Stellenbosch
UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT

Engineering
EyobuNjineli
Ingenieurswese

Integrated Biorefineries for Advancing a Circular Bioeconomy

Prof Annie Chimphango (Chemical Engineering Dept)

Faculty of Engineering

Industry Showcase 2025

Contact: achimpha@sun.ac.za

Integrated Biorefineries for Advancing a Circular Bioeconomy

Outline

Introduction: Research Group and Research Areas

Bio-Resource Engineering Group

Biomass processing:
- Multi-feedstock/**Multiproduct Biorefineries**
- Green processing technologies

Bioproducts & Biomaterials
- Biopolymers; biofilms, biochemicals and biofuels
- Smart packaging and coatings
- Hydrogels, aerogels, and cryogels
- Functional micro-/nano-biocomposites

Bioprocess engineering:
- Enzyme production and application
- Biomaterials modification and application

Sustainable systems:
- Systems approach; Integrated & circular systems, Techno-economic & sustainability analysis

Introduction: Research Focus

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

Research Focus

- Convert or transform agricultural and forestry residues into high-value products
- Develop sustainable systems and processing technologies to advance material circularity
- Scale-up and optimize the conversion processes
- Innovative applications

Introduction: Integrated Biorefineries for Advancing a Circular Bioeconomy

Research Governing Principles

RESOURCES EFFICIENCY

MINIMIZE WASTE/ PROMOTION MATERIAL CIRCULARITY

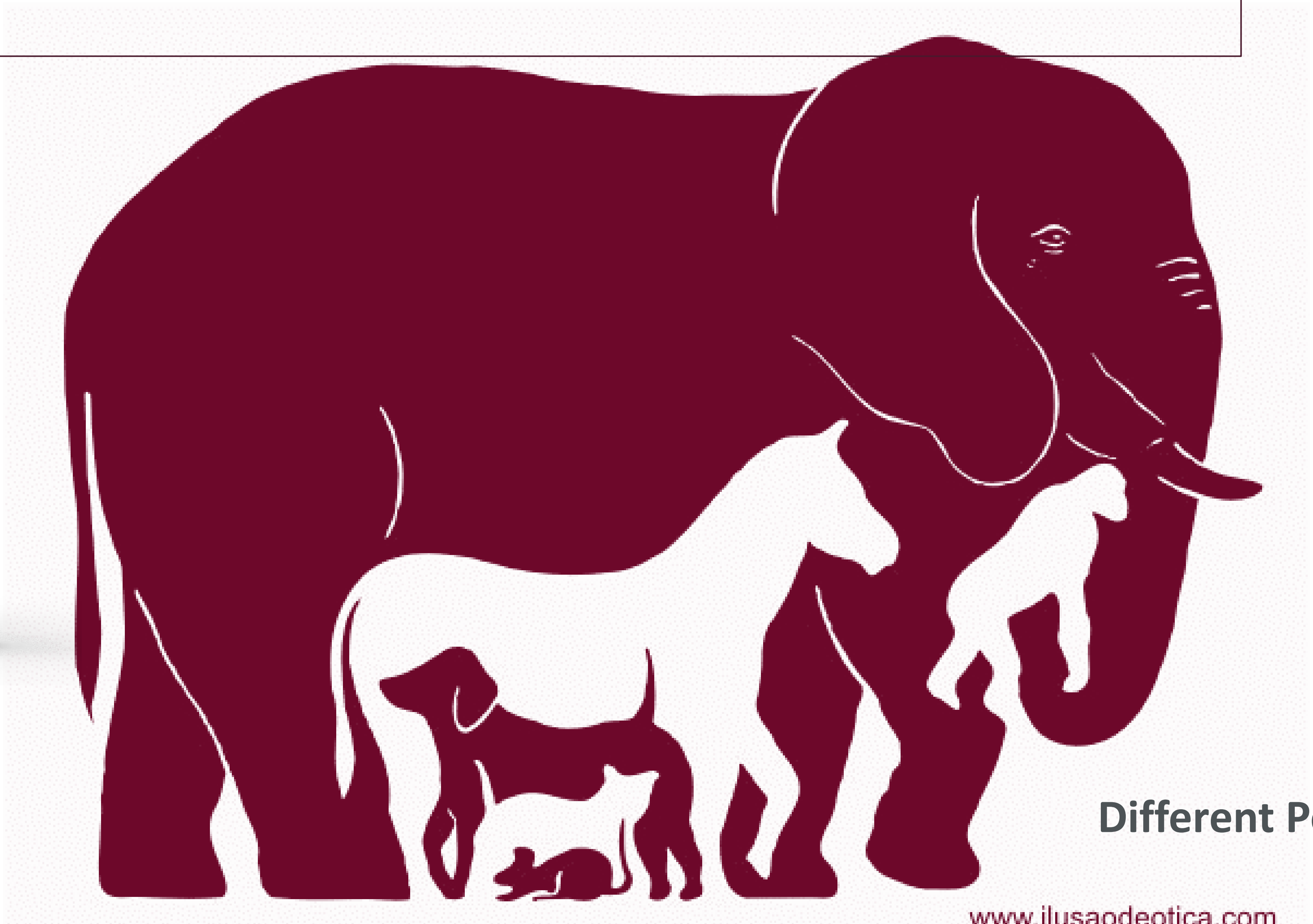
GREEN PRODUCTS & PROCESSES

RENEWABLE RESOURCES

POLLUTION PREVENTION

A Circular Bioeconomy

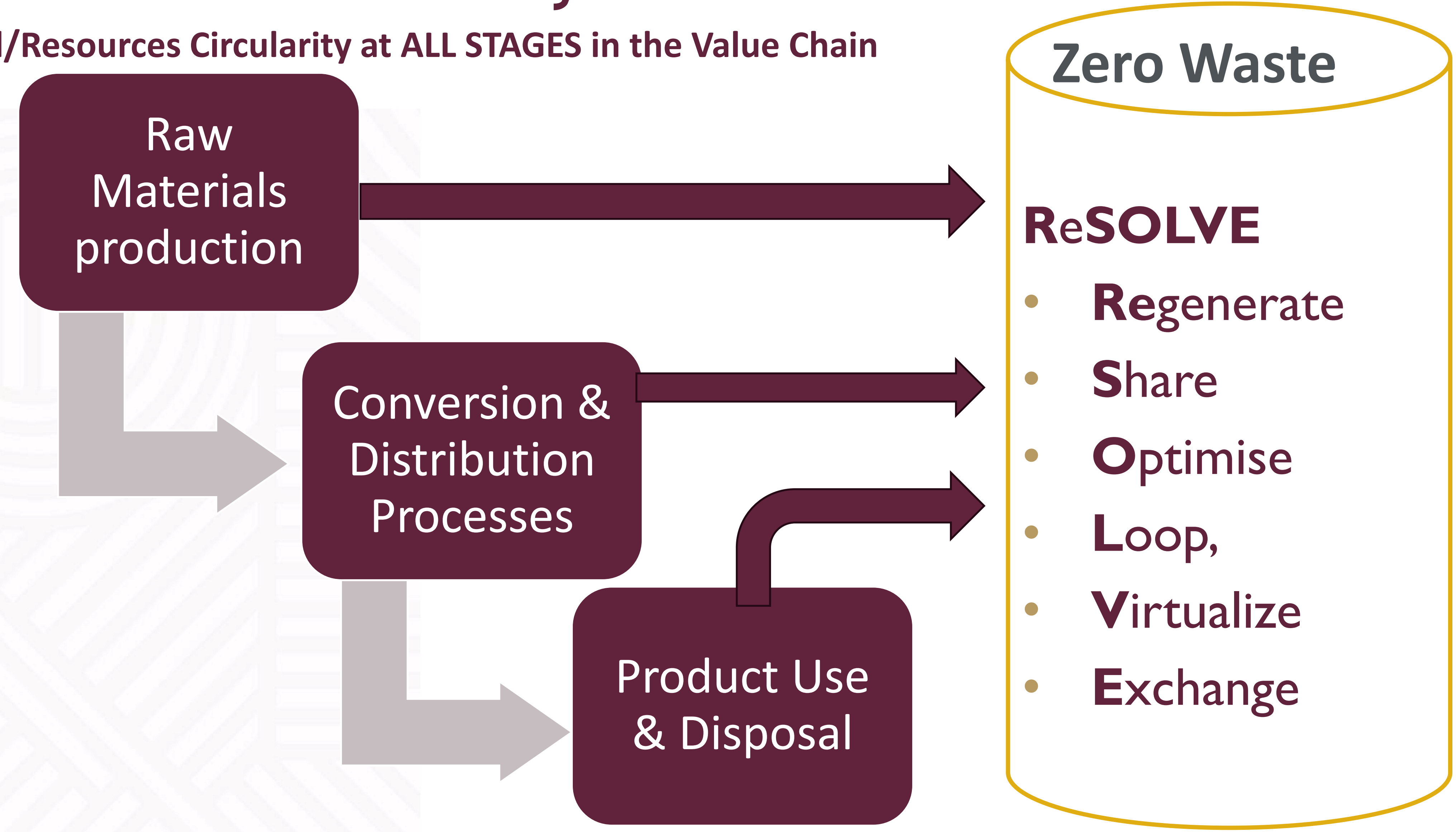
What is a Circular Bioeconomy



Different Perspectives

A Circular Bioeconomy

Material/Resources Circularity at ALL STAGES in the Value Chain



A Framework developed by the Ellen MacArthur Foundation to guide the transition towards circularity

