PLA)- sustainable, bio-based, and industrially compostable polymer, recalcitrant abiotic degradation phase. Thermoplastic starch (TPS) and PLA reactively blended by adding a chemical modifier and peroxide radicals to obtain PLA-*g*-TPS blend by twin screw extrusion and later processed into films.

Mayekar et al., ACS Sustainable Chem. Eng. 2023, 11, 26, 9729−9737
https://doi.org/10.1021/acssuschemeng.3c01676

Sustainable Materials - Foods

A few facts to set the stage….

We will have to feed ~**2 billion more people by 2050:**

This will require →

70% more food

30% more water

50% more energy

Our current agriculture system is not equipped to meet these demands

USDA

A few more facts to set the stage….

In the United States, the number of farms peaked in 1935 at **7 million**

→ in 2022 we have **2 million** (~71% loss)

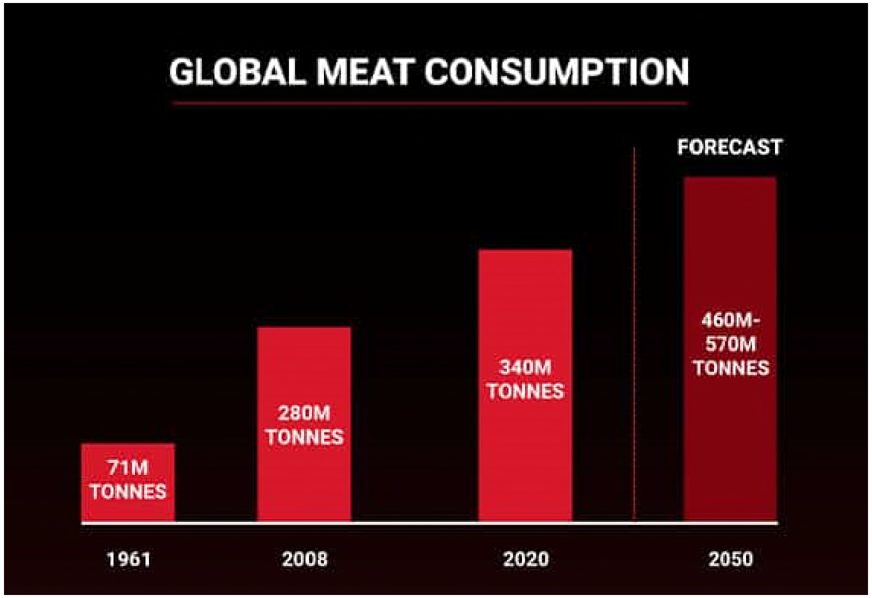
→ Since 1980, 440,000 farms lost, >141 million acres of farmland lost

Today: 87% of farmers rely on non-farm sources of income to feed their families [50% of these farmers are in the red]

USDA

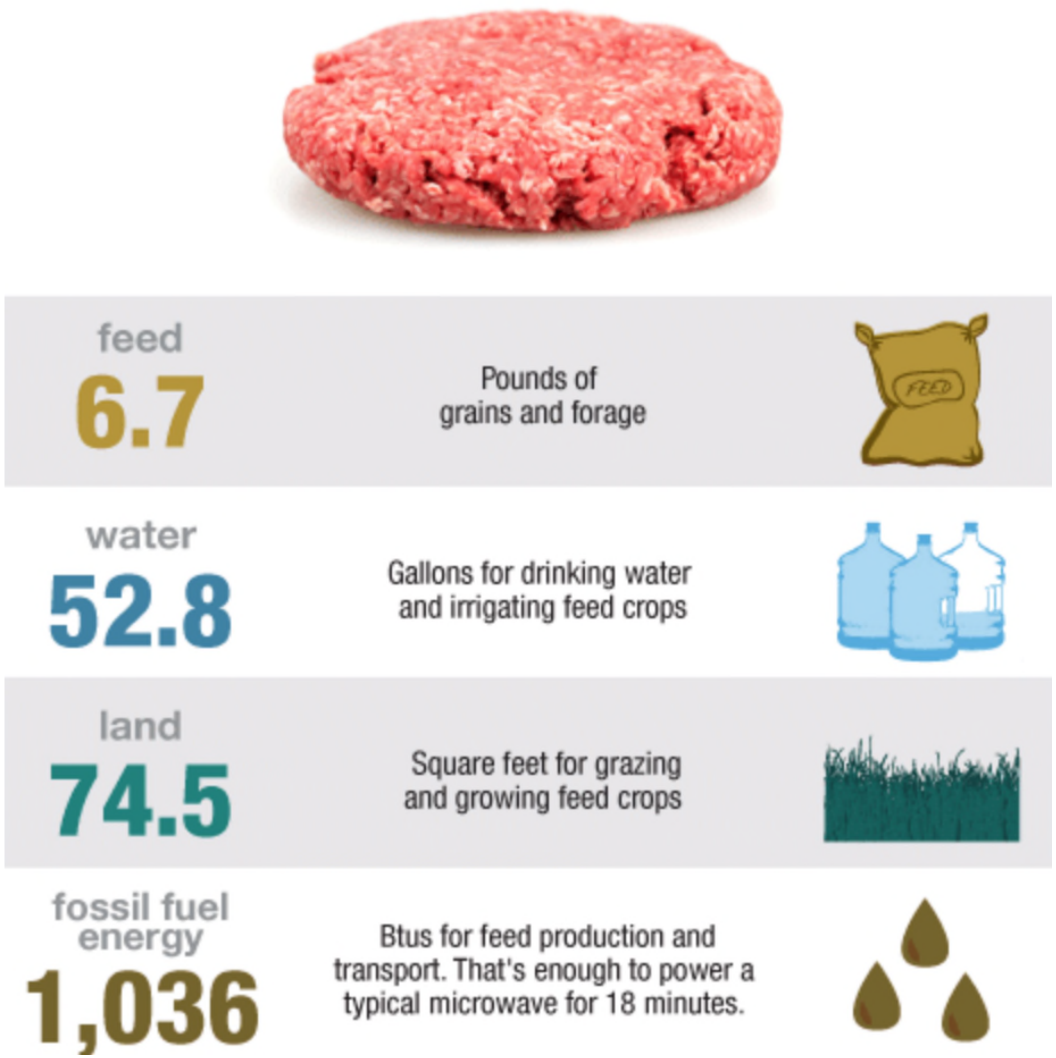
The Growing Demand for Meat:

- **Applicable worldwide**
- **Increasing economic status = increase in meat consumption**
- **Consumer campaigns have failed to reduce this growth**



→ **focus on proteins in foods - meats**

A model of inefficiency:



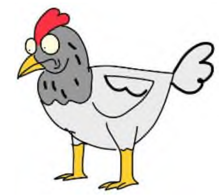
resources required to produce a *quarter-pound of beef*

Capper, J. Animal Science, 2011

Future Foods – Cellular Agriculture

[growing food without the use of animals]



Cellular Agriculture = tissue engineering food or pharming without animals

Kaplan Lab: david.kaplan@tufts.edu

Why Do We Need Alternative Foods?

Population growth - ~10 billion people by 2050

Sustainability - environmental resources, land & water use, green house gases….

Food safety, security, public health – growing concern

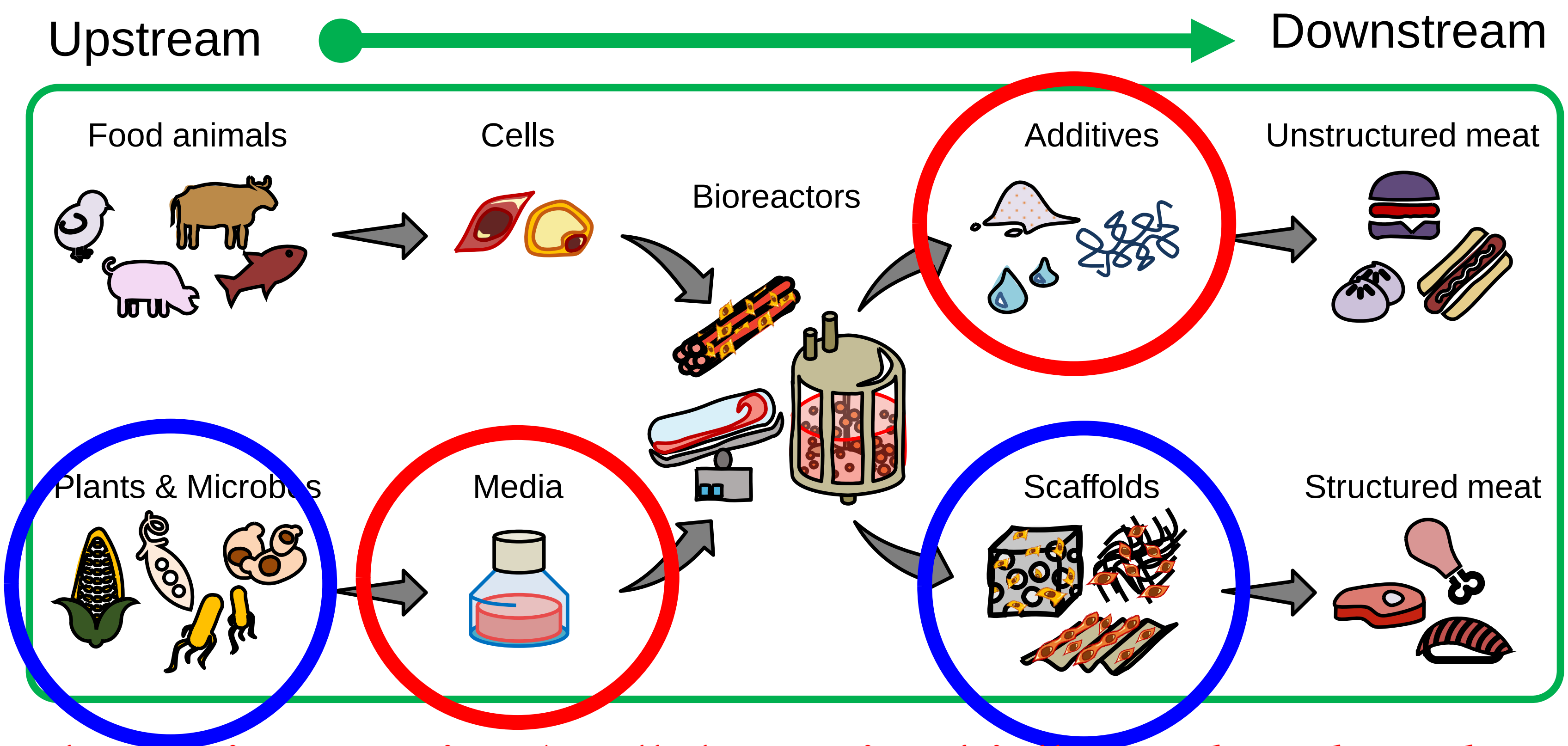
Animal welfare – quality, health and safety

