University of Nottingham
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Efficiency, efficiency, efficiency, …the challenges of cultivated meat production

Prof. Ramiro Alberio
School of Biosciences,
University of Nottingham, UK

CARMA annual conference
9th September 2025

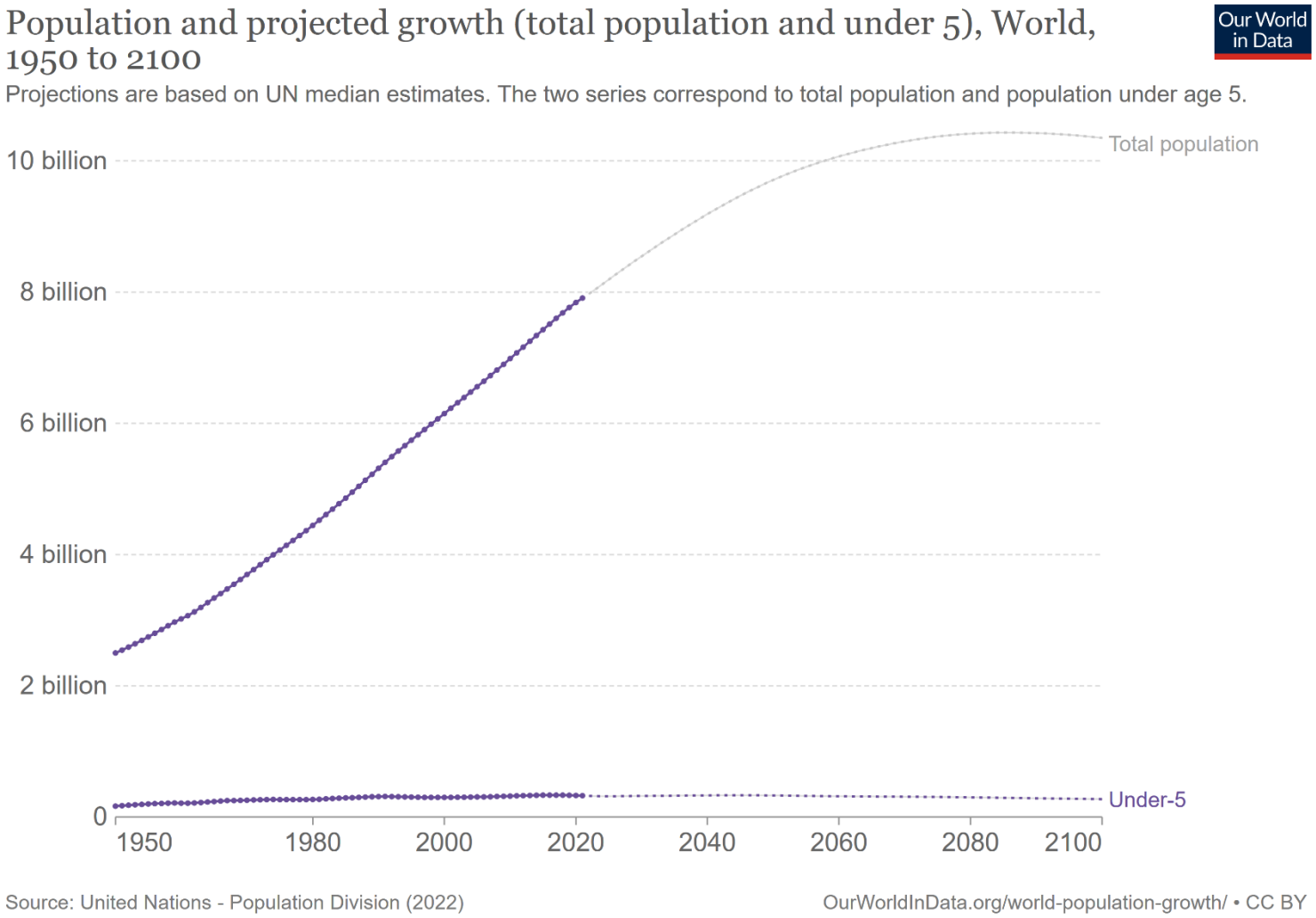
Outline of the talk

- **The challenge of feeding 10 billion**
- **Cultivated meat: Definitions and processes**
- **Inputs: cell lines, media, growth factors**
- **Building a robust supply chain**
- **Integration with existing industrial capabilities and sectors**

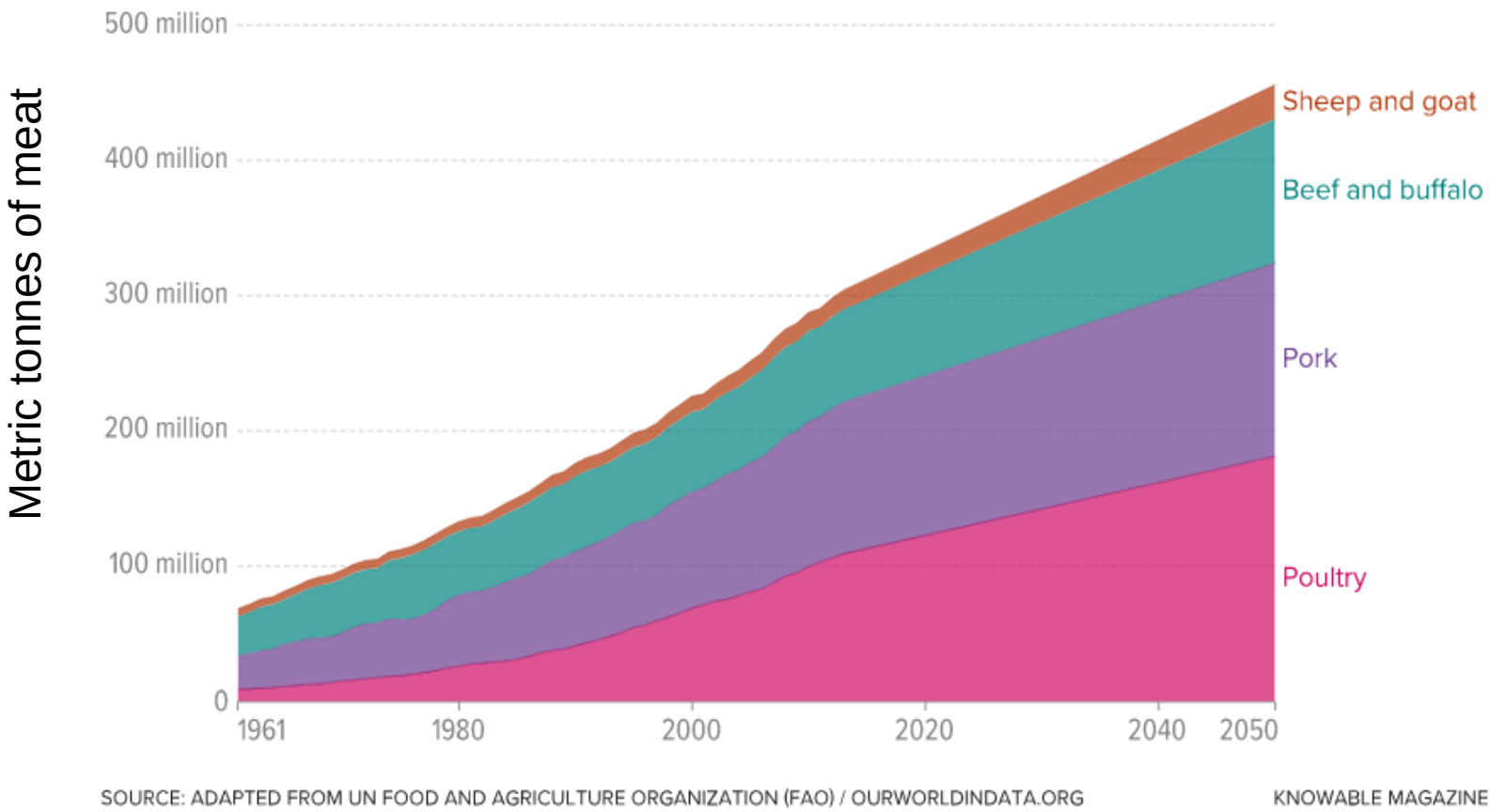
The Challenge: Develop sustainable food production to support the demands of global increase in human population