Integrated Biorefineries: Biomass Valorization

Bagasse

Woodchips

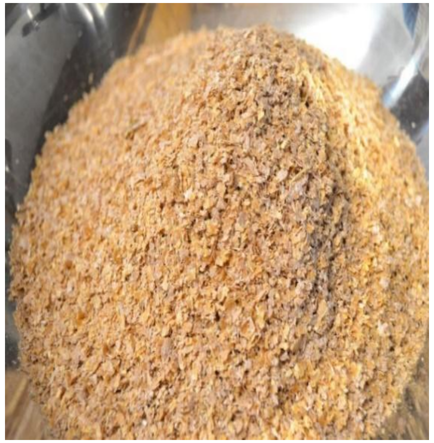
Paper Sludge

Mango Seed

Grape Waste

Maize Stover

Wheat Straw

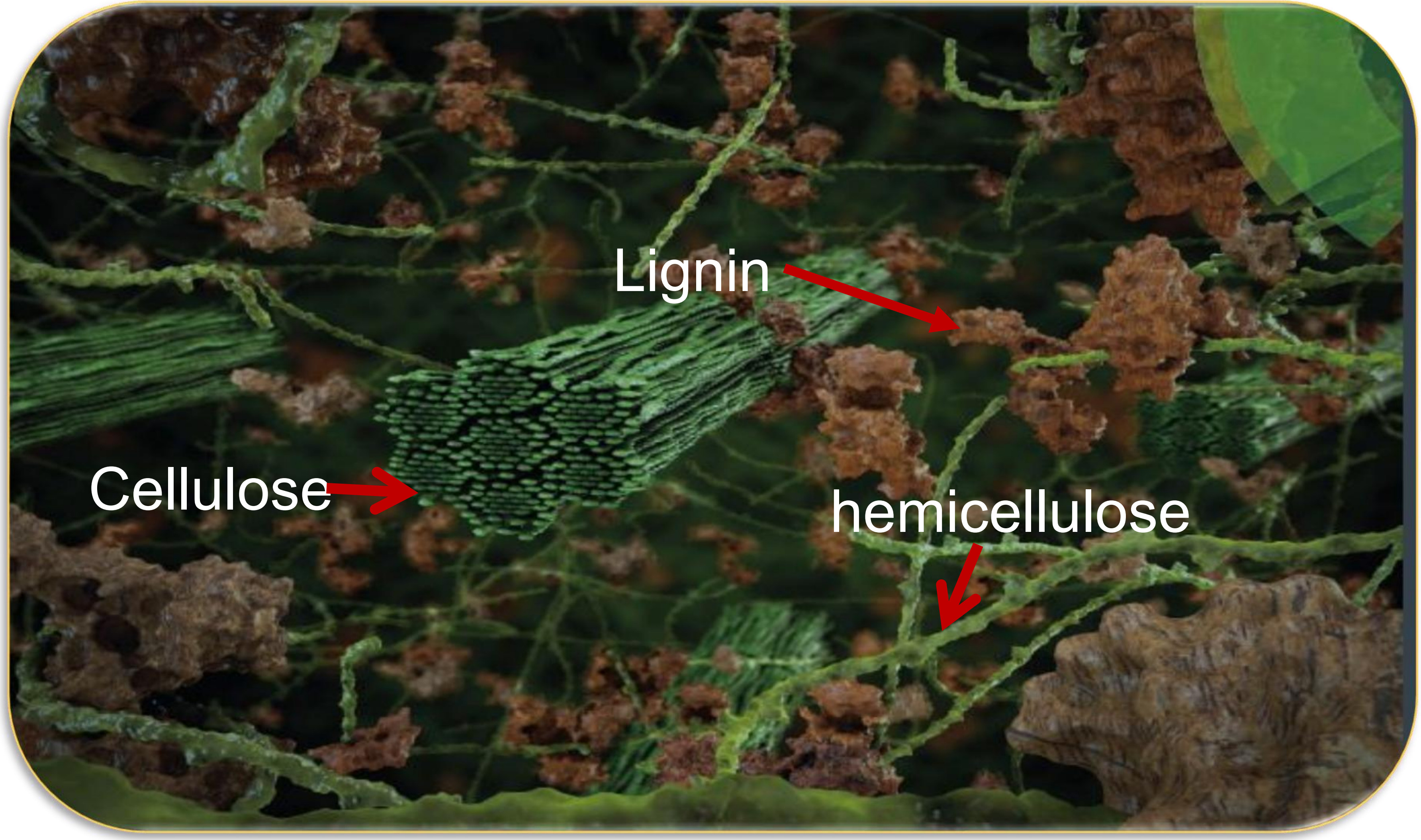


Wheat Bran

Mango Peels

Potato(b) Peels

Integrated Biorefineries: Biomass Valorization

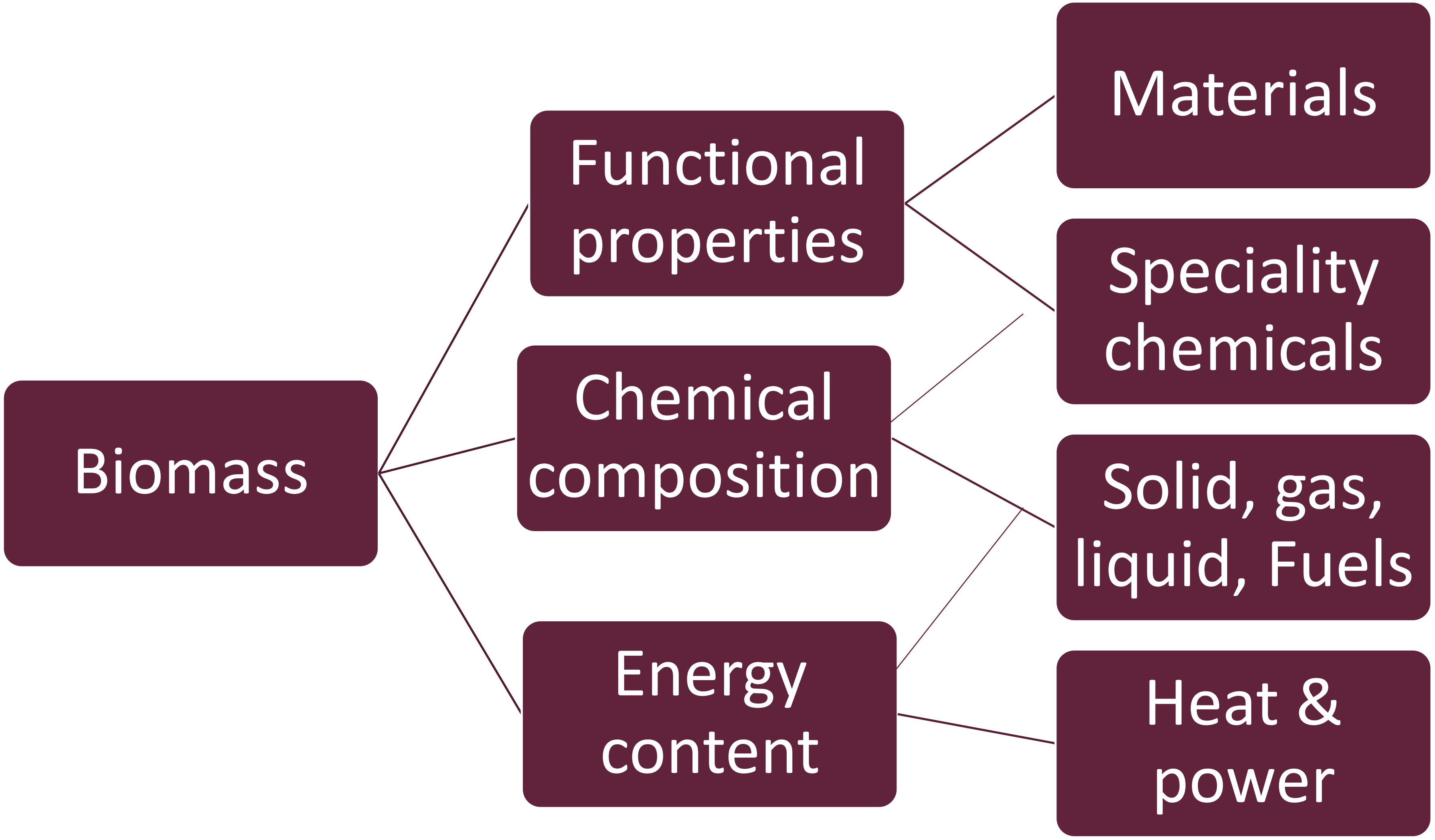


(Brian H. Davison et al. 2014)

