



***Technical insights into bioprocess design for cultivated meat***

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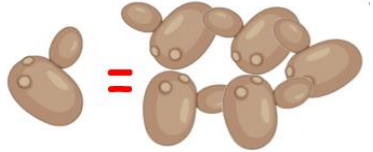
**University of Bath, UK**

# 1. An introduction to cellular agriculture

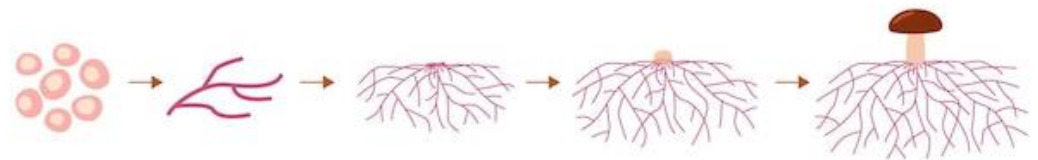


## Cellular Agriculture

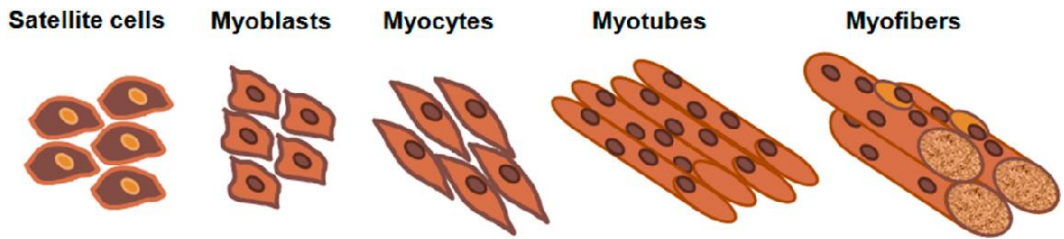
A collection of technologies seeking to produce consumables that are traditionally produced in livestock-based agriculture systems through other means such as precision fermentation or tissue engineering.



Yeast for oils/fats, proteins and vitamins



Mycelium\* for protein



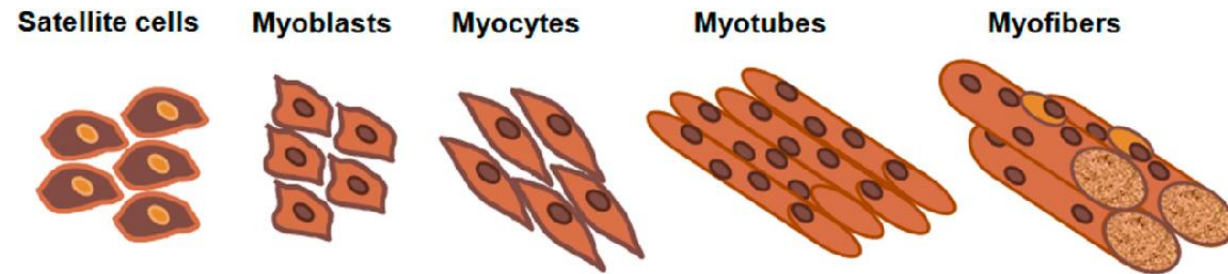
muscle cells for protein

\*the root-like structure of fungus

# Cultured meat is a cellular agriculture product

Other names include cultivated meat, lab-grown meat

In its basic form, cultured meat is a protein ingredient made up of muscle cells only.



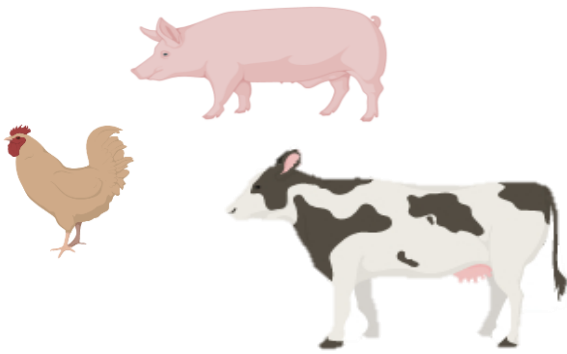
Muscle cells begin as stem cells, and need to mature to form skeletal muscle

A longer term goal is to grow 'full cut' cultured meat, with the complex structure that results from combining the different cells in muscle.