AGRICULTURE ALSO NEEDS TO PRODUCE
50% MORE FOOD TO NUTRITIOUSLY
FEED **9 BILLION BY 2050**

Source: FAO



Projected demand for meat set to increase by 14% by 2030

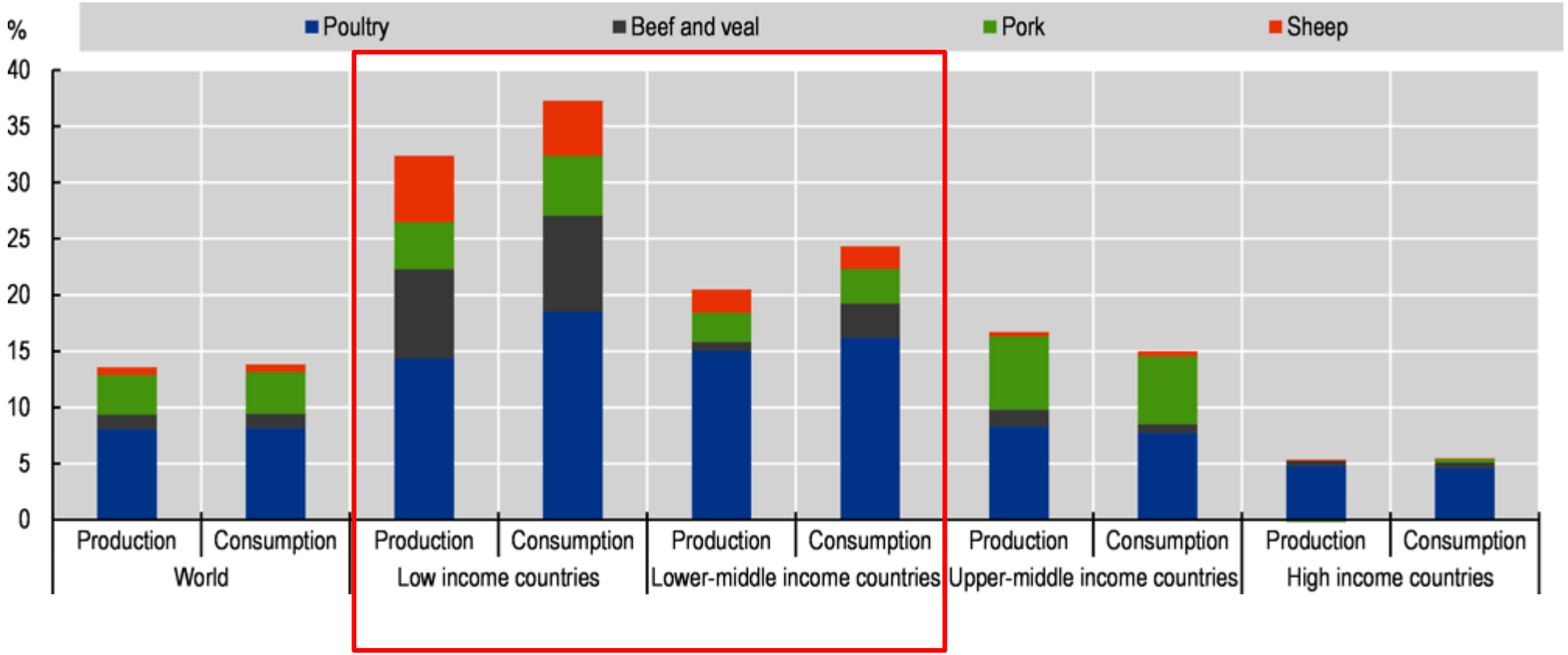


Plant-Based Market

-13%
Dollars Sales
U.S. 2021 - 2023

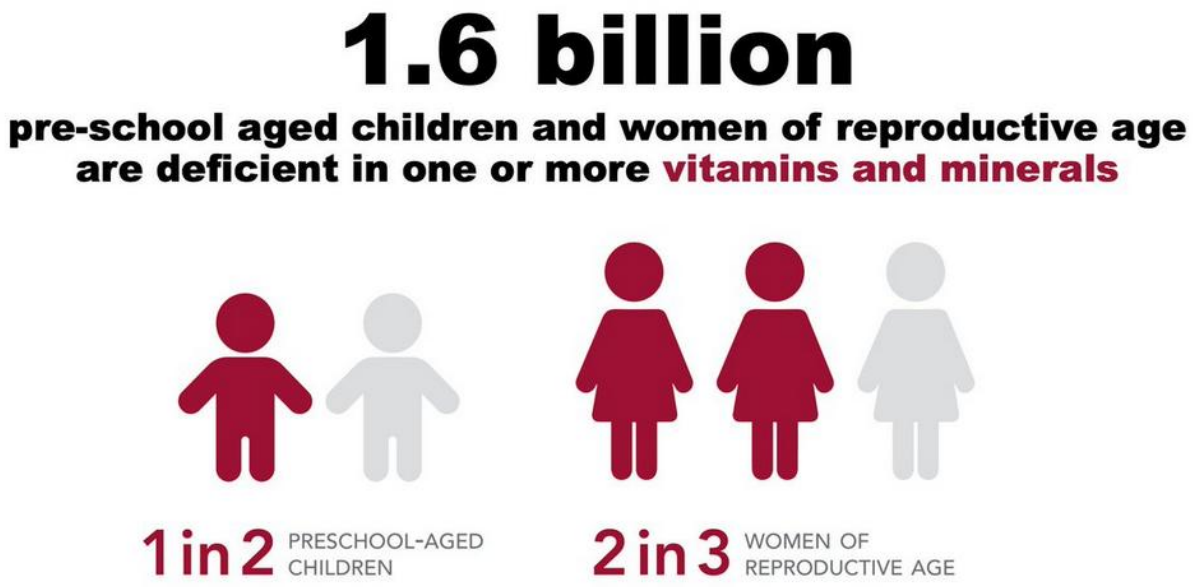
-26%
Unit Sales
U.S. 2021 - 2023

Demand for meat set to increase mainly in low and middle-income countries



OECD, 2021

Meat as a part of a highly nutritious diet

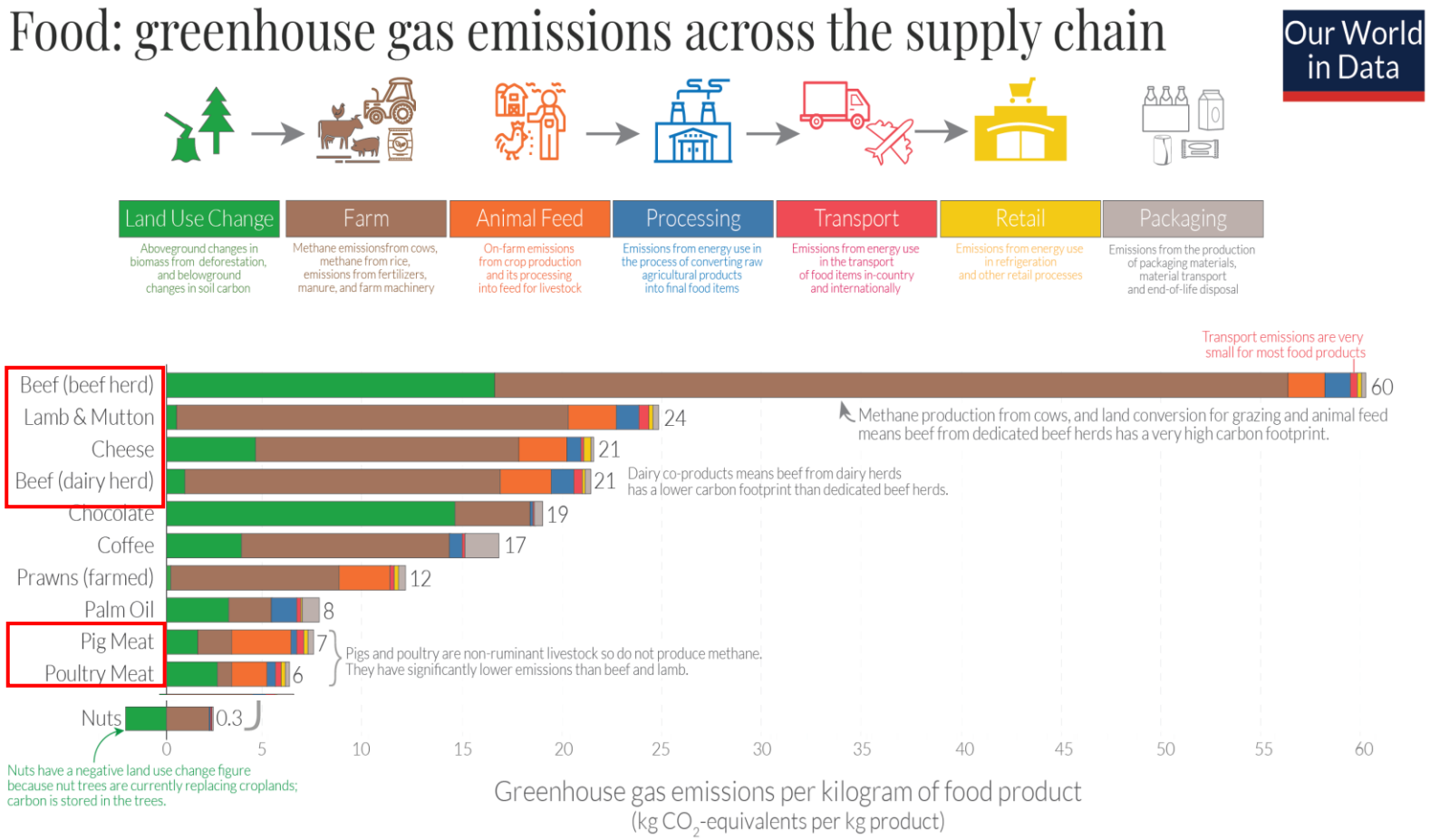


Stevens et al., Lancet Global Health 2022

- Only dietary source of intrinsic retinol, heme iron, Vit B12 and D (except some mushrooms)
- Highly bioavailable zinc
- Complete amino acid profile (essential and non-essential) and bioavailable protein
- Source of eicosapentataenoic acid (EPA) and docosahexaenoic acid (DHA)
- Unique source of creatine, anserine, taurine, carnosine, bioactive peptides cysteamine
- Anti-oxidants.

Van Vliet 2021 Front in Sust Food Syst.

Livestock contribute 15% GHG emissions



Is Cultivated meat the solution?

Aim:

1- Nutritious,
2- Tasty,
3- Sustainable,
4- Affordable

What is Cultivated meat and can it meet these aims?