Other High-Value Compounds:

- Antioxidants
- Extractives
- Pectin
- Polyphenols
- Proteins
- Starch

Integrated Biorefineries: Biomass Valorization



Integrated Biorefineries: Biomass Valorization

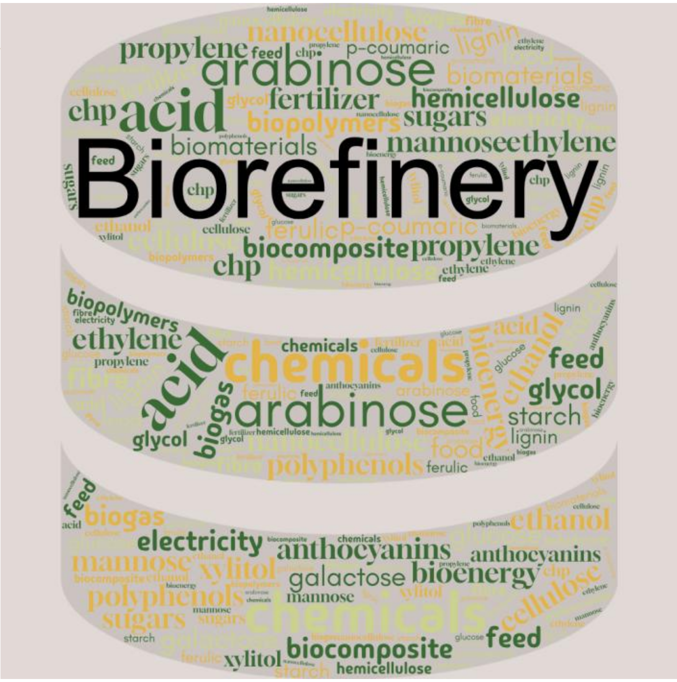
Biomaterials- Polymers

Biochemicals
Flavours
Antioxidants
proteins

Biofuels
Bioethanol
Biodiesel
Biogas

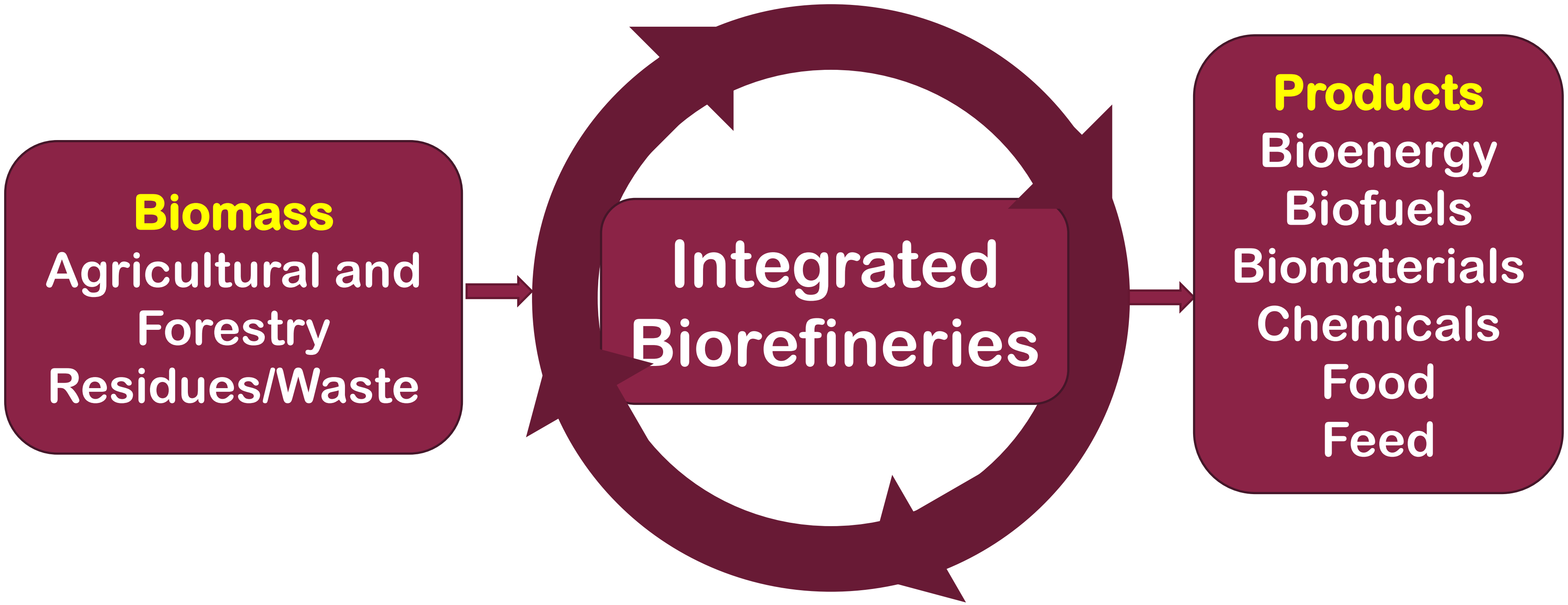
Bioenergy
Electricity
Heat and Power
Solid fuel
Liquid fuel

Value Creation



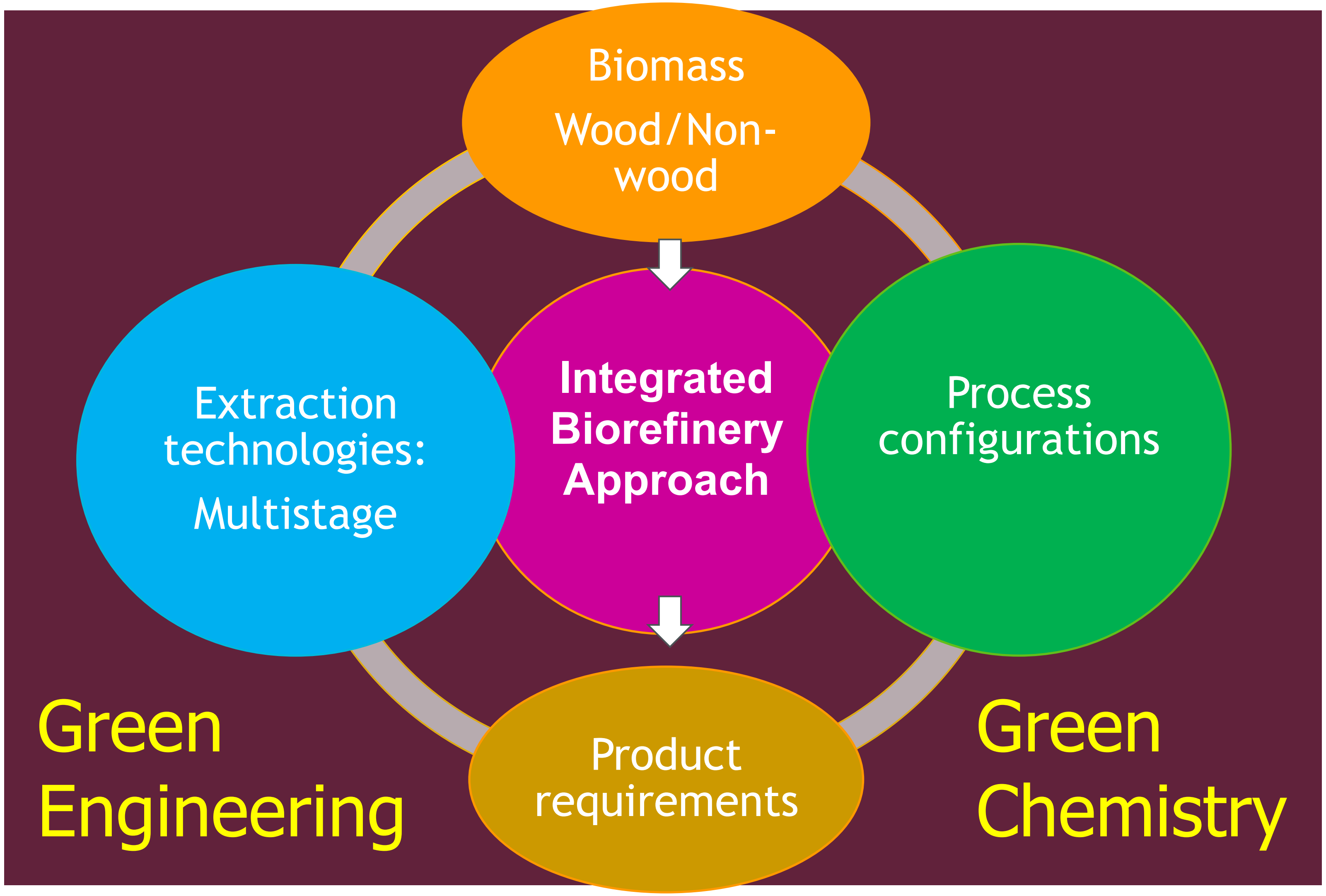
- **Green Chemicals and Products from Renewable Resources to Substitute Petroleum-Based Chemicals and Products.**
- **Guided by the Market Value**