# How is cultured meat grown? The process

## Input

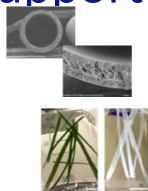
Satellite (stem) cells



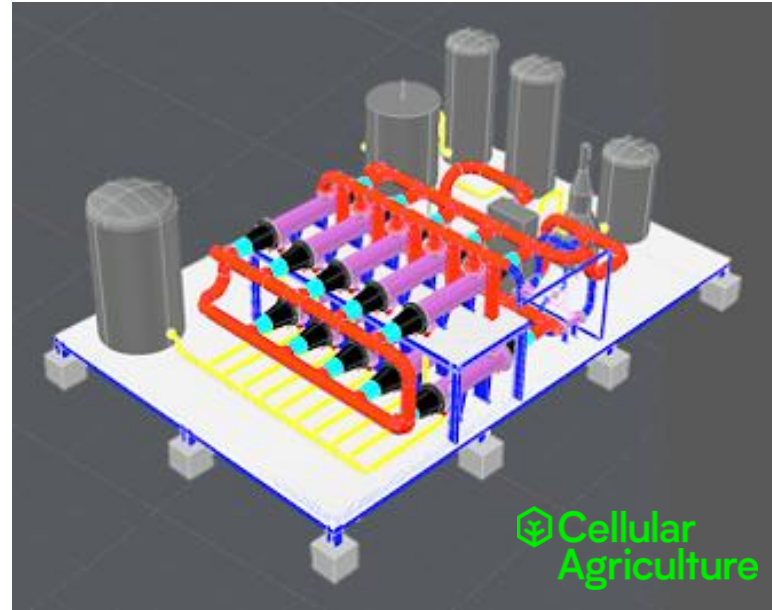
'media' to feed the cells



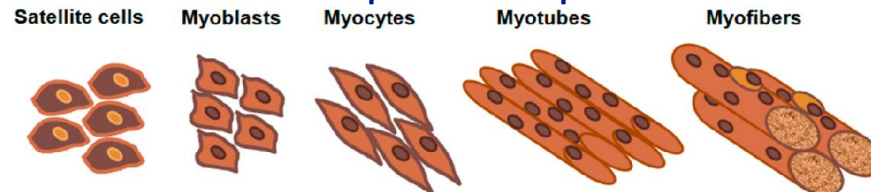
Scaffold to support the cells



## Bioprocess



The stem cells first multiply, then mature and produce protein



## Output

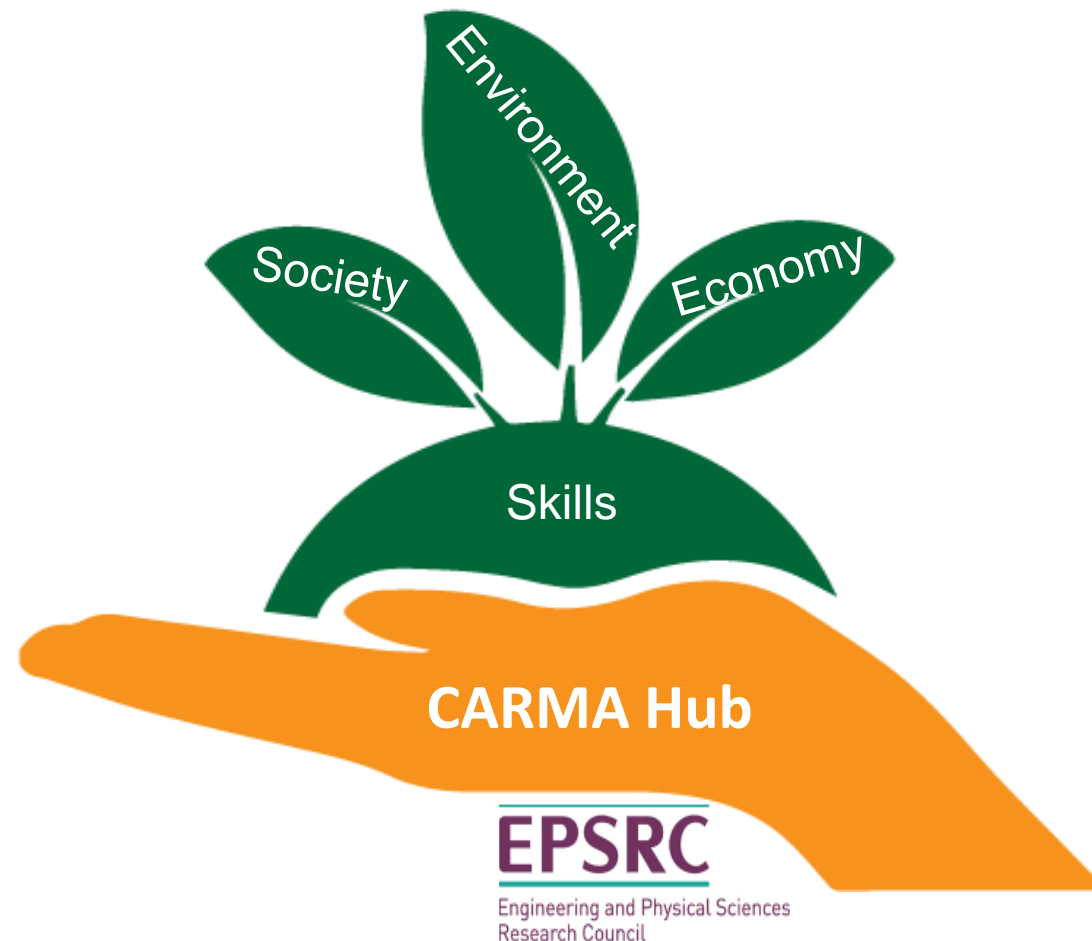


Food producers make the desired product



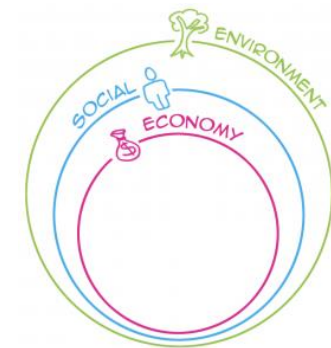
Some of the waste products can be further processed or recycled