Cultivated meat
Production of meat in a food manufacturing plant.
There is no need to kill animals to produce this product and complements the offering from conventional farming.

	Chicken	Pork	Beef
Carbon footprint	↘ 17%	↘ 52%	↘ 92%
Land use	↘ 63	↘ 72%	↘ 95%

Swartz, E. W. (2021)..

What do consumers tell us?

Sausage and meatball prototypes scored at a tasting session

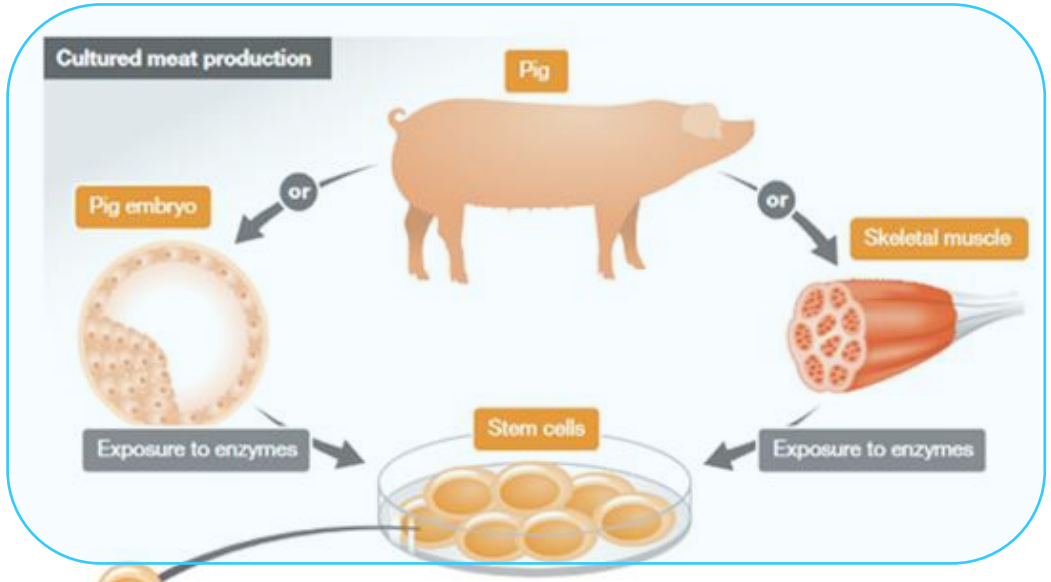
MEATABLE

Sausages

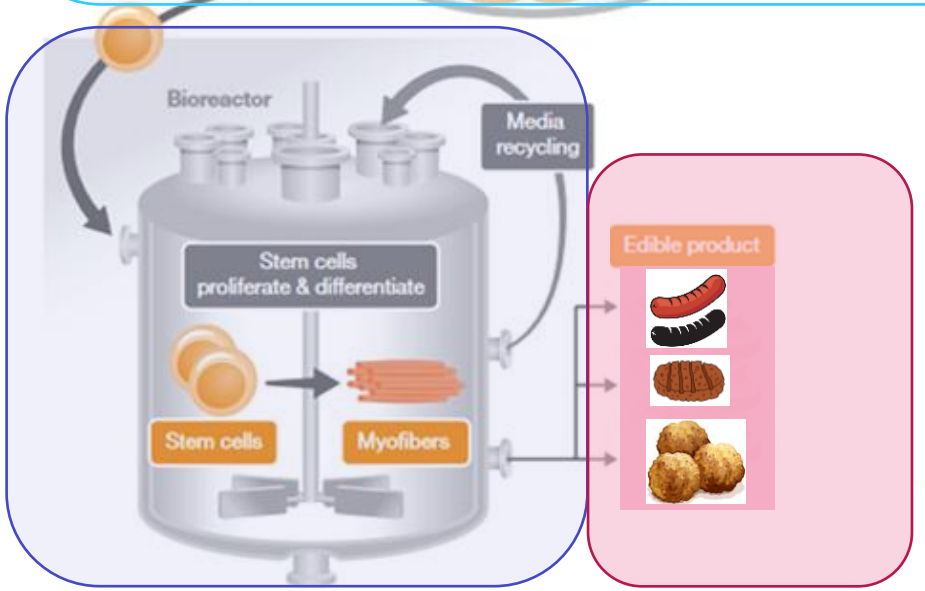
Meatballs

How is Cultivated meat manufactured?

1- Cell isolation, purification, and initial expansion



2- Large scale expansion



Production costs:

£250K beef burger in 2013

£40 chicken nugget in 2019

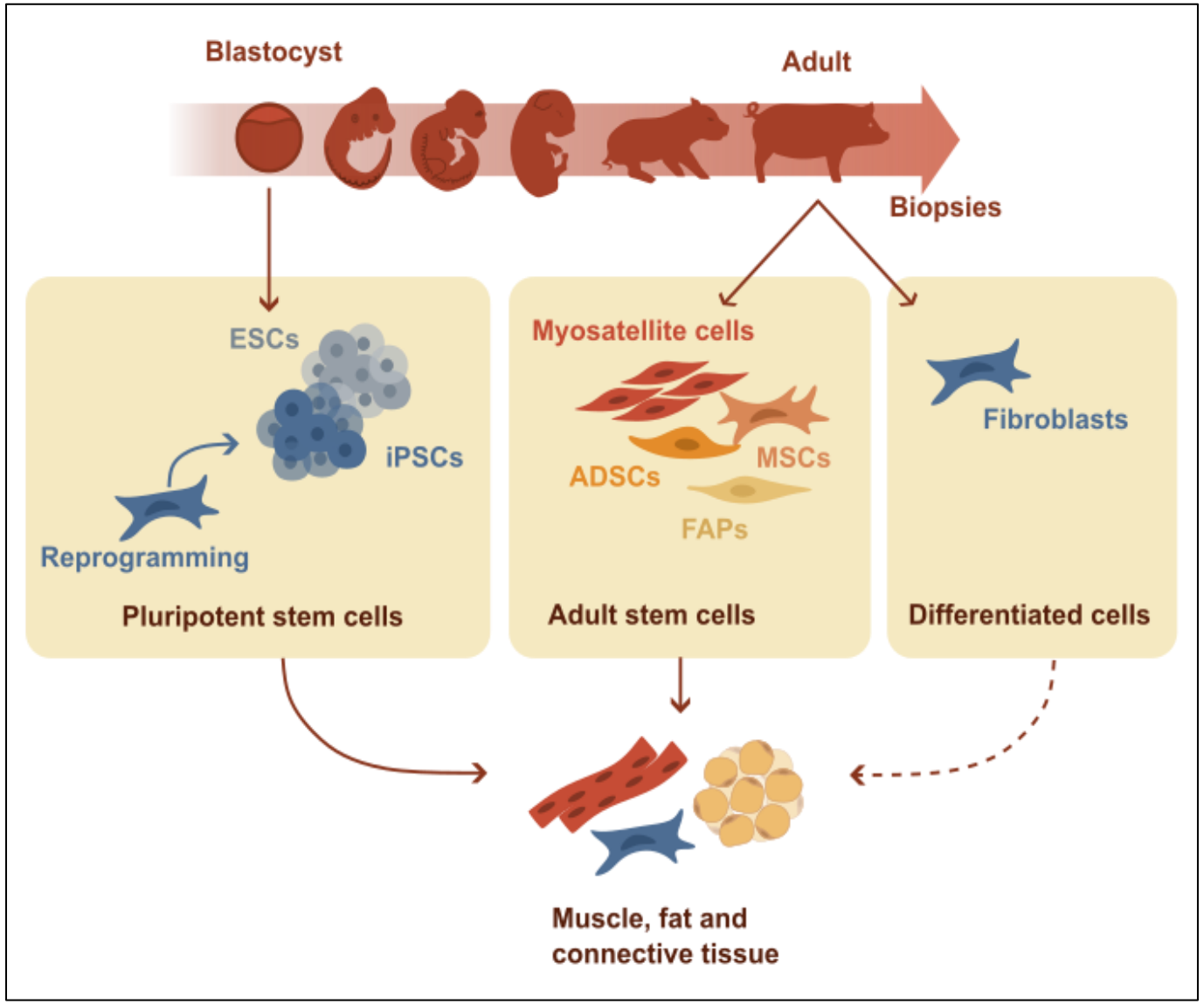
Estimated LCA anticipate (Schwarz, 2021):

£5/kg by 2030.

3- Cell differentiation, tissue maturation and product processing

- The challenge of feeding 10 billion
- Cultivated meat: Definitions and processes
- **Inputs: cell lines, media, growth factors**
- **Building a robust supply chain**
- **Opportunities for integration with existing industrial capabilities and sectors**

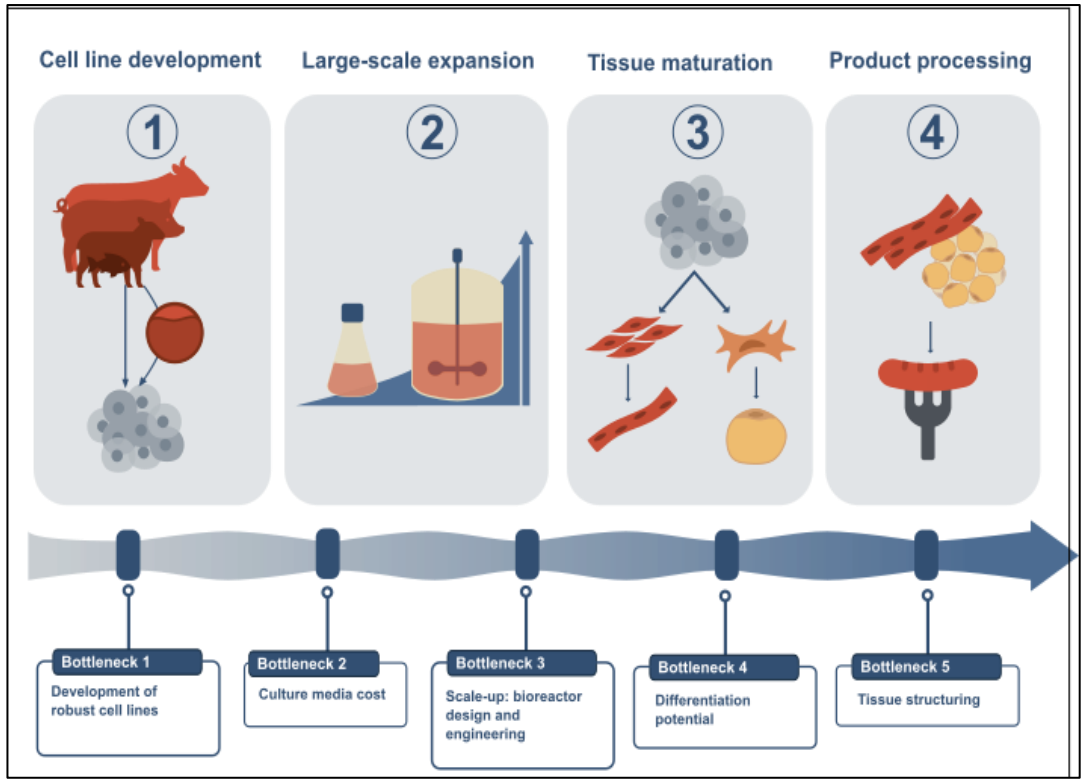
What cell types are used for cultivated meat?



Properties of different cell types used in cultivated meat

	Tissue stem cells (primary)	Somatic cells (immortalized)	Pluripotent stem cells (ESCs)	Pluripotent Stem cells (iPSCs)
Origin (slaughter free)	Yes	Yes	Yes	Yes
Use of antibiotics	Yes	Yes	No	Yes
Differentiation potential	Limited/variable	Limited/variable	Variable/high	Variable/high
Proliferation	Variable (~20-70 hrs)	Rapid	Rapid (~16 hrs)	Rapid
Long term genetic stability	Variable	Variable	High	Variable/high
Phenotypic stability	High	High	High	High
Reproducibility and traceability	Variable	Variable	High	Variable
Derivation efficiency	High	Variable	High	Variable
Commercially available	Yes	Yes	Yes	Yes

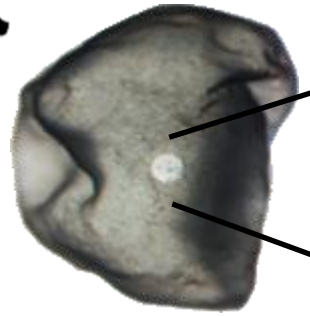
Addressing critical bottlenecks for improving efficiency of CM production