Designing Integrated Biorefineries for a Circular Bioeconomy



Designing Integrated Biorefineries for a Circular Bioeconomy

1. Bioprocessing
2. Biotechnology
3. Green solvent
4. Chemical Free



Designing Integrated Biorefineries for a Circular Bioeconomy: Examples

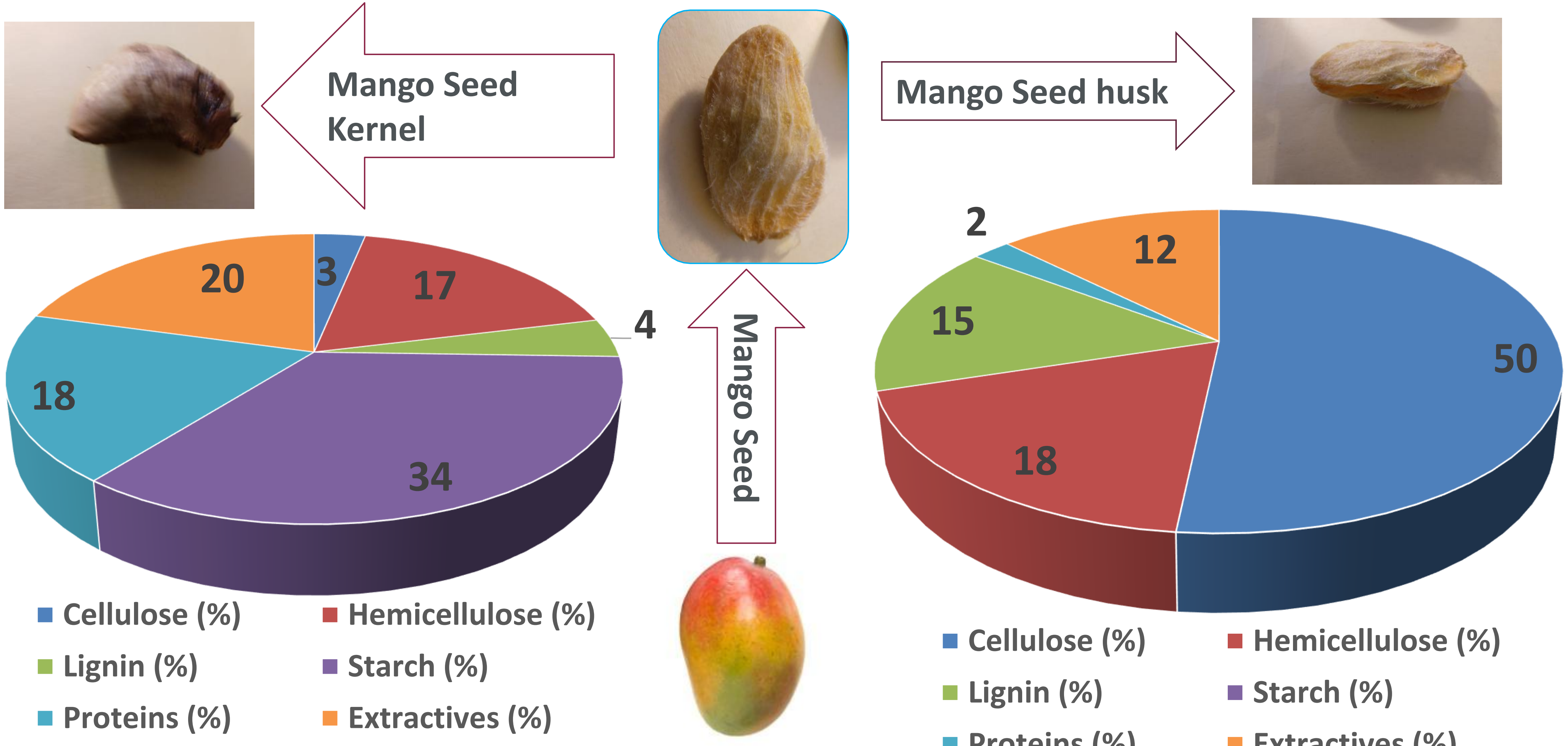
Mango Waste

- **Mango peel (7-24%)**
- **Mango seed (30-60%)**
  - Made of a husk and a kernel

Waste Valorization

Designing Integrated Biorefineries for a Circular Bioeconomy

Mango Waste Chemical Composition



Guided by the Composition

Designing Integrated Biorefineries for a Circular Economy

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

forward together sonke siya phambili saam vorentoe

7-24% of the mango fruit

Mango peels

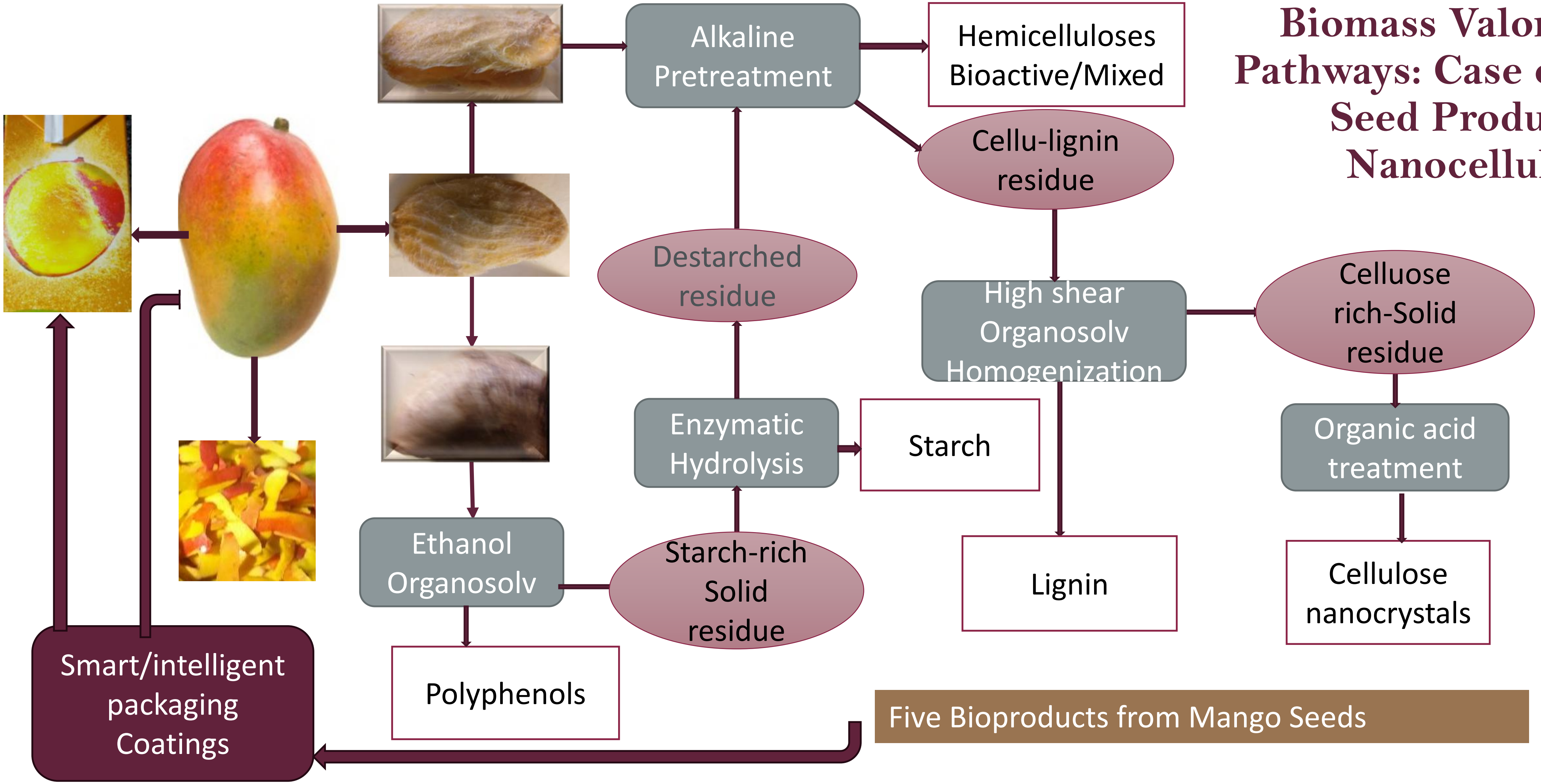
Anthocyanins- Natural colourant & antioxidant- 565 mg/ 100g
Mkt Value > U$ 387.4 Million in 2021