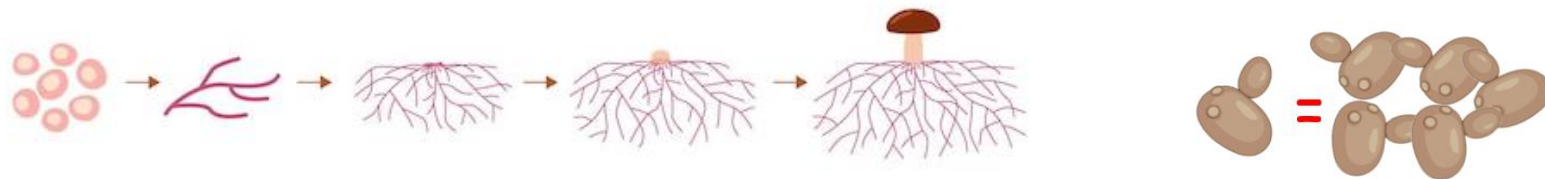
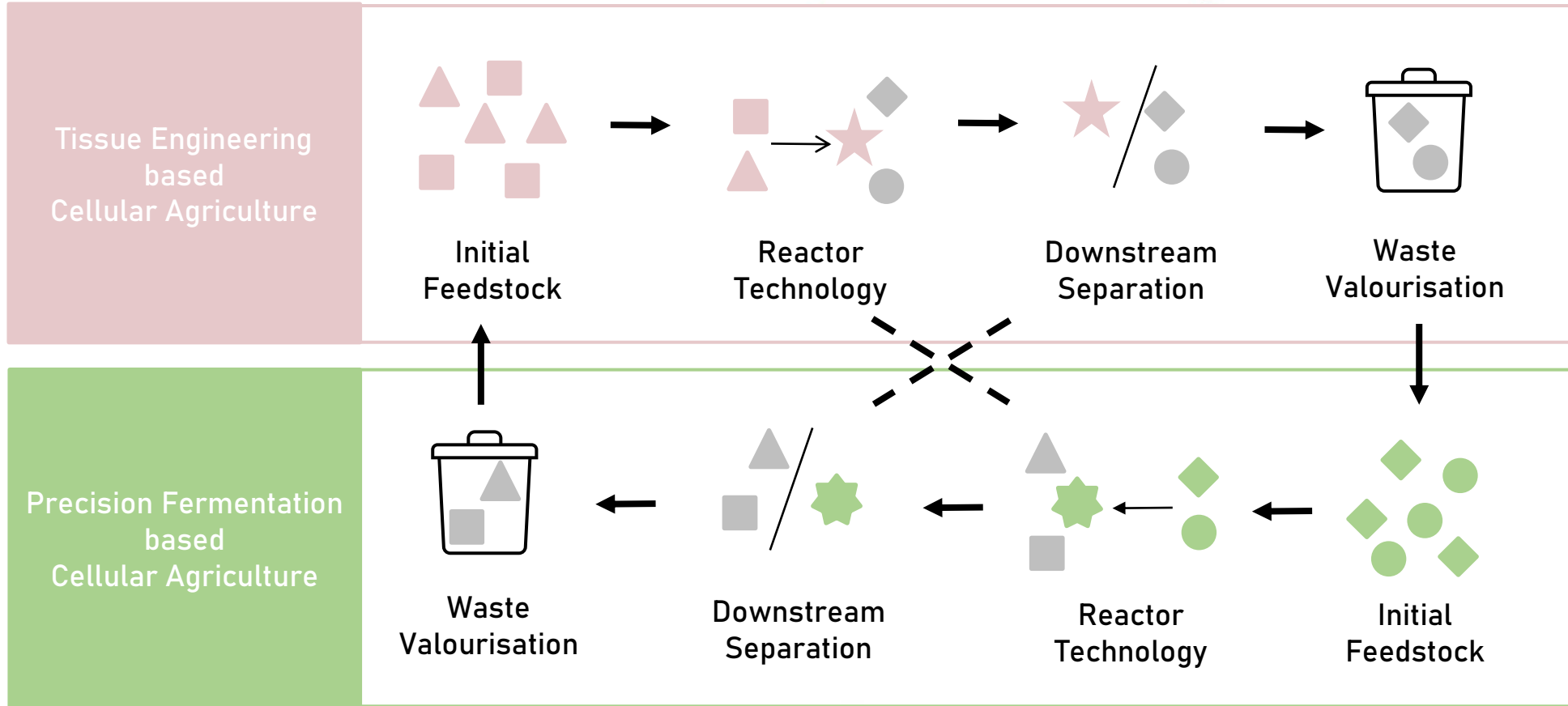
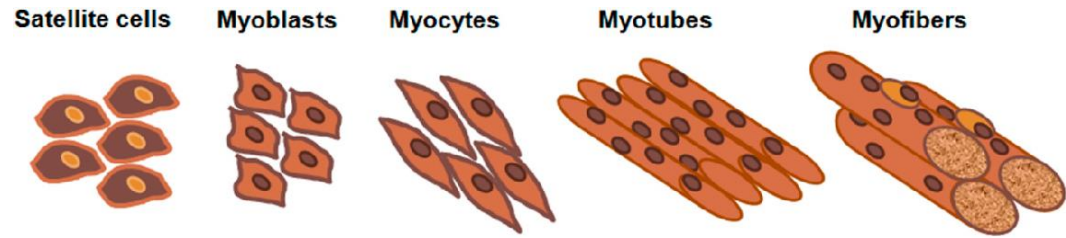
Our **Vision** is to **transform** food production, **transitioning** to an environmentally, economically, and socially sustainable model in which **novel** cellular agriculture manufacturing systems **complement** traditional food production.



## Mission

*Solve the challenge of how to produce affordable cultured meat at scale in a **triple bottom line** bioprocess.*





## 2. The manufacturing challenges

### Grand Challenge 1 Value Chain Integration



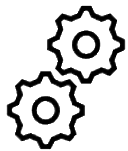
Ethical and Sustainable

- Cell Ag as part of agricultural plans and policy\*\*\*



Social

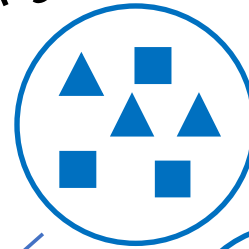
- Life Cycle Assessment (LCA)\*\*
- Understanding Public Perception\*\*\*



Operational

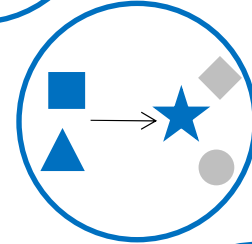
- Manufacturing Systems\*\*
- Supply Chain\*\*