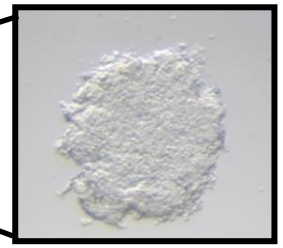
Bottlenecks	Solution
1- Standardized cell sourcing from a variety of species (domestic and exotic) and breeds (e.g. Wagyu, Aberdeen Angus, Berkshire pig, etc)	Develop efficient and reproducible GM-free iPSCs
2- Reduce production costs (**80% cost**)	Develop new food grade culture media (Vitamins, AAs, energy) and genetic engineering for growth factor-free cultures: Growth Factors.
3- Scale-up	Develop suspension culture systems for bioreactors
4- Differentiation efficiency	Forward programming methods yielding high efficiency muscle and fat differentiation
5- Tissue structuring	Develop hybrid products using plant-based proteins as scaffolds (soya, peas, alginate, etc)

EPISC are available from multiple livestock

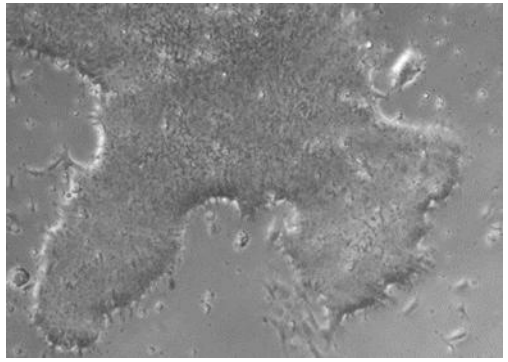
Pig day 10 embryo

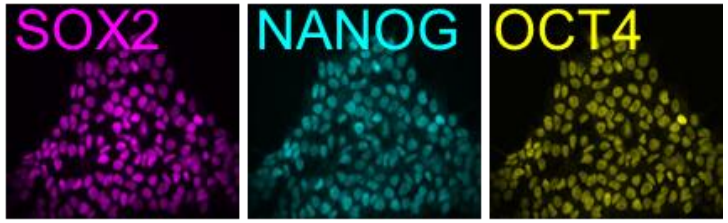


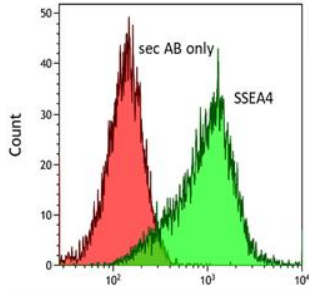
Pig epiblast

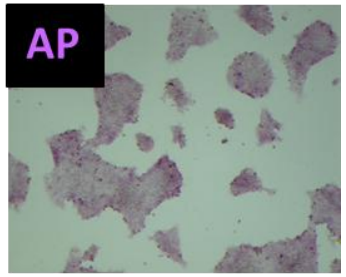


Pig epiblast stem cells



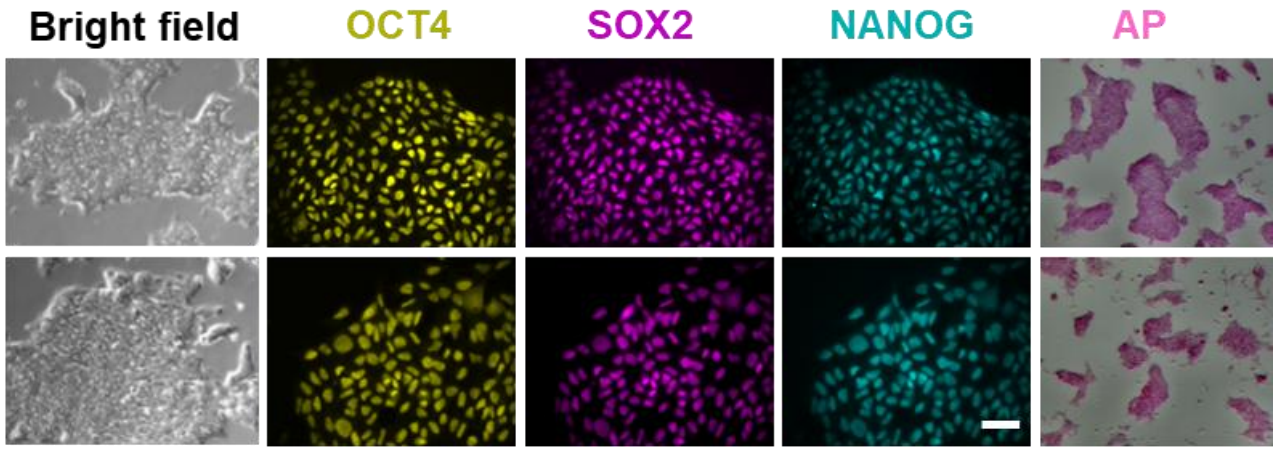






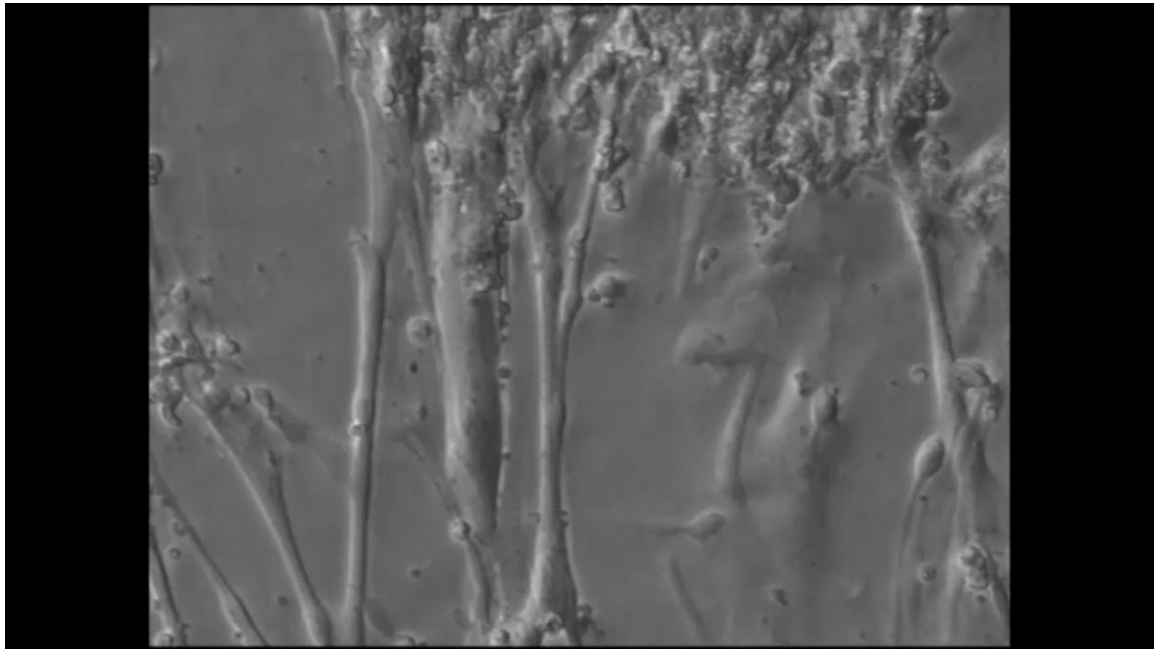
Key Features of livestock stem cells:

- ✓ Chemically defined medium
- ✓ Feeder-free
- ✓ Antibiotic free
- ✓ Long term self-renewal
- ✓ Rapid proliferation (~16 hrs)
- ✓ Phenotypic stability
- ✓ Amenable for GM
- ✓ Fully traceable
- ✓ Multilineage differentiation capacity



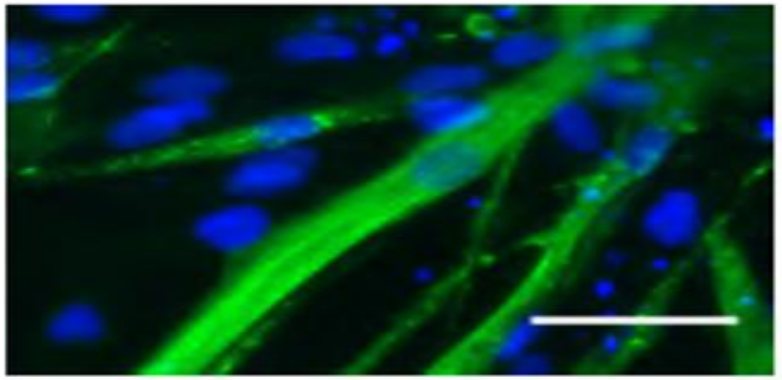
Kinoshita et al., 2021 PMID: 34874452

Epiblast stem cell muscle cells in vitro

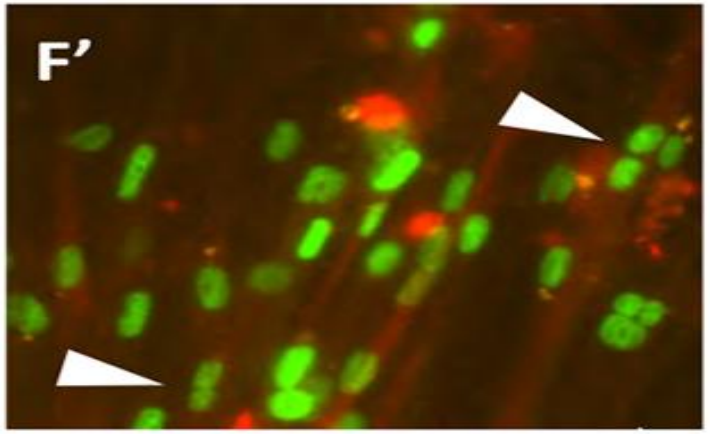


Muscle markers

TITIN



MYOG



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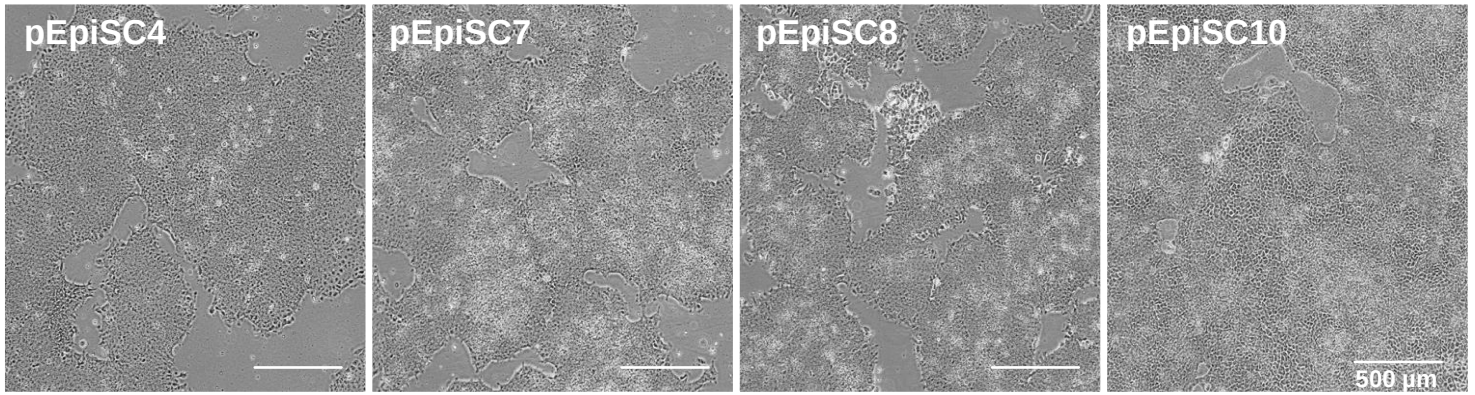
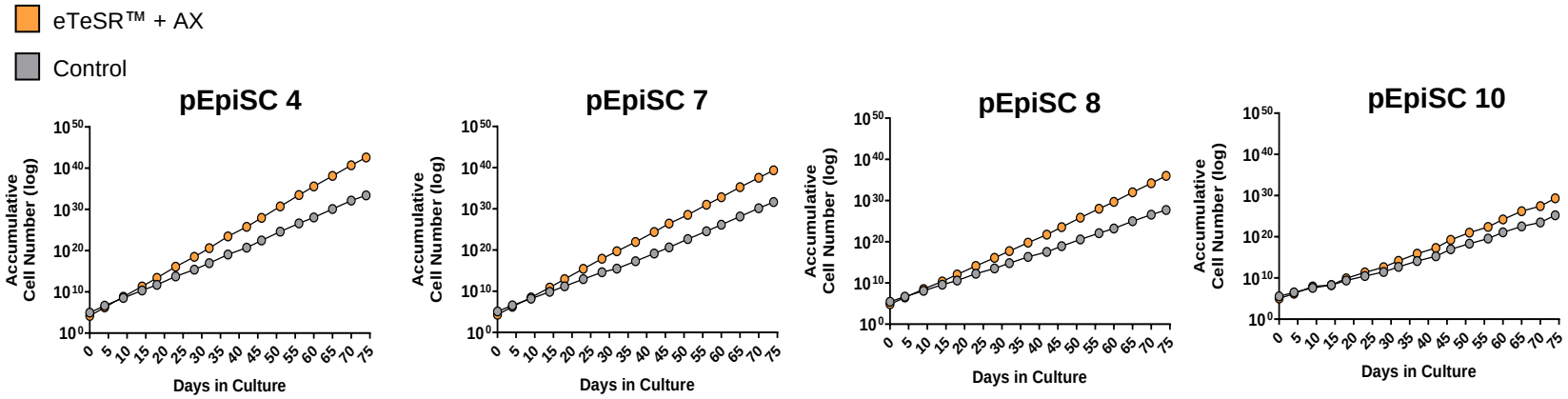
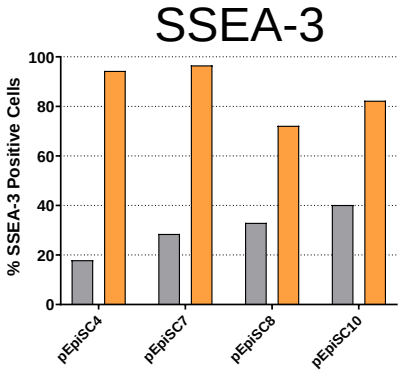
eTeSR™ Supports Expansion of highly homogeneous cultures of Pig Epiblast Stem Cell Lines