Pectin-Stabilizer, thickner, gelling agent, dietary fibre **U$ 958 million in 2015 and 7.3% increase in 2018-2023.**

Polyphenols- Antimicrobial, antioxidants etc. Polyphenols Market Projection **U$1.33 Billion By 2024**

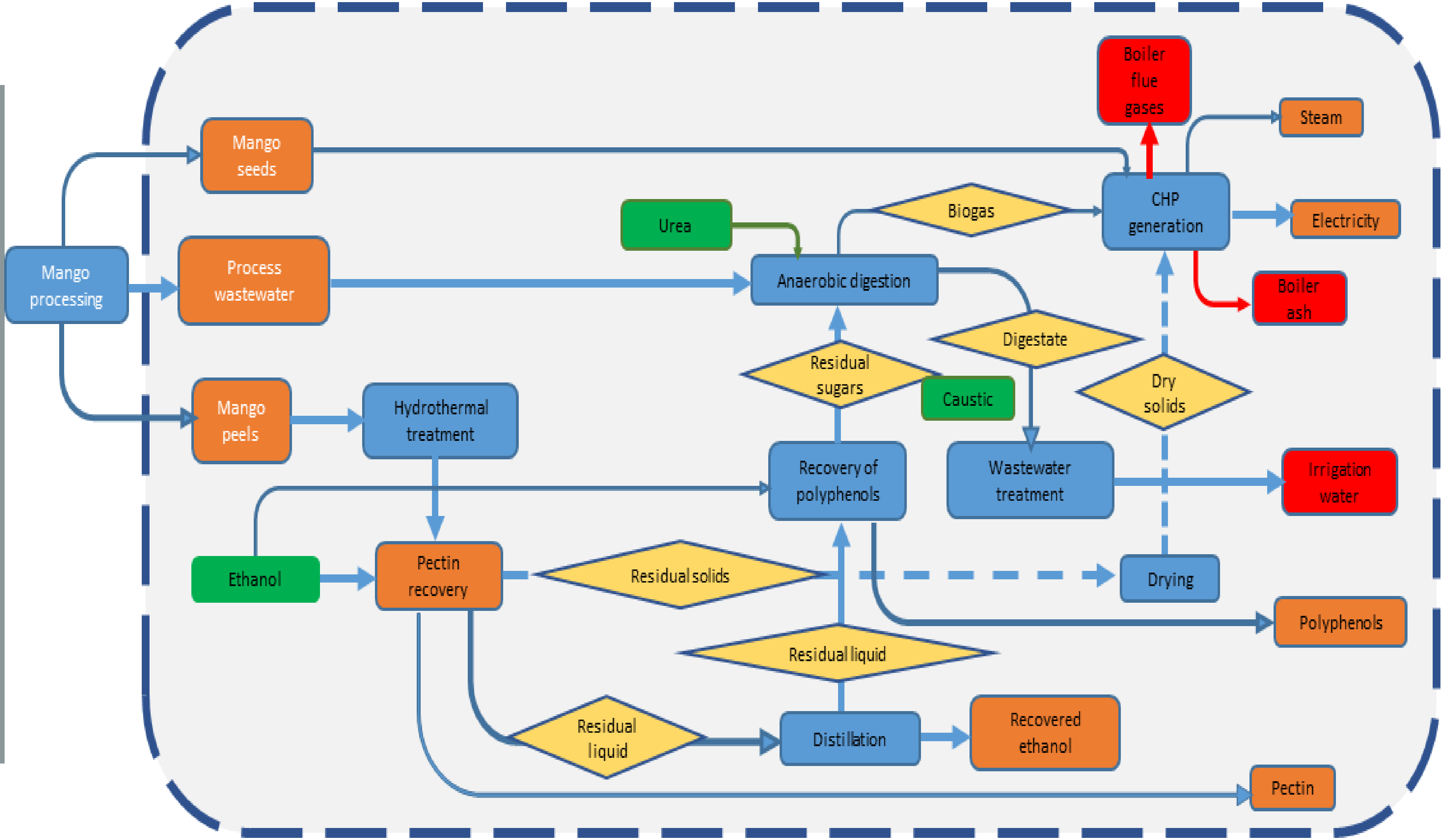
Designing Integrated Biorefineries for a Circular Bioeconomy

Biomass Valorisation Pathways: Case of Mango Seed Producing Nanocellulose



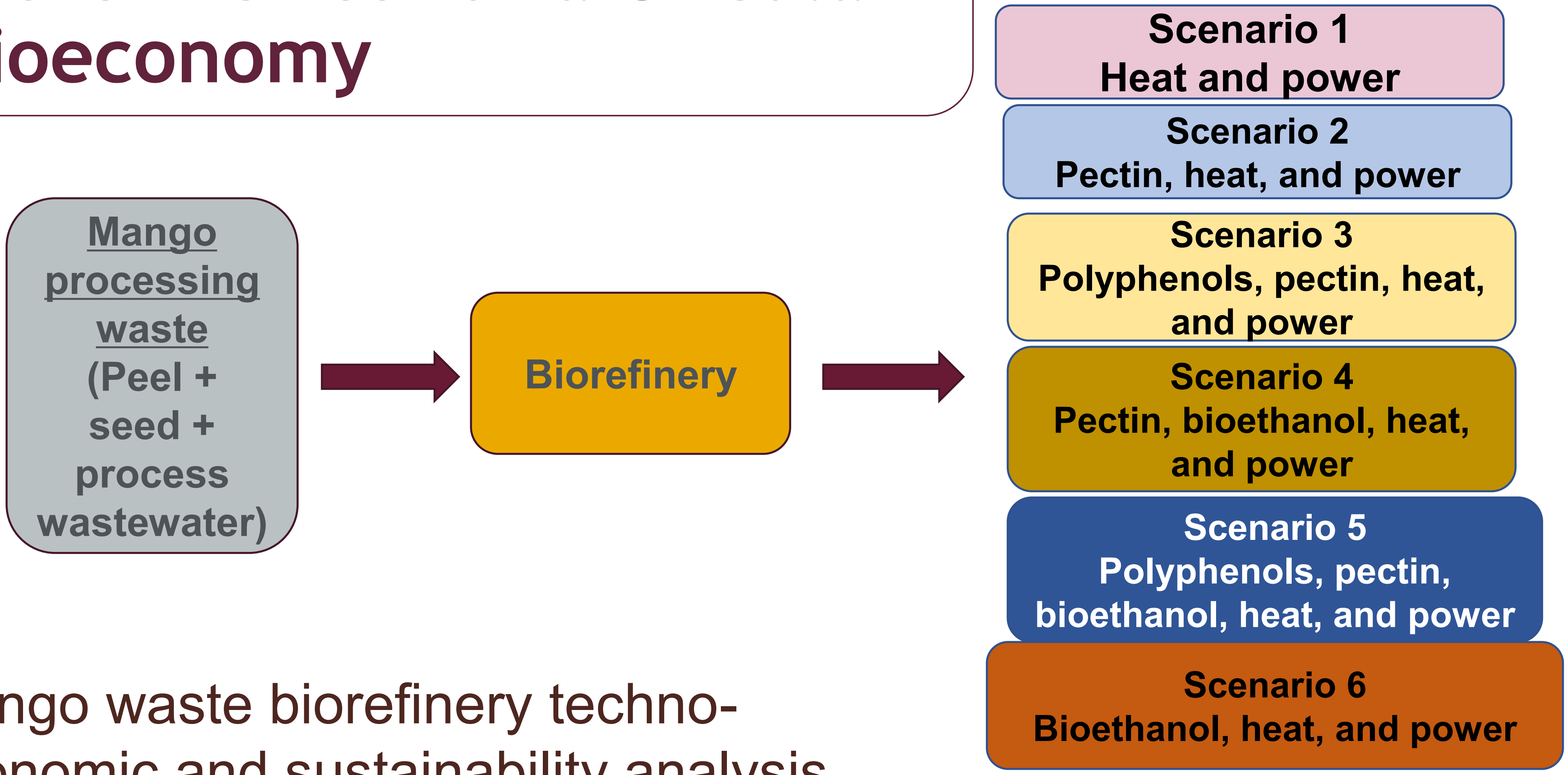
Designing Integrated Biorefineries for a Circular Bioeconomy: Techno-economic and sustainability Studies