Food equity – nutritional, scalable systems, local resources, distributed or central networks

Tufts UNIVERSITY

Future Foods - Cellular Agriculture

Integrated plants, alternative proteins & cellular production - process



alternative proteins (acellular - microbially produced products)

plant-derived materials (acellular - plant products)

cellular agriculture - tissue engineering (cells as key ingredients)

Sustainable Materials - Foods

Tufts UNIVERSITY

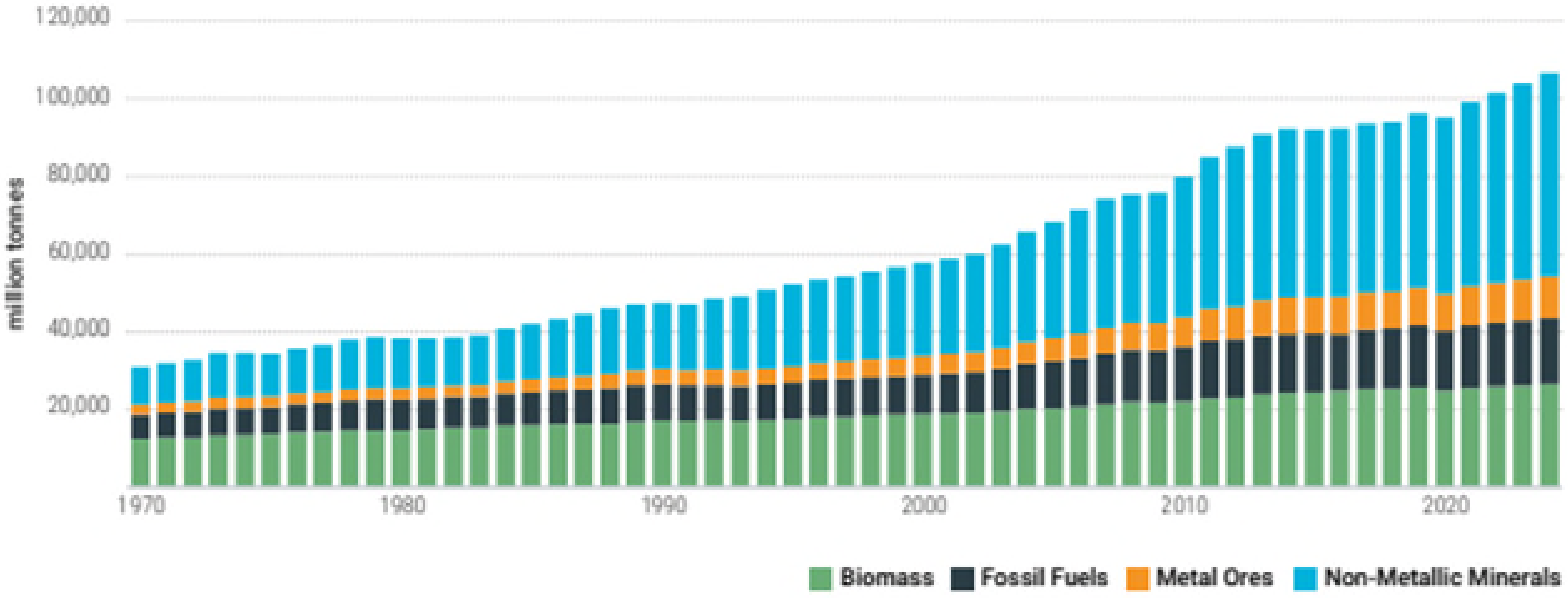
Sustainable Materials

Introduction

- Definitions
- Course coverage – topics
- Overview of materials, examples
- Context – why now?
- Trends: historical context: past – present- future
- What can you do to make an impact ?
- What is the future if we are successful or not?
- News and views – hot topics

Resource utilization – material sources per last ~50+ years

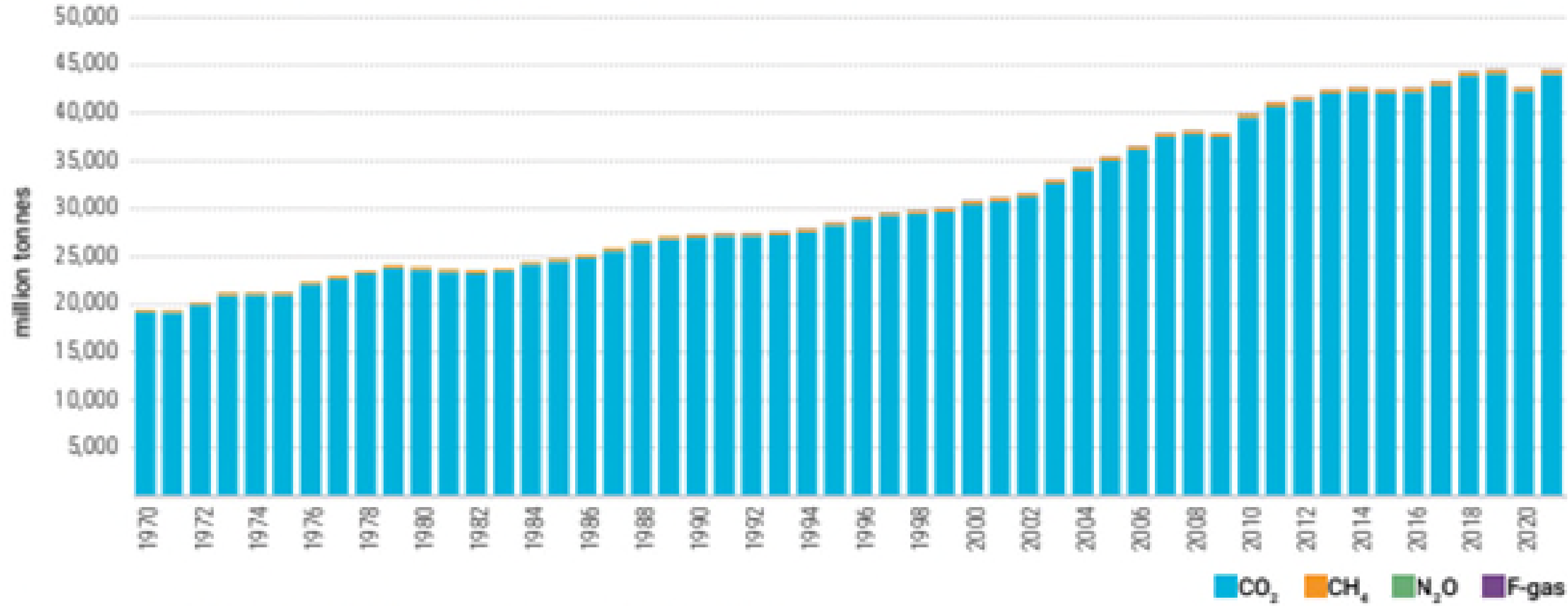
Figure 2.9: **Global material extraction, four main material categories, 1970 – 2024, million tonnes.**



Source: Global Material Flows Database (UNEP 2023a).

Emissions – per last ~50+ years

Figure 2.21: **Global GHG emissions by gas, 1970 – 2021, million tonnes.**



Source: Emissions Database for Global Atmospheric Research (EDGAR) 2023.

Sustainable Materials

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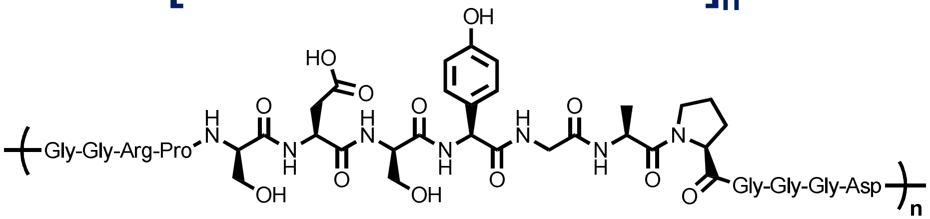
take our class ☺
get involved
learn and educate
buy/use what you believe in
help in the research
etc.
Kaplan Lab
Tufts
UNIVERSITY

Fibrous Proteins in Nature - tough materials & building blocks

Resilin

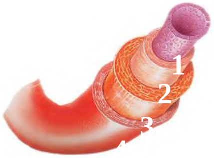
- Elastomer
- Energy storage
- Tyrosine cross-links, controllable

$[GGRPSDSYGAPGGGN]_n$



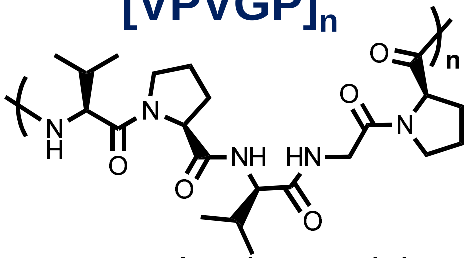
Qin et al., *Nature Comm.*, 2012

Elastin



- Elastomer
- Inverse temperature transition, controllable (temp, pH, etc.)