### Grand Challenge 2 Underpinning Technologies



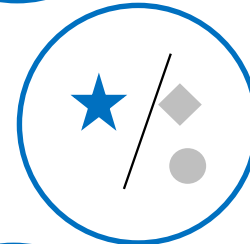
Feedstock

- Cost and Sourcing: cells\*\*\*, media\*\*, scaffold\*
- Serum Replacement\*\*



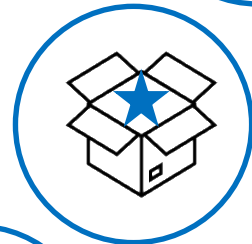
Bioreactor Technology

- Product generation at scale\*\*\*
- Yield\*\*\*



Downstream Separation

- Intercellular\*\*; Extracellular\*
- Product purification\*\*



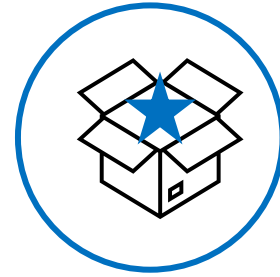
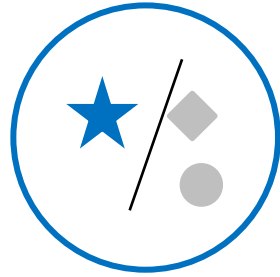
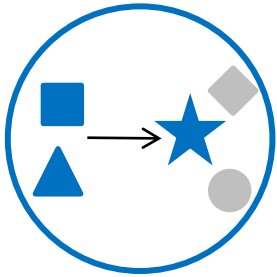
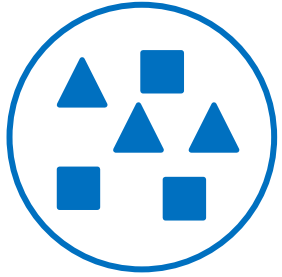
Product

- Product formulation and formation\*
- Additives\*
- Nutritional profile, bioavailability, digestibility\*



Waste Valorisation

- Value added from waste to media source\*\*\*
- Combined heat and power\*
- Water recycling\*\*



## Feedstocks

## Bioreactor technology

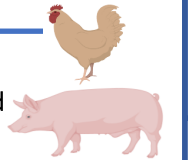
## Downstream separation

## Waste valorisation

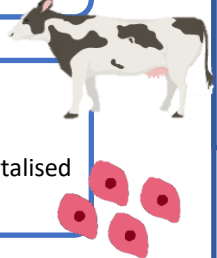
## Product

## Manufacturing systems

Animal  
Species; Breed  
Location;  
Kosha; Halal



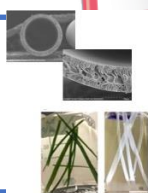
Cells  
Primary; Immortalised



Serum replacement  
Animal-free;  
Waste valorisation



Scaffold  
Reusable; edible



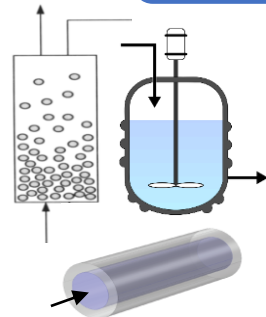
Seed train

Bioreactor  
configuration

Continuous v batch

Recycling

Waste valorisation



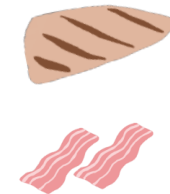
Co-products

Media source



Form; Taste; Texture

Shelf-life  
Nutritional profile  
Allergens

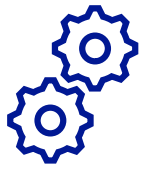


Combined heat and  
power

Water source

# Different choices for different approaches

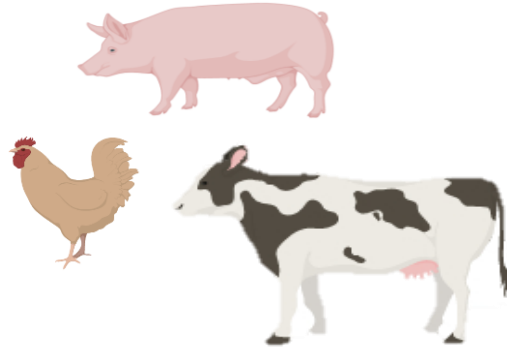




# The supply chain - cells and media

## Current availability

- ❖ Research cell suppliers
- ❖ Specialist cell suppliers
- ❖ Own animals

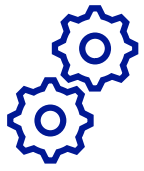


- ❖ Research media suppliers £££
- ❖ In-house formulations
- ❖ Sourced from:
  - Research suppliers