Sequential recovery of pectin and polyphenols coupled with production of biogas CHP (PPCHP)



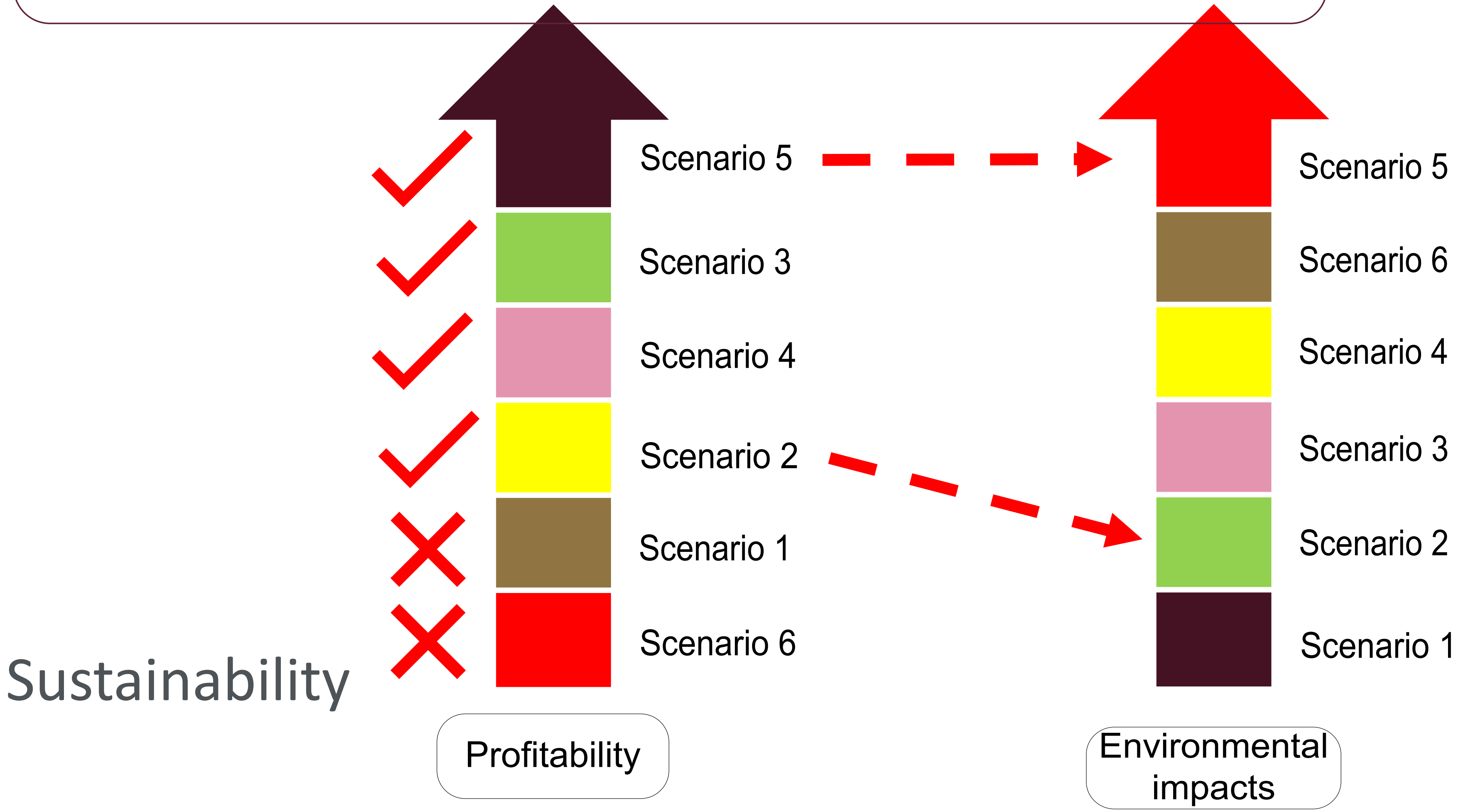
Designing Integrated Biorefineries for a Circular Bioeconomy

Stellenbosch
UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT
forward together
sonke siya phambili
saam vorentoe



Mango waste biorefinery techno-economic and sustainability analysis

Designing Integrated Biorefineries for a Circular Bioeconomy

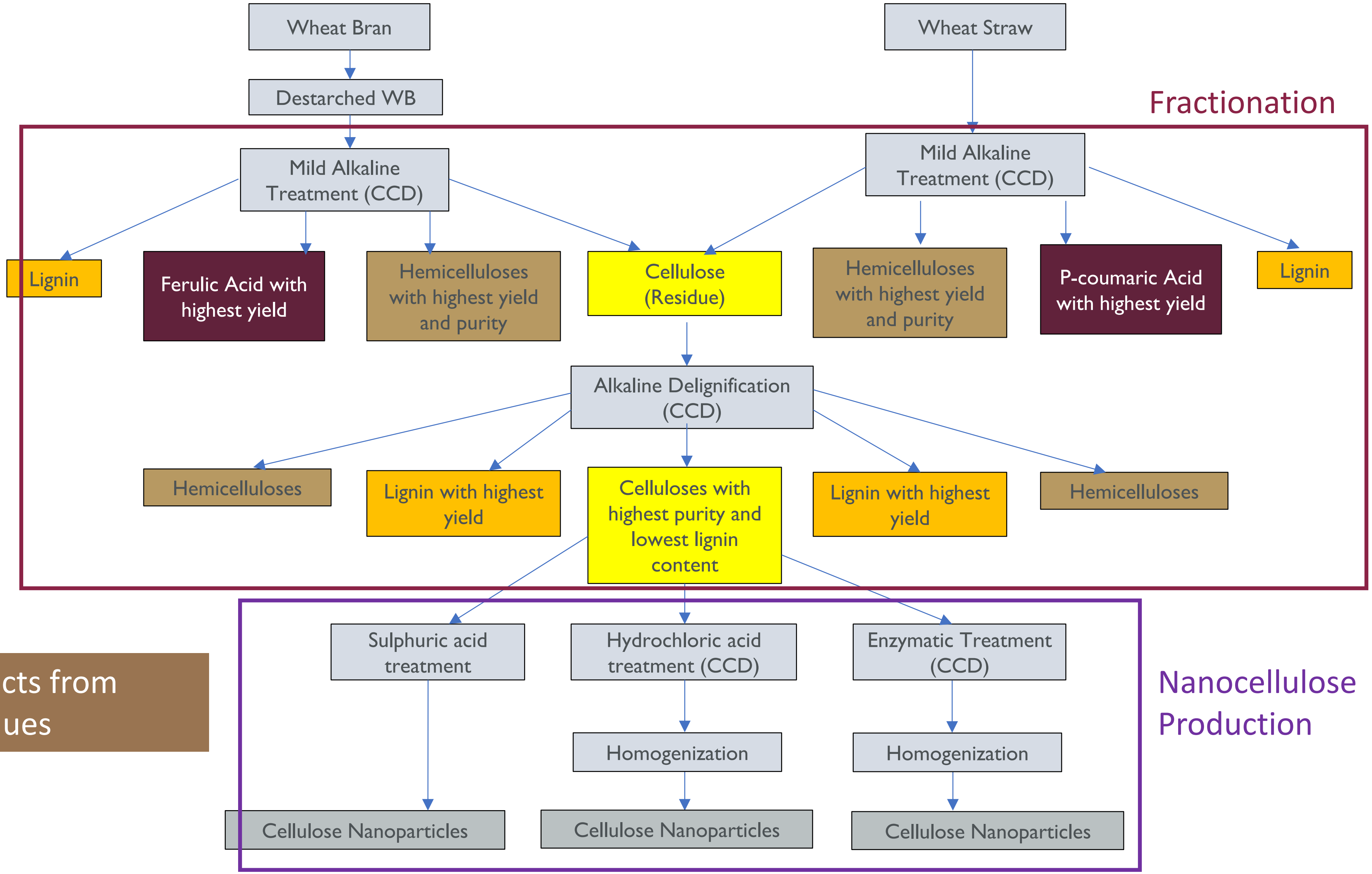


Designing Integrated Biorefineries for a Circular Bioeconomy- Examples

- Annual Wheat Production/yr in SA ~ **2 Million Tonnes**
- **1.0 kg** wheat grain = **1.5 kg** wheat straw
- **1.0 kg** wheat grain ~ 0.2 kg wheat bran.