$[VPVGP]_n$

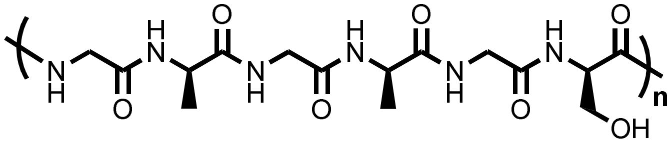


Hu et al., *Biomaterials*, 2011

Silks

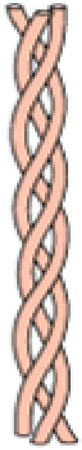
- Tough material
- Physical cross-links

$[GAGAGS]_n$

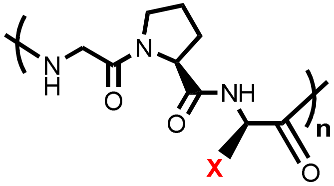


Omenetto and Kaplan, *Science*, 2010

Collagens



- Structural hierarchy
- Cell signaling
- Thermal transitions



$[GPX]_n$

An et al., *Biomaterials*, 2012

Stabilization & Recovery of Bioactive Molecules in Silk
Silk coatings for preservation

no coating

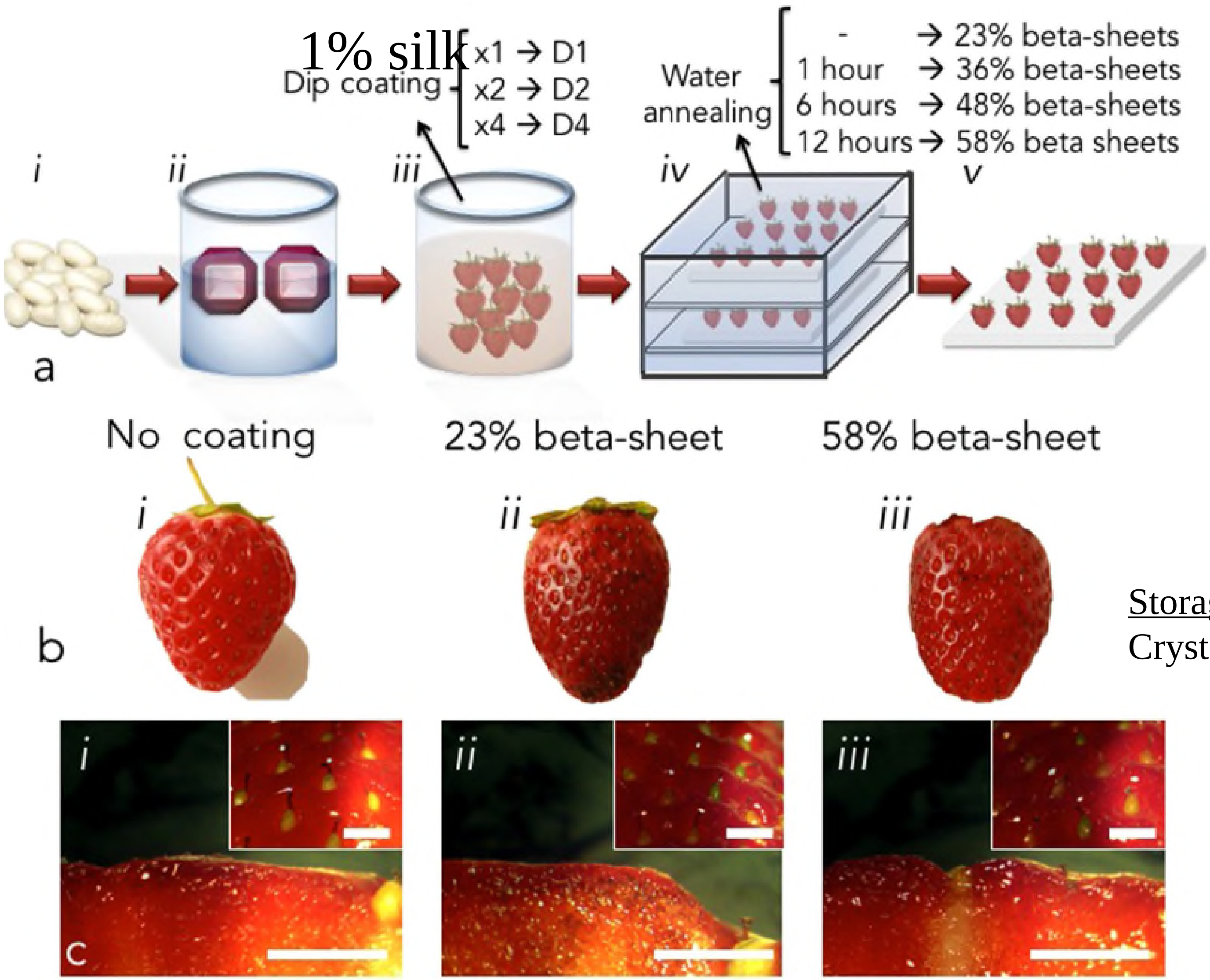
coating

one week at room temperature

Marelli et al., ***Scientific Reports***, 2016

Stabilization & Recovery of Bioactive Molecules in Silk

Silk coatings for preservation

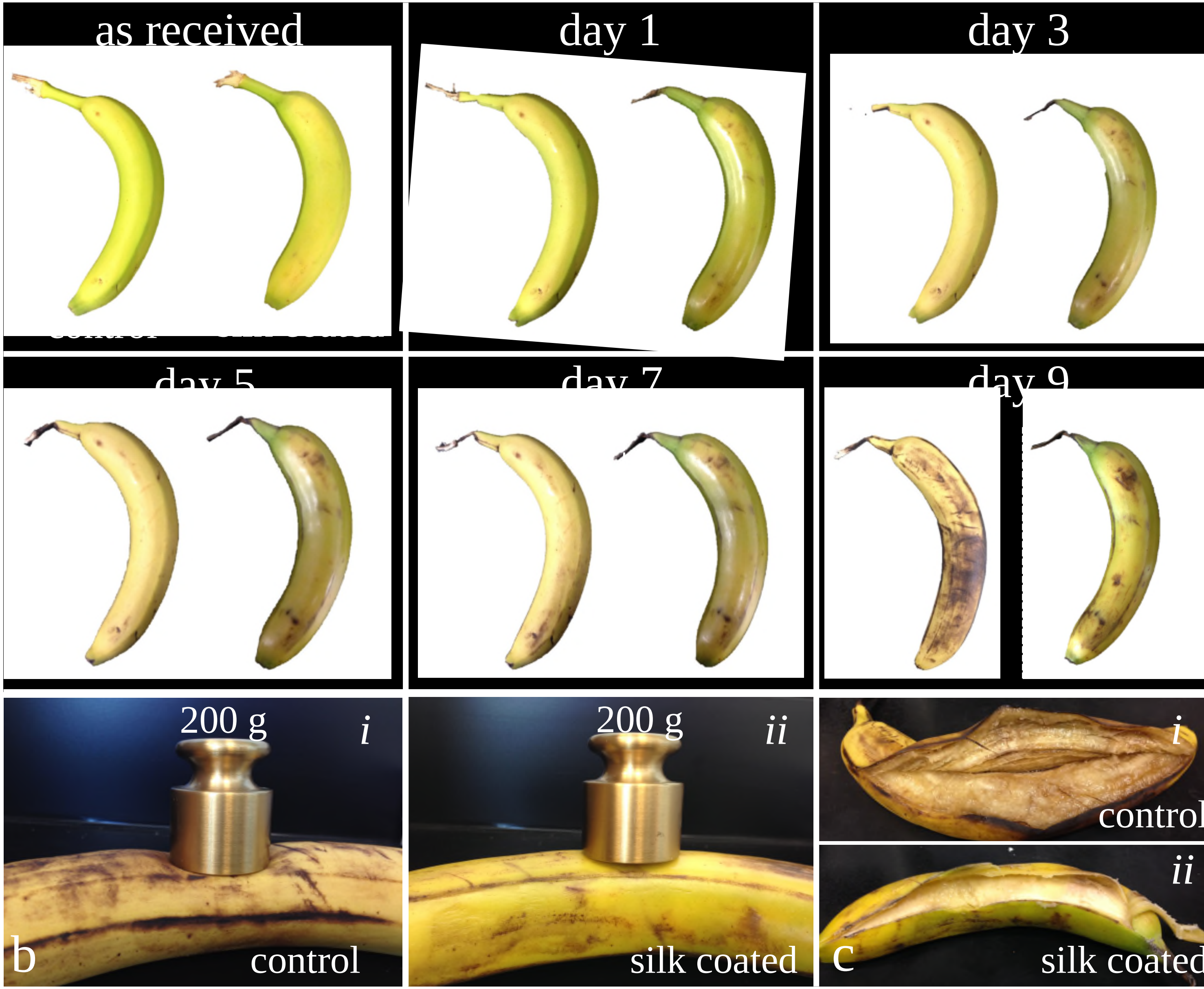


Scale bars = 2 mm

Storage: 22^{0}C, 38% RH
Crystal violet staining

Stabilization & Recovery of Bioactive Molecules in Silk

Silk coatings for preservation



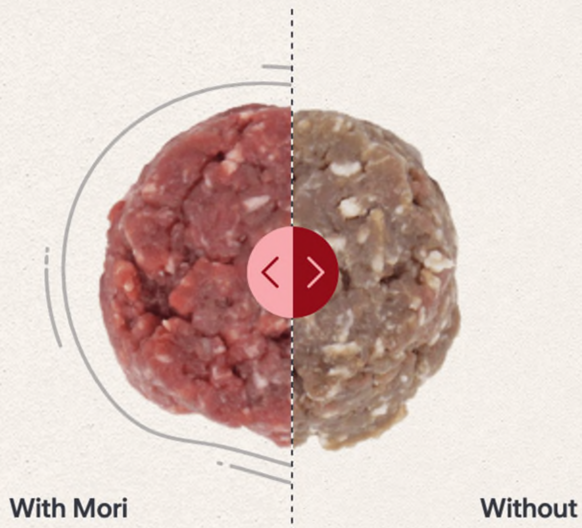
mori

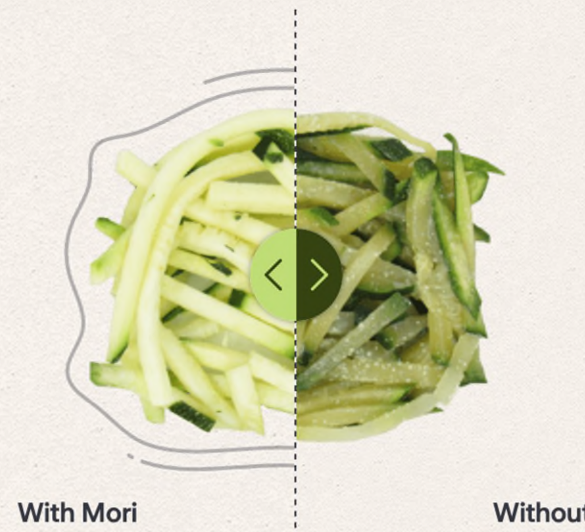
https://www.mori.com/

One-third of food gets lost or wasted every year.