## Future opportunities

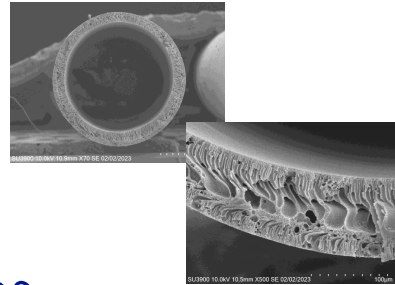
- ↑ Specialist cell suppliers
  - Farms/abattoirs
  - Supermarkets
  - Own animals
- 
- Cultured meat media suppliers £
  - In-house formulations
  - Sourced from:
    - Cultured meat suppliers
    - Local farms
    - Precision fermentation companies



# The supply chain - scaffold

## Current availability

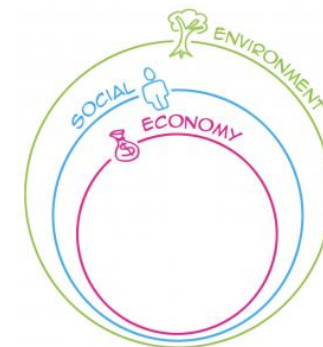
- ❖ Research suppliers
- ❖ In-house from research consumables
- ❖ In-house from local sources



## Future opportunities

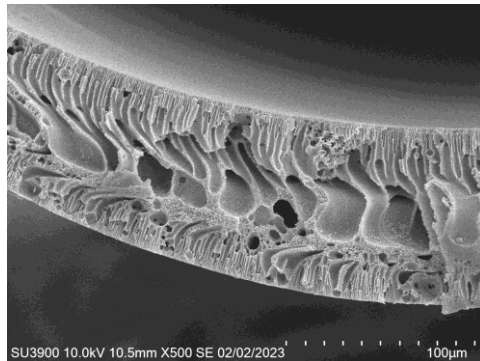
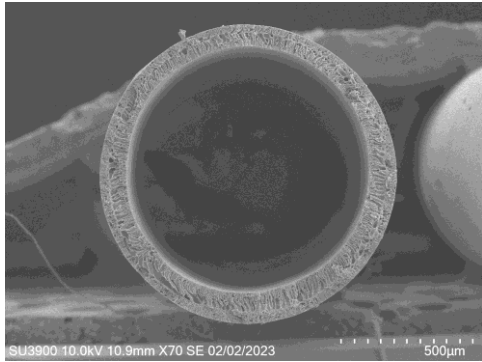
- Specialist cultivated meat suppliers
- Waste valorisation
  - Precision fermentation companies
  - Farms/abattoirs
  - Supermarkets/delis/restaurants

**Supply chain: reliable, consistent, transparent, safe**



# Scaffold material, fabrication, and destination

## Reusable (e.g. polystyrene) hollow fibres

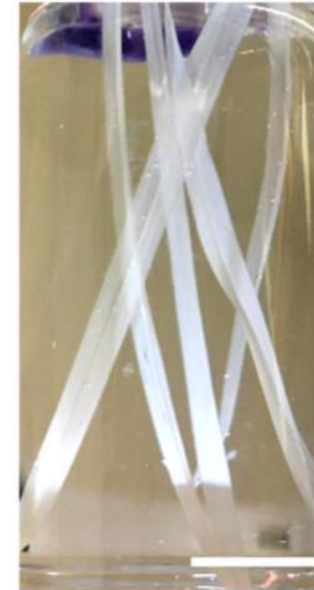


Outer diameter: ~1,100 µm

Wall thickness: ~90 µm

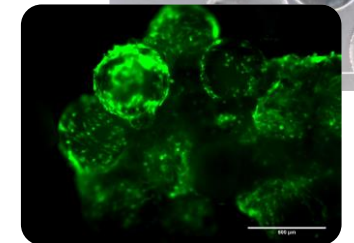
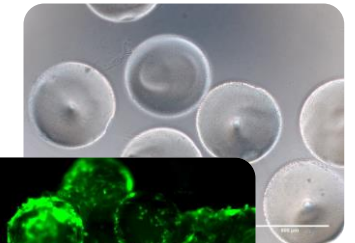
Pore size: 1 - 5 µm