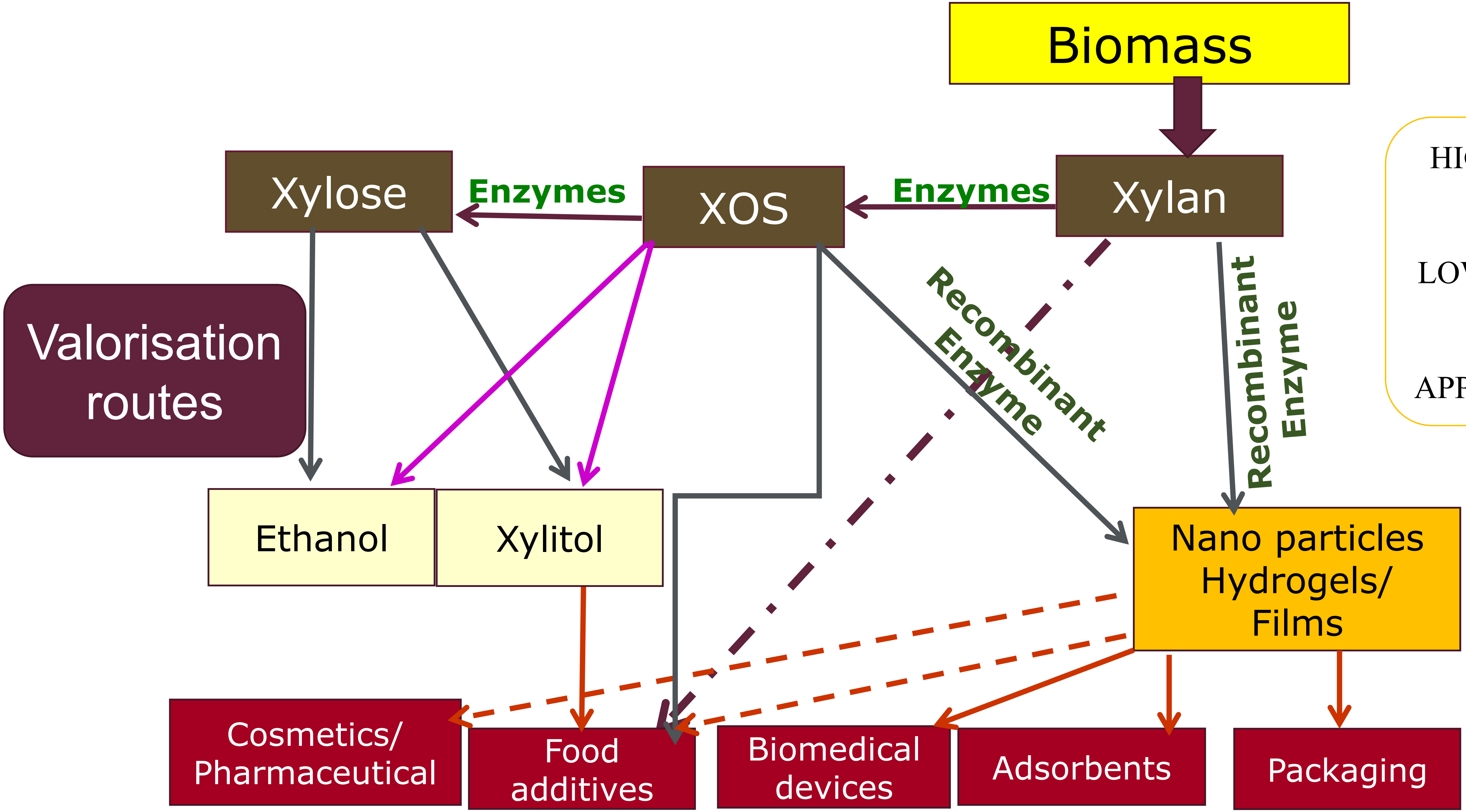
Design guided by the **Volume (Availability)**

Biomass Valorization Pathways: The case of Wheat straw and Wheat Bran



Six Bioproducts from Wheat Residues

Designing Integrated Biorefineries for a Circular Bioeconomy



HIGH VALUE
$2000/kg

LOW VOLUME

NOVEL APPLICATIONS

Integrated Biorefineries for a Circular Bioeconomy- Example: Agriculture and Forestry

Sugarcane Trashes & Bagasse

Wood shavings

Lignocellulosic Feedstock

Biomaterials

- Biofuels (e.g. 2G-Bioethanol)
- Biopolymers
- BioChemicals

INTEGRATED BIOREFINERY FACILITY

Bio-energy

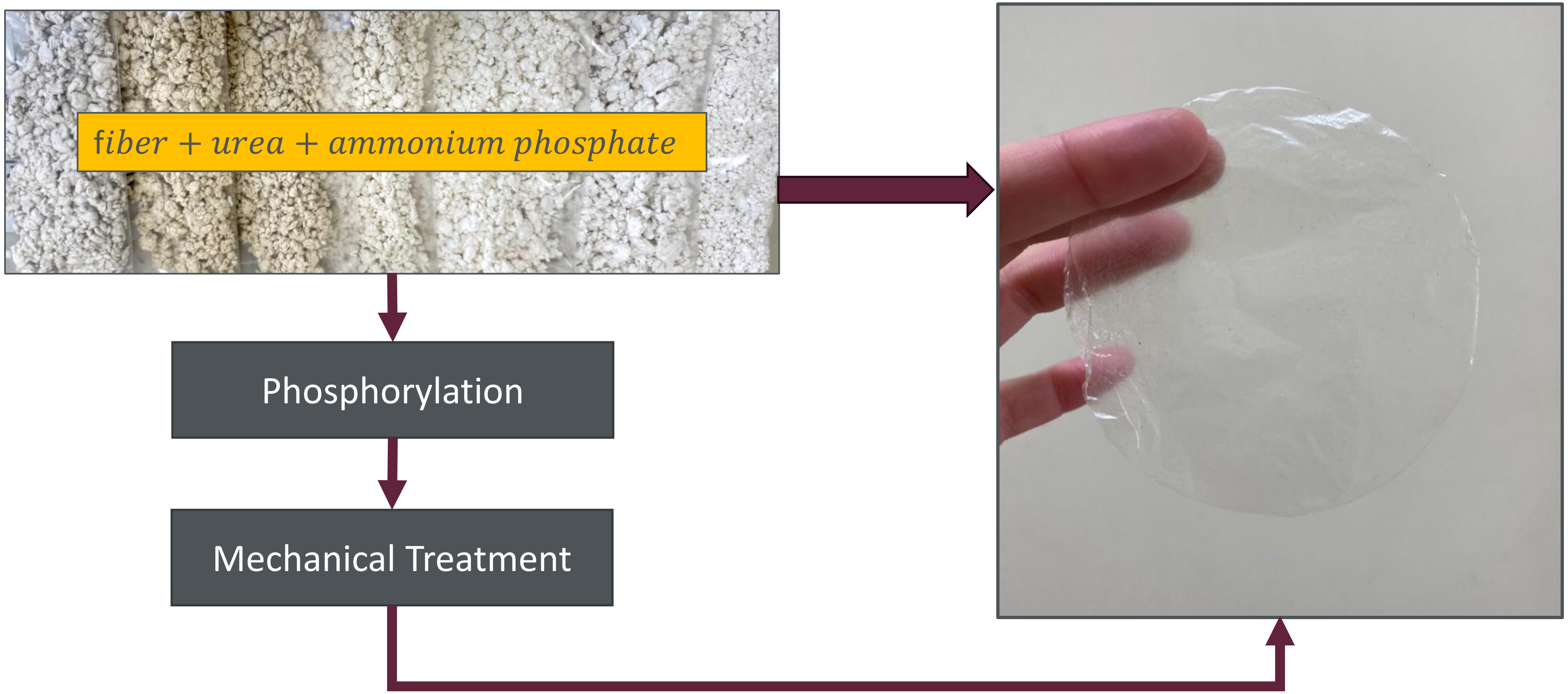
Combined Heat & Power Generation (CHP-Plant)