“That’s bad for people who don’t have enough to eat, bad for farmers, and bad for the environment. [Mori] is working on protective skins that keep food fresh longer.”

Bill Gates





Printing Underwater – *functionalized architectures*

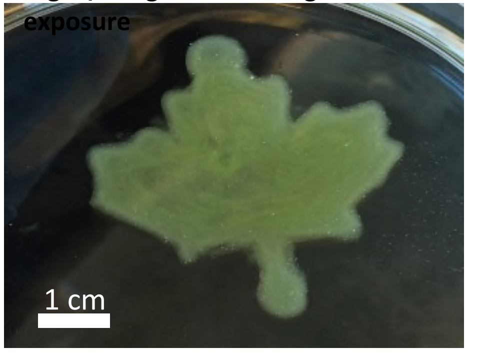
+

Green Algae - Functionality

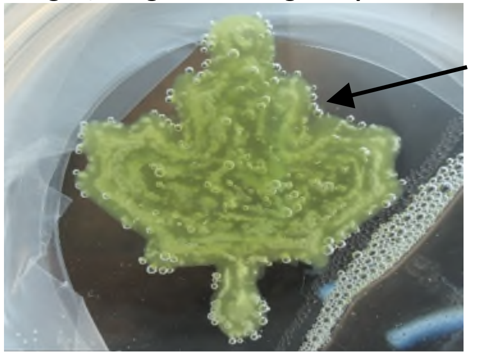
=

Living cell-enabled functional architectures (photosynthesis):

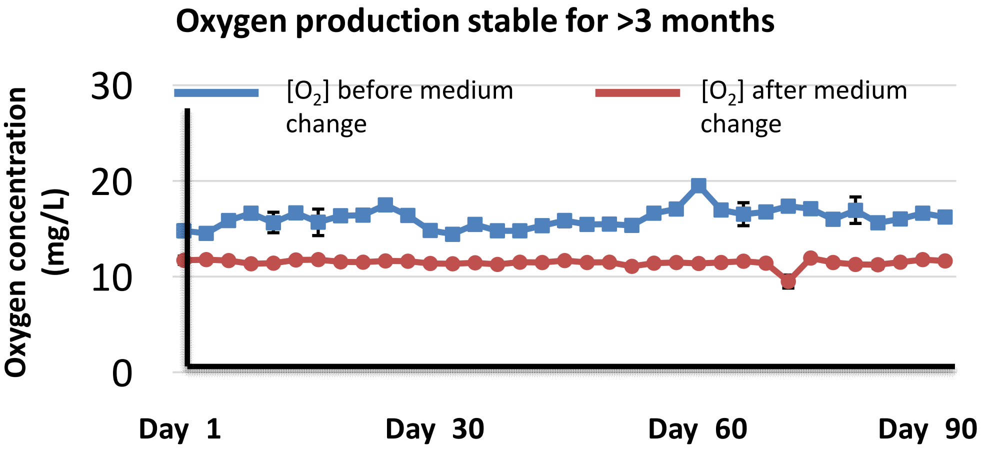
Algae/silk gel – before light exposure



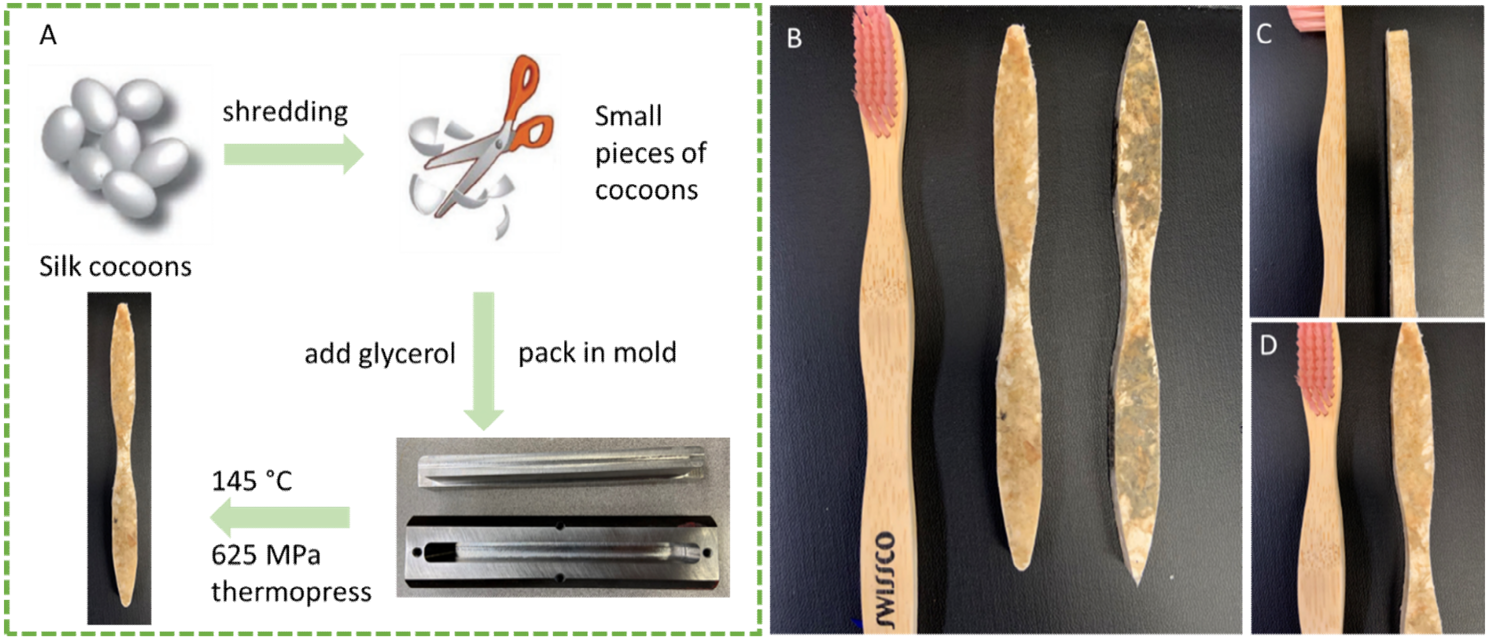
Algae/silk gel – after light exposure



Oxygen bubbles

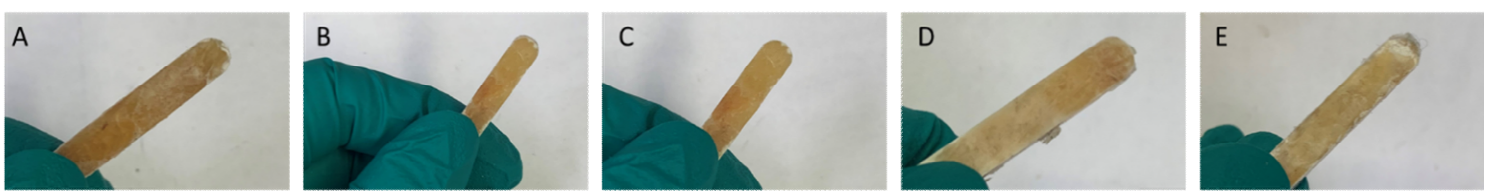


Thermoplastic molding of silk protein composite plastic toothbrush handles with on-demand degradability



Shelf stable

on-demand degradation: sequestered enzyme



20% cellulose | 50% cellulose | 10% HAP | 20% HAP | 10% chitosan

Composites made from one-step solid mixing of silk cocoons. Examples include with (A) 20% cellulose, (B) 50% cellulose, (C), 10% HAP, (D), 20% HAP, and (E) 10% chitosan.