## Edible grass strips (cellulose)

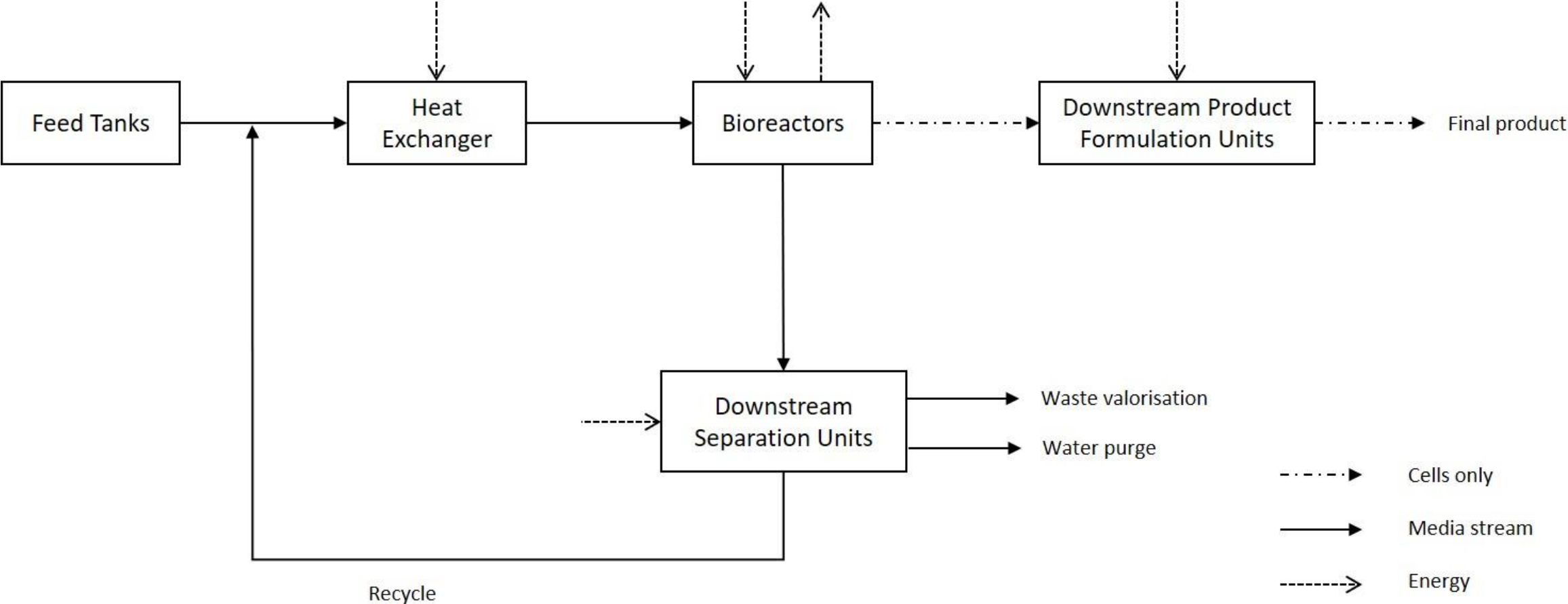


Grass, before and after decellularisation

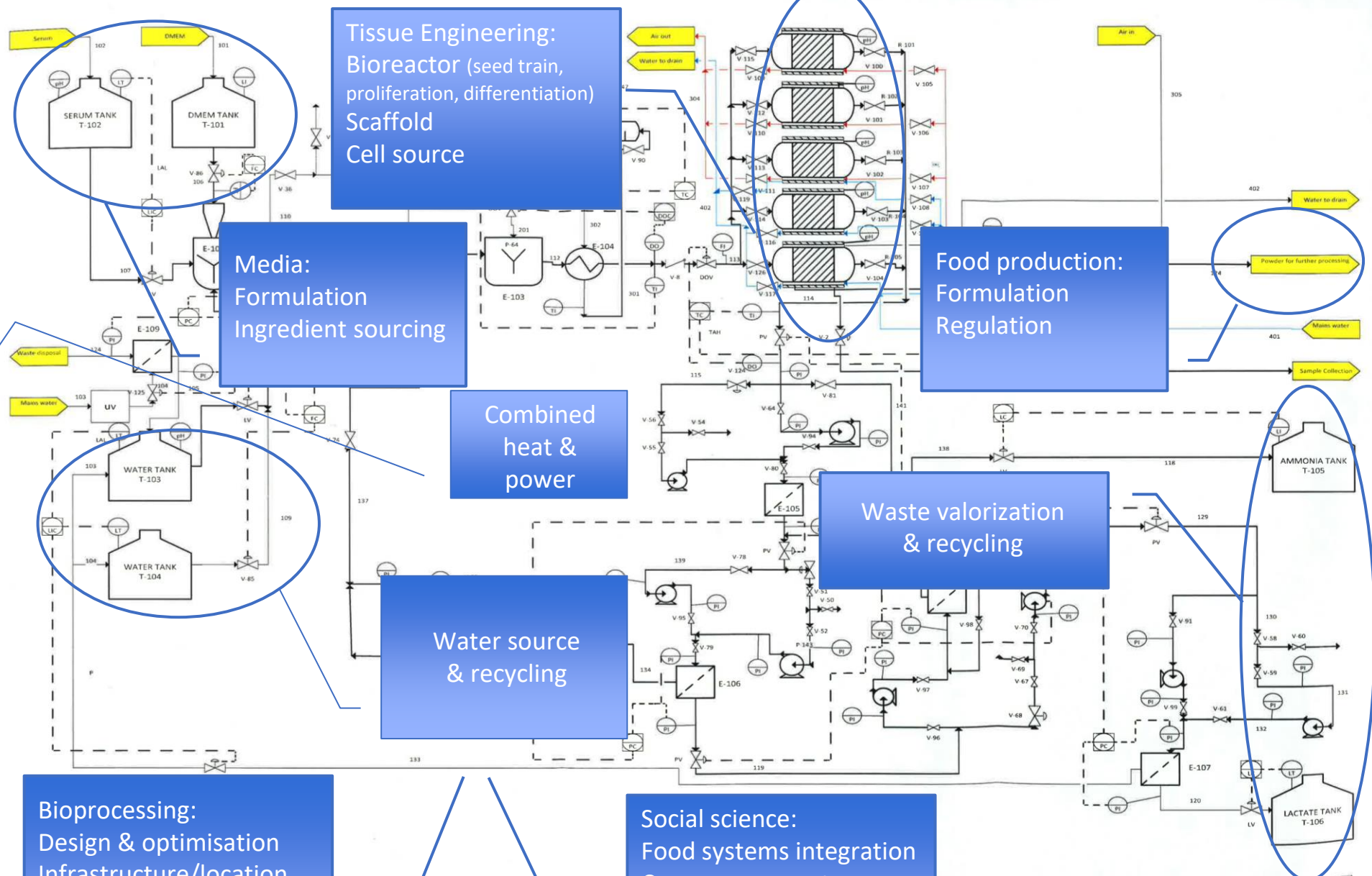
## Silk microcarriers



# 3. Bioprocess design



# Conceptual Bioprocess design



Llanelli, Wales, UK  
 Ave. annual temp  
 11°C  
 (ave. month range  
 2-18°C)

Turkana, Kenya,  
 Ave. annual temp  
 30°C  
 (ave. month range  
 21-35°C)

Tissue Engineering:  
 Bioreactor (seed train,  
 proliferation, differentiation)  
 Scaffold  
 Cell source

Media:  
 Formulation  
 Ingredient sourcing

Combined  
 heat &  
 power

Food production:  
 Formulation  
 Regulation

Waste valorization  
 & recycling

Water source  
 & recycling

Bioprocessing:  
 Design & optimisation  
 Infrastructure/location  
 LCA  
 Supply chain/logistics  
 Legislation/regulation

Social science:  
 Food systems integration  
 Consumer acceptance  
 Public engagement  
 Behaviour change

Allan et al 2017 (MEng Design project) Cell Ag. Co. P&ID  
 27/03/2017  
 Ben Woods, Jonathan Barnard & Lucy Butterfield  
 Darrion Ooi, Tim Johnson, Annabel O'fee, Patrick Raizerov & Scott Allan