Multi-Feedstock Co-Production of High-Value Materials and Bioenergy

Mitigation of Climate Change

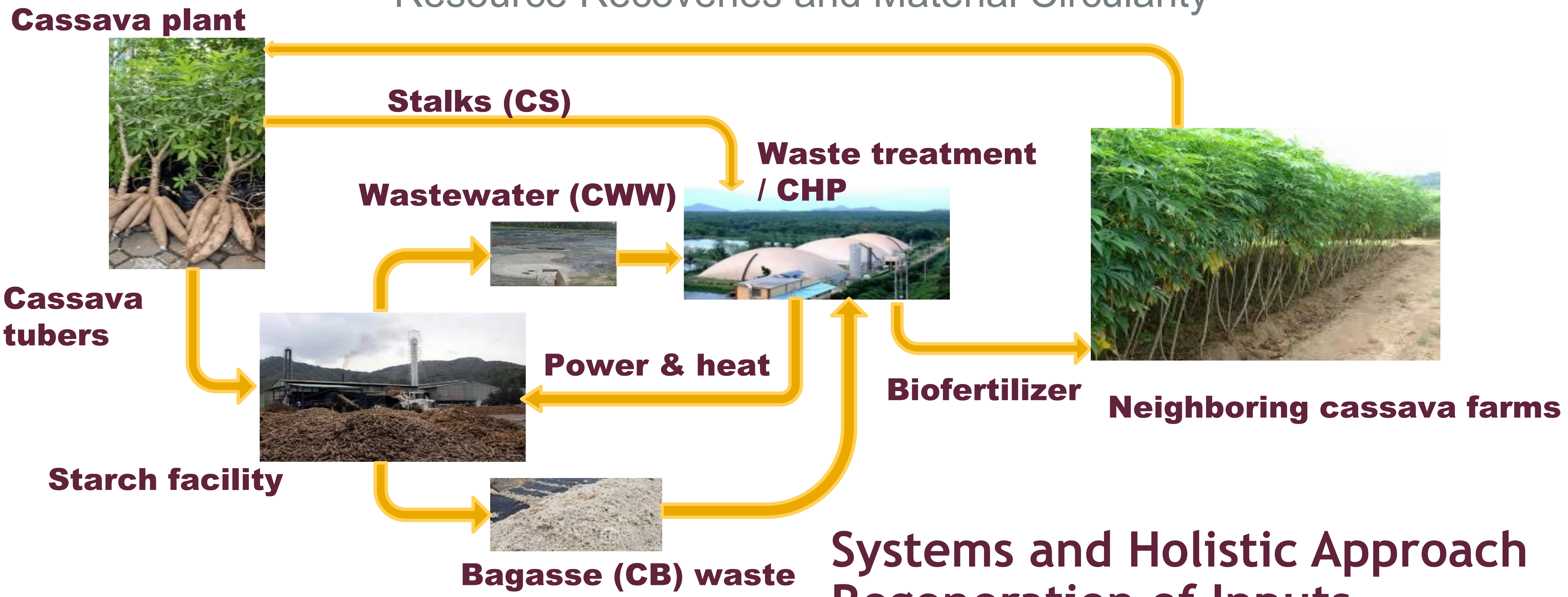
Designing Integrated Biorefineries for a Circular Bioeconomy-Fibre recovered from Pulp and Paper Mill Waste Streams

- Gel-like nanocellulose suspensions obtained after 5 min
- Thin transparent films



Designing Integrated Biorefineries for a Circular Bioeconomy-Example

Biorefineries Integrated into Cassava Starch Processing Maximizing Resource Recoveries and Material Circularity



Systems and Holistic Approach
Regeneration of Inputs

Designing Integrated Biorefineries for a Circular Bioeconomy- Example

Grape and Wine Industry

Grape and wine waste streams
- Stems
- Pomace
- Lees

→ Integrated Biorefinery →

Bioproducts and Biomaterials
- Oils/waxes
- Polyphenols

Biopolymers
- Pectin
- Cellulose
- Hemicellulose
- Lignin

→ Nanoparticles, Hydrogel, Aerogel, Emulsions, Granules

→ Other Industries

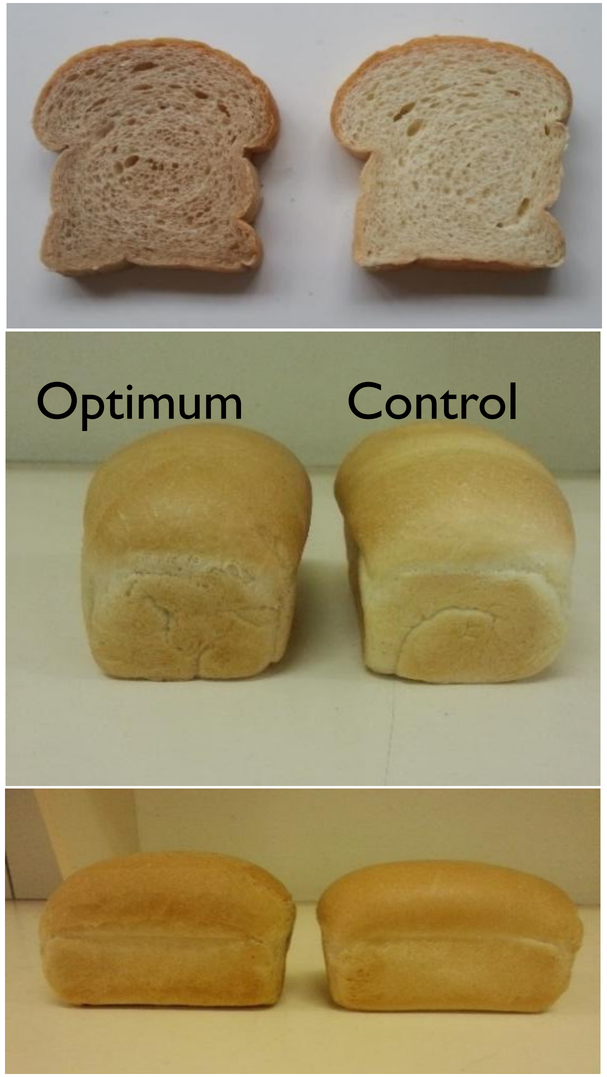
Designing Integrated Biorefineries for a Circular Bioeconomy: Additives

Wheat ban arabinoxylan 0.8% added to flour dough: Displaces 2.5% flour for the same bread volume.

Baking industry

Novel Applications

Hemicelluloses as Flour Replacer takes advantage of the hemicellulose water-holding capabilities



Designing Integrated Biorefineries for a Circular Bioeconomy- Functional/ Smart/Intelligent Packaging

2% starch, 1% sorbitol

2% starch, 1% sorbitol, 10% (w/w) citric acid 20% (w/w) carboxymethylcellulose

+1% (v/v) extract

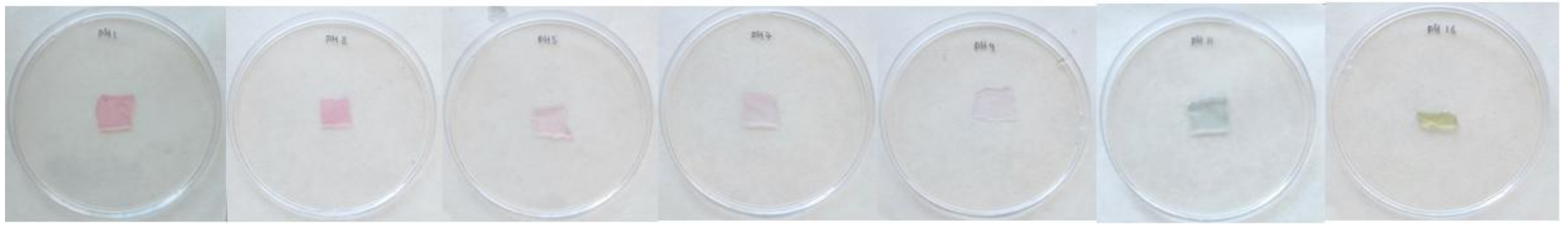
+ 3% (v/v) extract

+ 5% (v/v) extract

* Extract – RC extract + NP extract (1:1)

Use as Biosensors

pH 1 pH 3 pH 5 pH 7 pH 9 pH 11 pH 13



+ 3% (v/v) extract

Designing Integrated Biorefineries for a Circular Bioeconomy

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT

Polyphenols + pectin+ Hemicelluloses + Nanocellulose

Active food packaging- taking advantage of natural anti-oxidants and antimicrobial properties

Designing Integrated Biorefineries for a Circular Bioeconomy

Stellenbosch
UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT
forward together
sonke siya phambili
saam vorentoe

Biomedical Applications- e.g., Wound Dressing

Cellulose-based biocomposite for potential application as barrier films

Designing Integrated Biorefineries for a Circular Bioeconomy
Cryogels: Wastewater Treatment

Superhydrophobic **aerogels absorb** oil **10-20 times** their weight

Reduce build-up of fats, oil and grease in pipes[a]

Removal of oil spills

Waste Water treatment

Designing Integrated Biorefineries for a Circular Bioeconomy: Key Considerations

Resource use efficiency and Economic viability

Minimize waste, generation and environmental impacts

Responsive to socioeconomic needs e.g. catalyst for job creation

Feedstock, Technology & Products Compatibility

Optimized for minimum inputs, product yields & quality

Apply Green Engineering and Green Chemistry principles

Diversification of feedstock and products (process configurations)


Stellenbosch
UNIVERSITY
IYUNIVESITHI
UNIVERSITEIT
Engineering
EyobuNjineli
Ingenieurswese
Thank you
Enkosi
Dankie