Sustainable Materials

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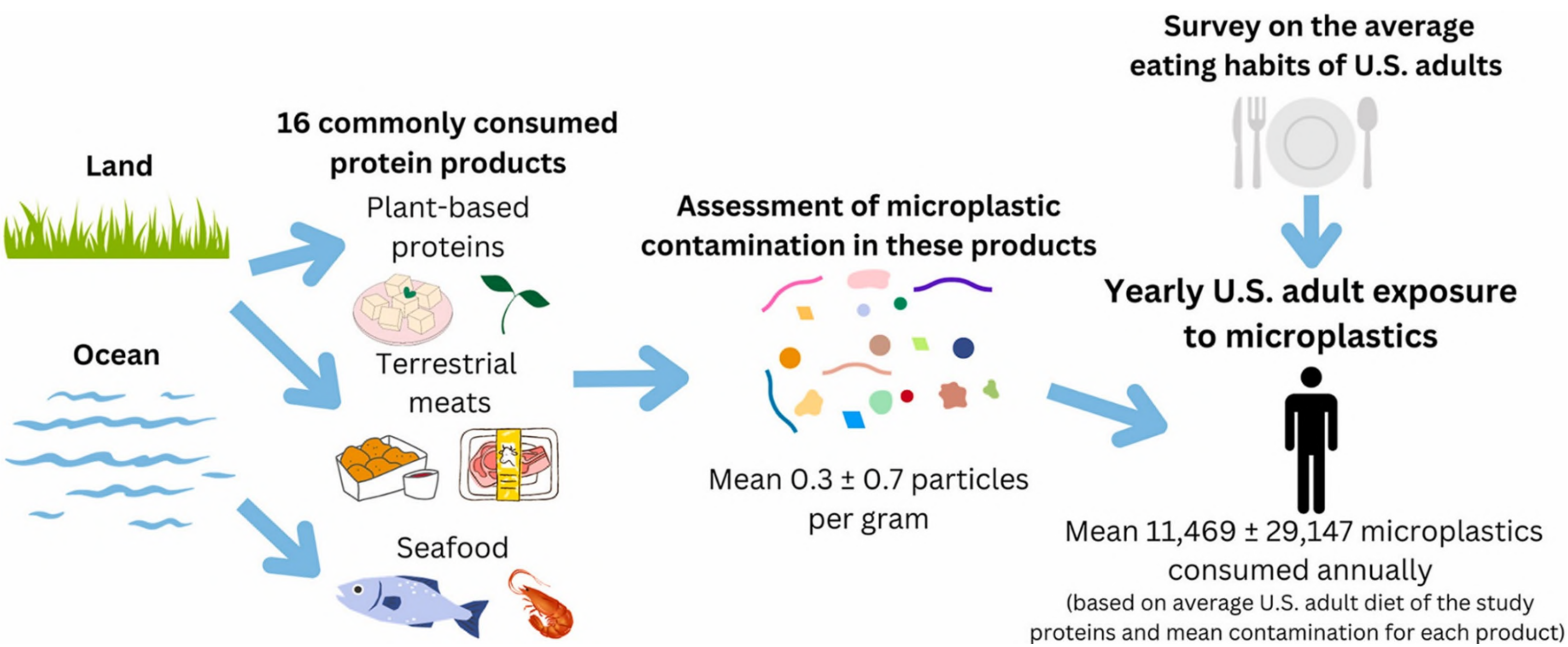
Exposure of U.S. adults to microplastics from commonly-consumed proteins



- microplastic contamination ≥45 µm in 16 U.S. protein products
- highly-processed products contained the most microplastics per gram
- microplastic contamination did not differ between brands or store types
- mean U.S. adult exposure >11,000 microplastics/year, maximum ~3.8 million

Milne et al., Environmental Pollution, Volume 343, 15 February 2024, 123233
https://doi.org/10.1016/j.envpol.2023.123233

Sustainability in Retail – Stella McCartney

Project Name- Stella McCartney
Location – London, New York, Los Angeles, Tokyo, Hong Kong, Paris, Milan and Shanghai

- Use of eco-friendly materials including recycled polyester, organic cotton, and regenerated cashmere.

- Wood used within our stores and offices are only FSC certified.

- Packaging and paper is either FSC certified or from recycled sources.

- Use of at least 50% post-consumer waste paper in stores, leading to a zero waste business.

- Using LED Energy efficient lighting.

- In the UK, all stores and offices are powered by wind energy.

- The brand has open three LEED certified stores in US, Las Vegas and Beijing, equipped with solar panels and energy efficient air-conditioning.

- .Furniture are locally bought or auctioned when ever possible.

Sustainability in Retail – Starbucks

Project Name- Starbucks
Location – Standard Design across

- These green stores use LED lighting.
- Use of recycled flooring tiles and wood products that are certified by the Forest Stewardship council.
- 25% more energy efficient and 30% more water efficient stores.
- Countries with solar and wind projects, the stores are run on 100% renewable energy.

Sustainability in Retail – Reformation

Project Name- Reformation
Location –Los Angeles

• Products maintain environmental footprint by maintaining the pounds of carbon dioxide emitted and gallons of water we use, and pounds of waste we generate.

• Use of 100% wind power suppliers for electricity and use LED lighting and Energy Star-rated appliances in our offices.

• Recycle, compost organic wastes, and recycle or donate our textile scraps.

• E-commerce uses about 30% less energy than traditional retail.

• Use recycled paper hangers

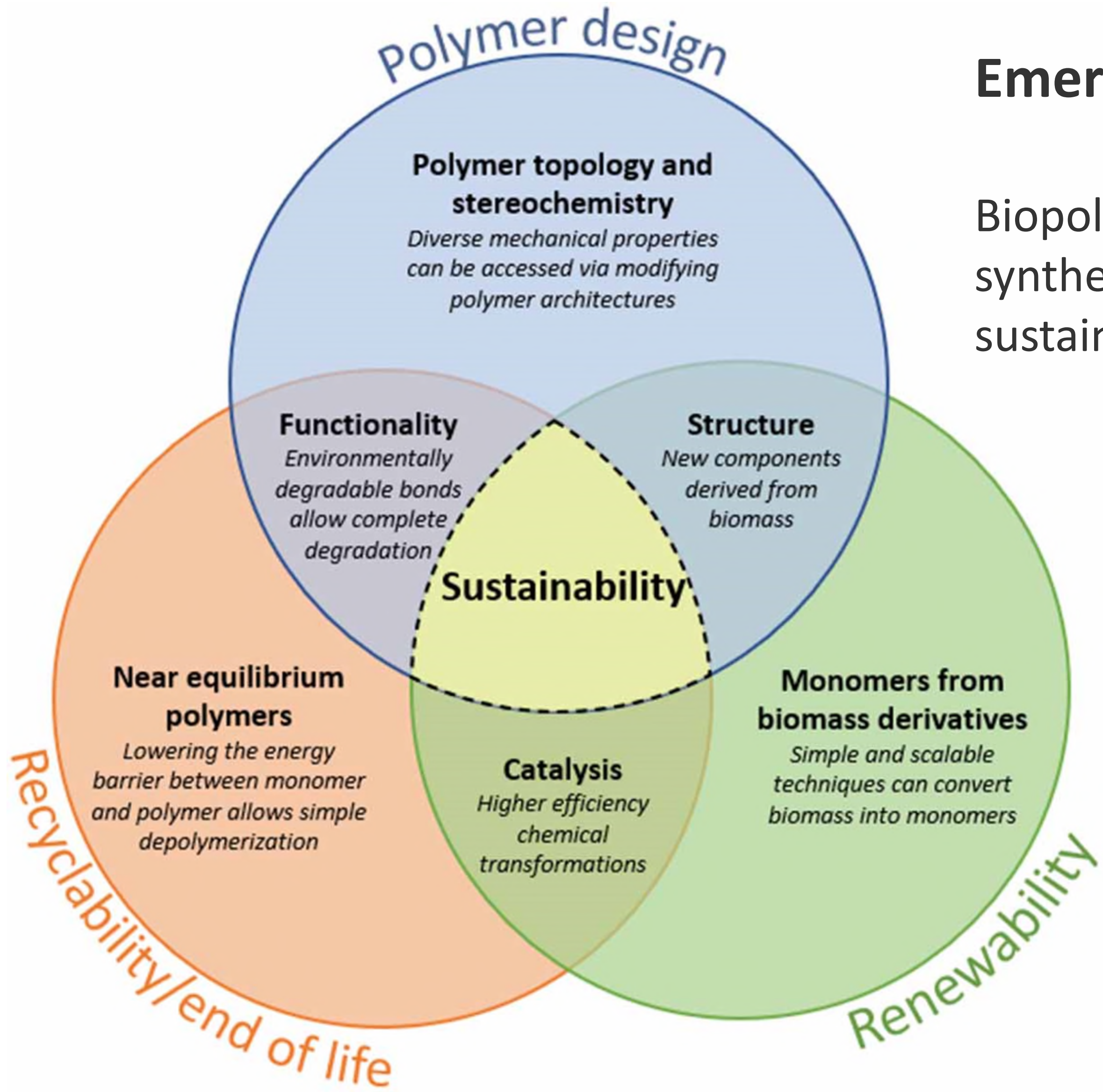
• Use of LED fixtures, rammed earth, recycled fabric insulation in store.

• Stores designed following strategies that improve energy savings, water efficiency, resource stewardship, and reducing CO2 emissions
,

Sustainability in Retail - IKEA

Project Name- Ikea
Location –Hyderabad
Architect –Marcus Engman

- Textiles are made from 100 percent better cotton.
- All lights are 100 percent LED.
- 77% wood come from sustainable sources.
- 100% home deliveries with electric vehicles (EVs) by 2025.
- As of today 20 percent of home deliveries in India are already done with EVs.
- IKEA has collaborated with different stakeholders to turn rice straw, a rice harvesting residue that is traditionally burnt and contributes heavily to air pollution in North India into a renewable material source for making IKEA products.
- No selling of single use plastic products.



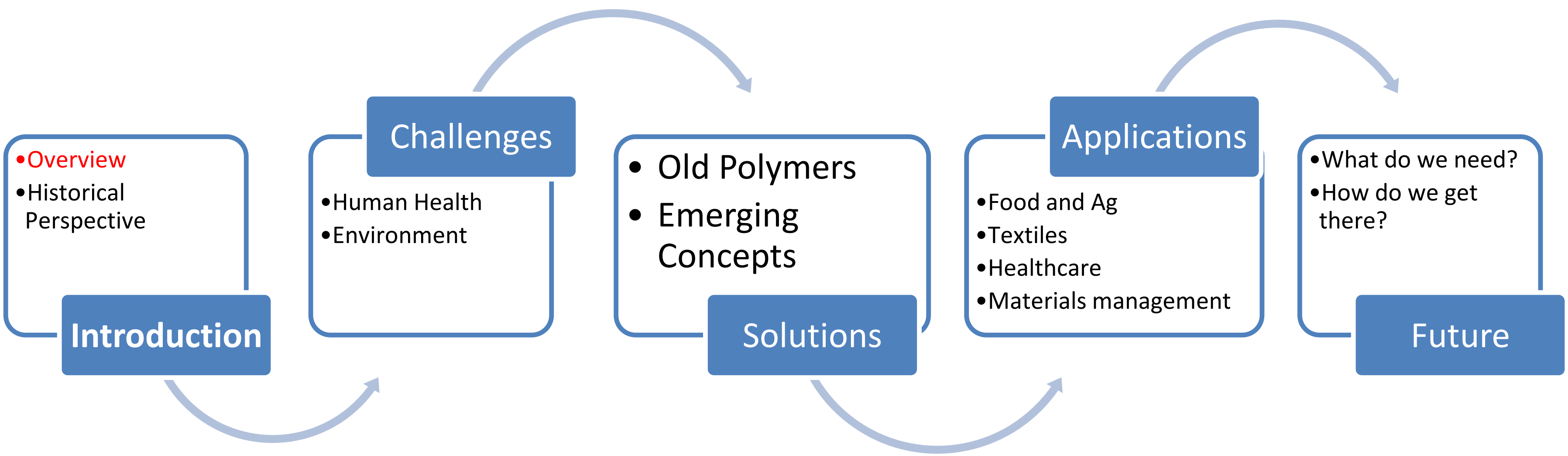
Emerging solutions

Biopolymer design and synthesis to improve sustainability

Solutions ?

Thank you !!

Course Overview



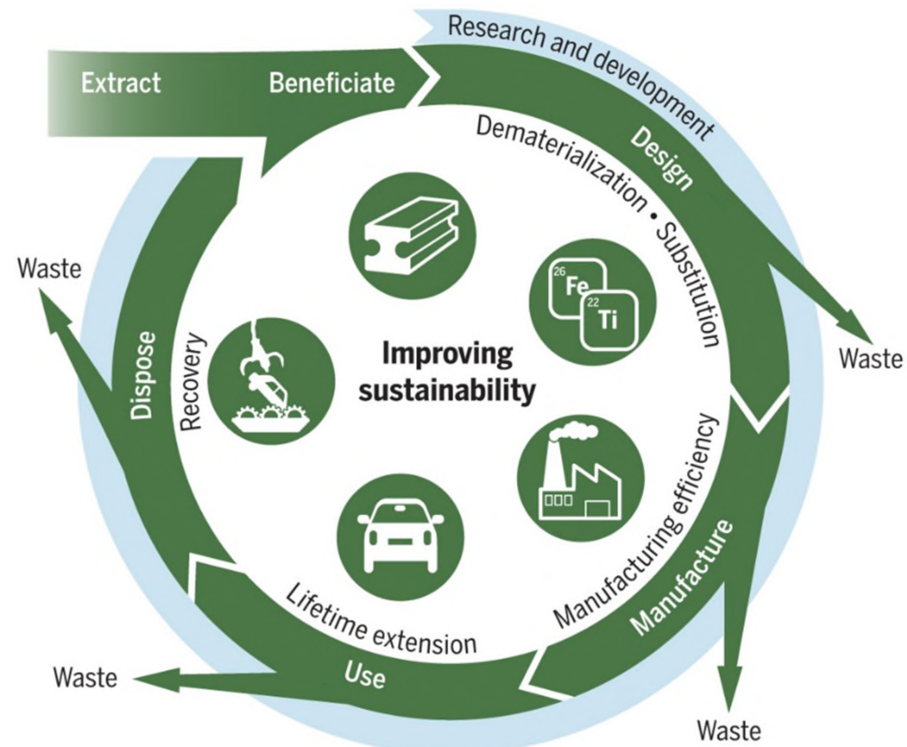
Introduction Lecture – **Additional Slides**

What are sustainable materials?

As per the Environmental Protection Agency - sustainability “creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations.”

sustainability concerns the environment, as well as factoring in impact on social and economic conditions into the future

Sustainable materials are produced from raw materials that are renewable and sourced in a manner that does not negatively impact the environment or decrease its supply permanently. This often entails replacing what has been used at a rate equal to or higher than its consumption so that future generations will have sufficient access to the resources.



Characteristics of Sustainable Materials

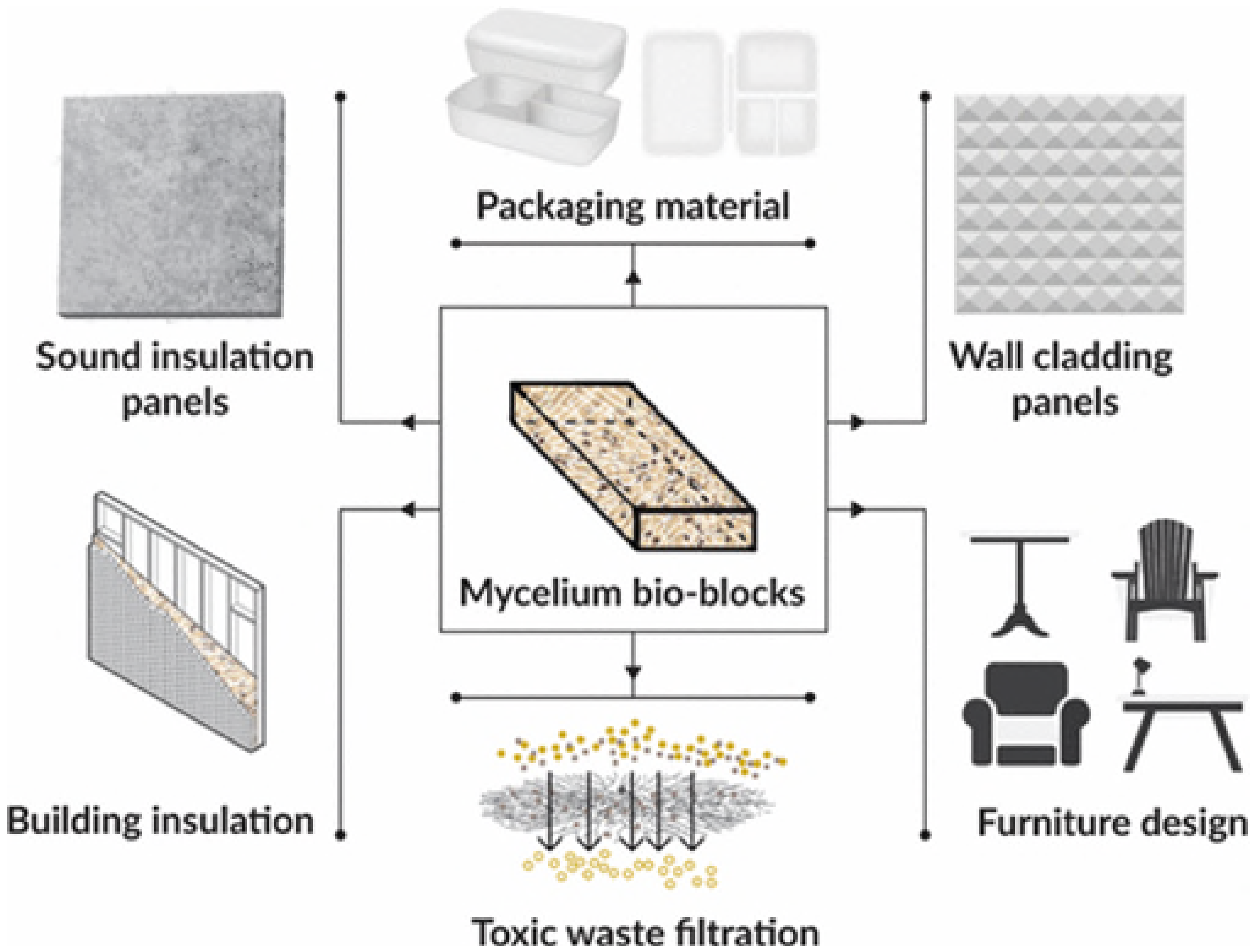
RENEWABLE
products should be made from renewable sources such as plant-based fibers or recyclable products like plastic bottles or aluminum cans

NON-TOXIC
products should be non-toxic and contain no hazardous substances

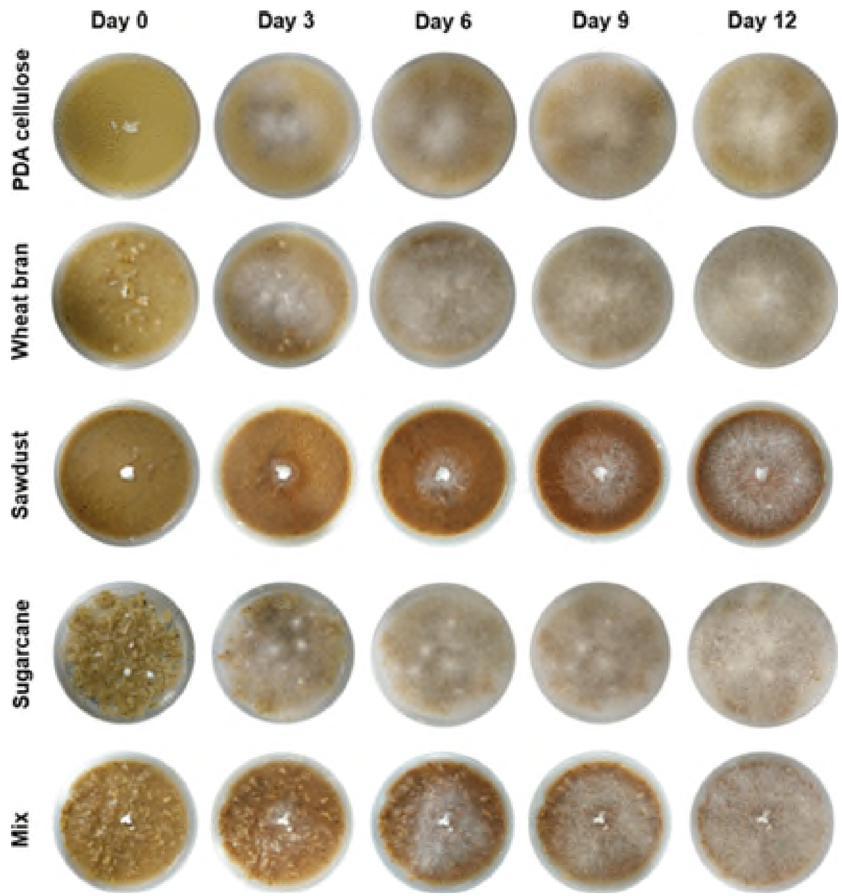
DURABLE
should be durable enough to stand up to wear and tear without needing frequent repairs or replacements

MINIMAL MAINTENANCE
require little maintenance over their lifetime

Fungal Mycelia for Construction and Device Design – sustainable source



Fungal Mycelia for Construction and Device Design – growth substrates

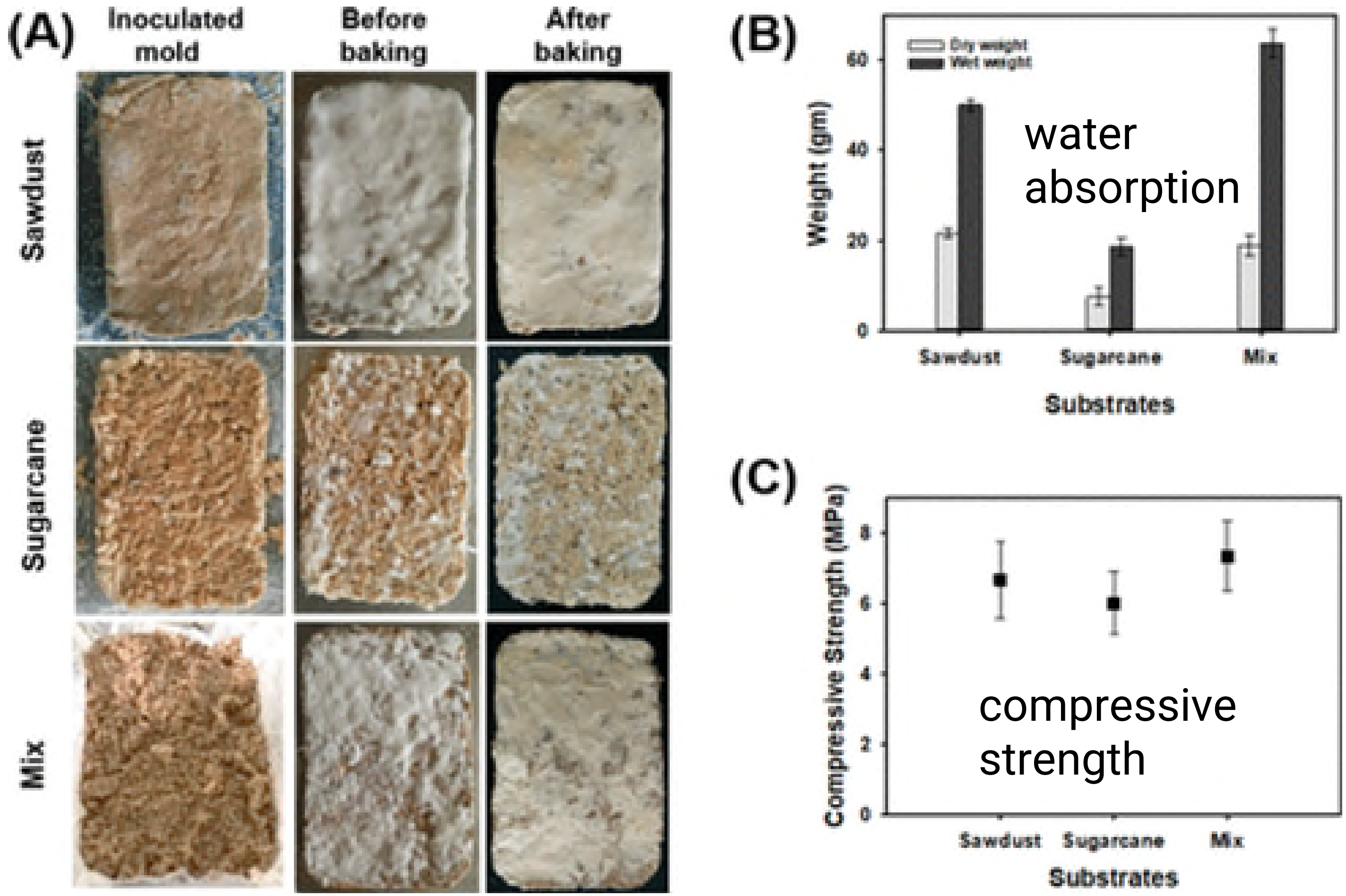


substrates	growth length (cm)	growth period (days)	growth rate (cm/day)
PDA cellulose	9	8	1.125 ± 0.1
wheat bran	9	6	1.5 ± 0.2
sawdust	9	12	0.66 ± 0.1
sugarcane	9	6	1.5 ± 0.2
mix	9	12	0.75 ± 0.2

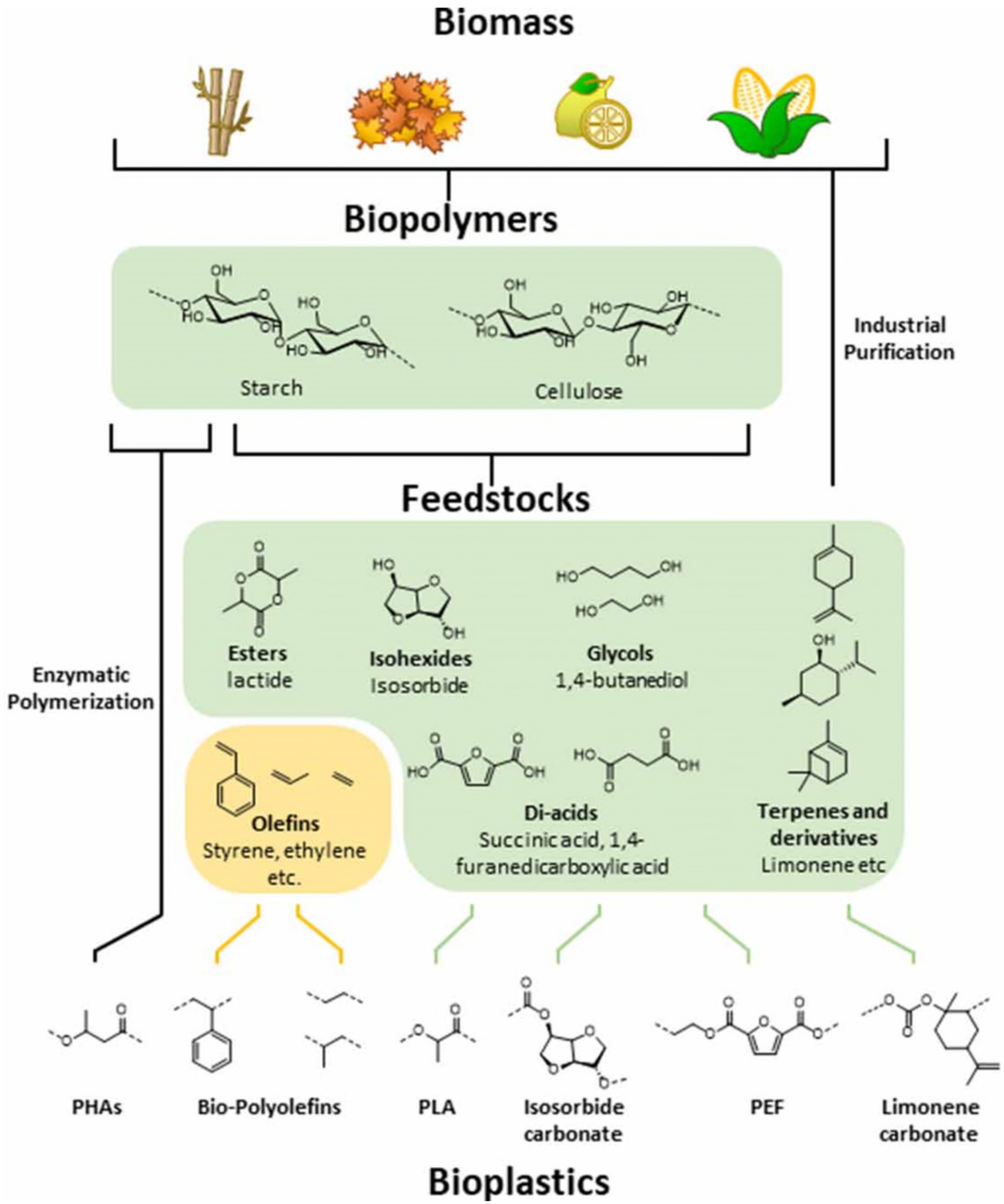
Growth Rate of Mycelium on Different Waste Substrates

Growth of *P. ostreatus* mushroom mycelium on various substrates such as polydopamine (PDA) cellulose, wheat bran, sawdust, sugarcane, and their mix (mixture of wheat bran, sugarcane, and sawdust in equal proportions)

mycelium blocks from agricultural waste substrates



(A) top view of bioblocks: (left) bioblocks taken out of mold just after inoculation in different substrates (e.g., sawdust, sugarcane, and their mix); (middle) before baking; (right) after baking



bioplastics (BPs) production

including synthetic polymers with novel composition from biomass feedstocks

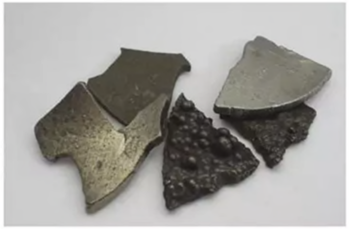
Sustainable Materials - Naturally Occurring - Metal

Why is Metal a Sustainable Material?

- No waste generation
- Be sourced locally
- Long life – provides strength and durability, does not get damaged easily
- Requires less energy for processing
- 100% Repairable, recyclable and re-purposing properties, infinite times

Examples of Sustainable Indian Metal

Copper



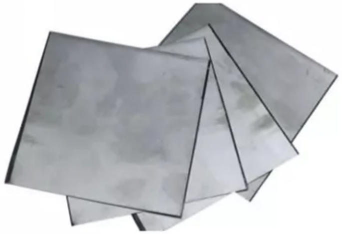
Cobalt

Bauxite

Bronze

Silver

Iron



Zinc

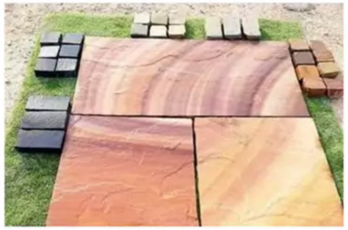
Sustainable Materials - Naturally Occurring - Stone

Why is Stone a Sustainable Material?

- No harmful chemicals or toxins
- Be sourced locally
- Long life – provides strength and durability and is maintenance free
- Recyclable and re-purposing properties
- Improves energy efficiency

Examples of Sustainable Indian Stone


Lime Stone


Sandstone


Laterite


Marble


Granite


Basalt


Quartzite

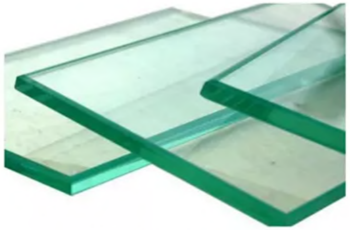

Slate

Sustainable Materials – Recycle & Composite - Silica

Why is Glass a Sustainable Material?

- Be sourced locally.
- Long life – provides strength and durability and is maintenance free.
- Recyclable and re-purposing properties.
- Glass can reflect and absorb solar energy.
- Requires less energy for processing.

Examples of Sustainable Indian Glass



Toughened Glass

Annealed Glass

Blown Glass

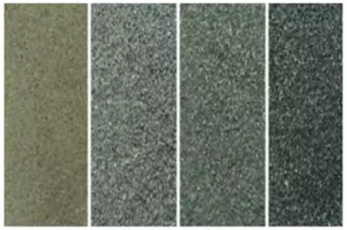
Ceramic

Porcelain

Patterned Glass

Coloured Glass

Textured Glass



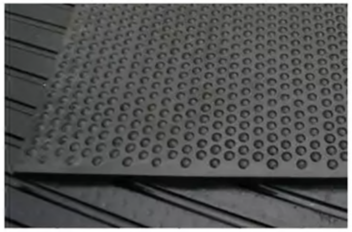
Quartz Slab

Sustainable Materials – Recycle & Composite - Latex

Why is Rubber a Sustainable Material?

- Be sourced locally
- Long life – provides strength and durability and is maintenance free
- Recyclable and re-purposing properties
- Improves energy efficiency
- Can be cultured easily
- Can be Processed as per application

Examples of Sustainable Indian Rubber



Hard Rubber Mats

Sound Proofing Panels

Silicone

Soft Flooring Tiles

Roofing Sheets

Paint

Sustainable Materials – Recycle and Composite – Wood Chips and Dust

Why is Wood Chips and Dust Composite a Sustainable Material?

- By-product of another industry
- Be sourced locally
- 100% Biodegradable
- Requires less energy for processing
- Grows naturally, and modern forestry standards harvest wood in a sustainable way to preserve the environment of the forest
- Organic or recycled composites used

Examples of Sustainable Indian Wood Chips and Dust Composite


Particle Board


Chip Board


Ply Boards

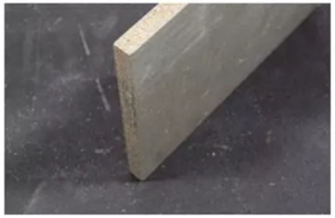

Ply Boards


Wppd Pulp Moulding


Block Boards


Wood Polymer Composite Decking Boards


Coloured Wood Fibre Board

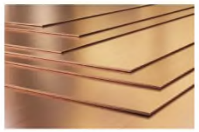

Wood Fibre Cement Board


Paper

Other Sustainable Materials

Metal Alloys


Brass


Copper


Steel


Aluminium


Bronze


Galvanized Iron

Stone Chips, Dust


Stone veneer


Mosaic


Terrazzo


Caststone

Crete Composites


Woodcrete


Papercrete


Stonecrete


Fibrecrete Woodwool


Resin Concrete


Foamconcrete


Ferrouscrete Gyp

Recycled Fabric, Plastic, E-Waste


Recycled Fabric

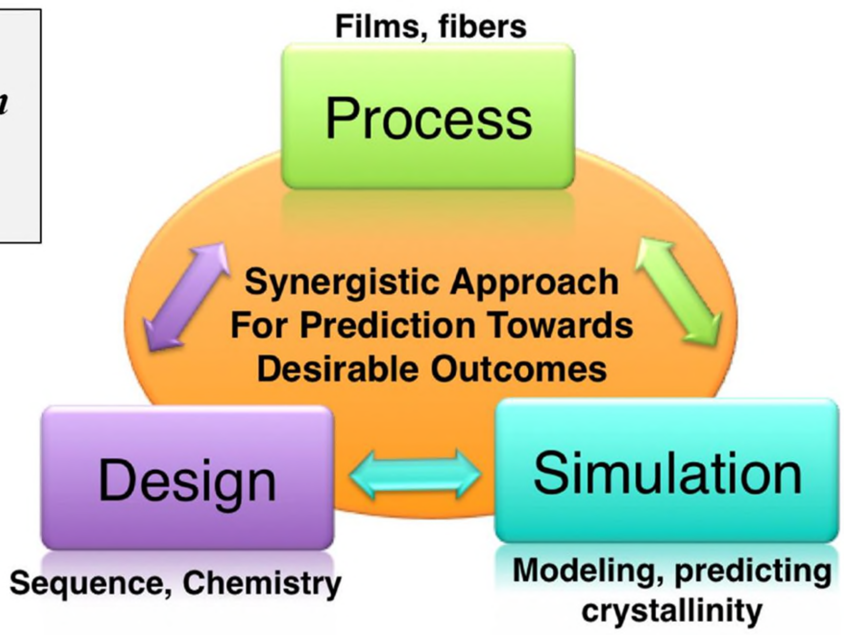

Recycled Fabric


Recycled Concrete


E-plastic

Challenge – expanded set of modeling tools to empower biopolymer discovery

Models to Predict Protein Biomaterial Performance



<u>GOAL</u>: **predictive assessments** of for protein biomaterials
→ **Reduce trial-and-error approach** with a **more rational approach**
→ **bottom-up multiscale modeling** to guide preparation of materials

Needs: high MW polymer systems
dense biopolymer matrices
other components (plasticizers, metals, second polymers…)