- Improved quality (e.g: SSEA3)
- Reduced apoptosis
- Rapid proliferation
- Genomic and phenotypic stability
- Reduced feeding regime
- Less handling

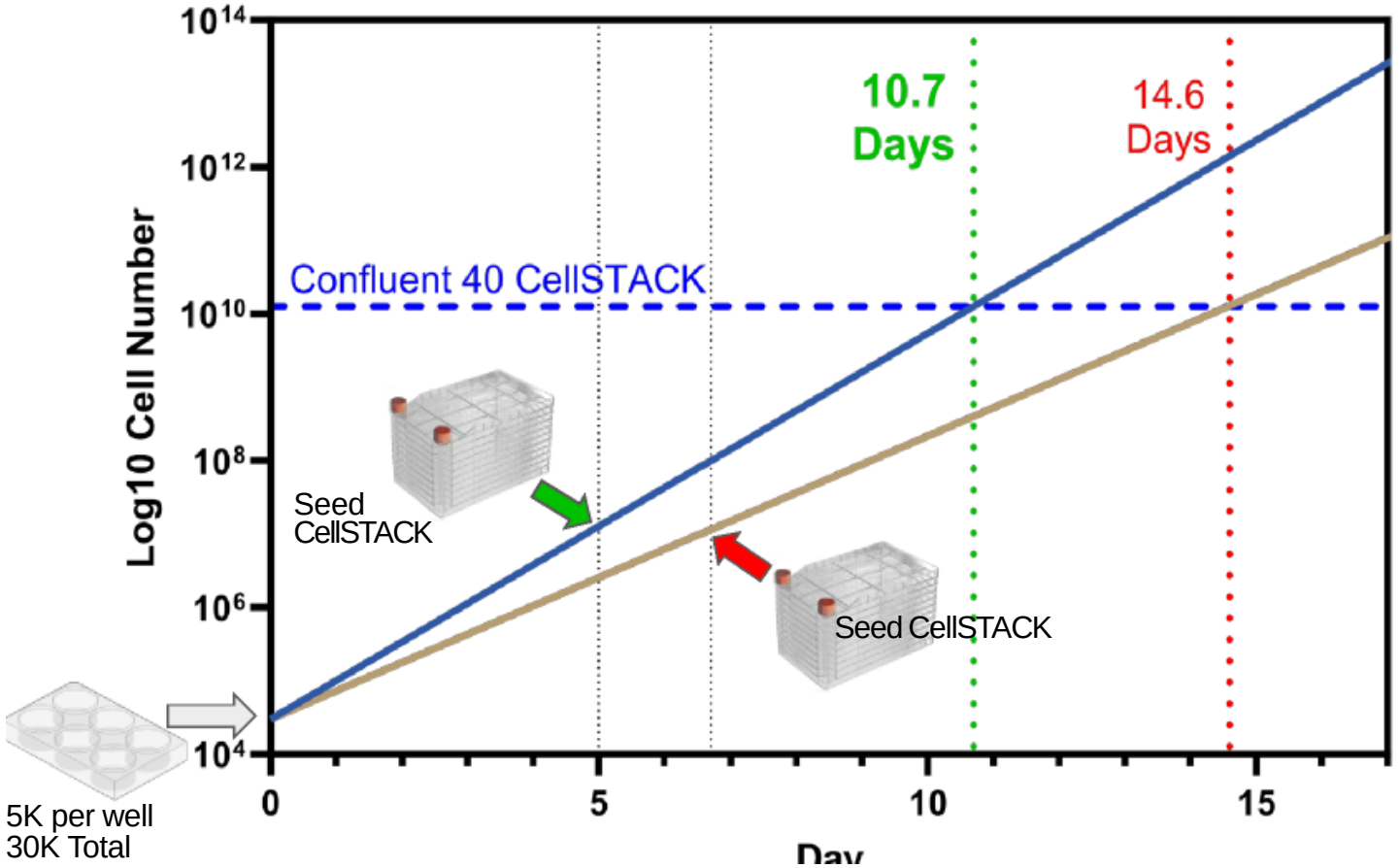
Less medium (~25%)= More cells





Media launched in 2025 (Q1)

eTeSR™ + AX yields ~60% saving in media and less time to produce more cells



Confluent 40-layer CellSTACK

Less time - (~4 days)

More cells -
(12,000,000,000) at day 10.7

Less medium (~25L)

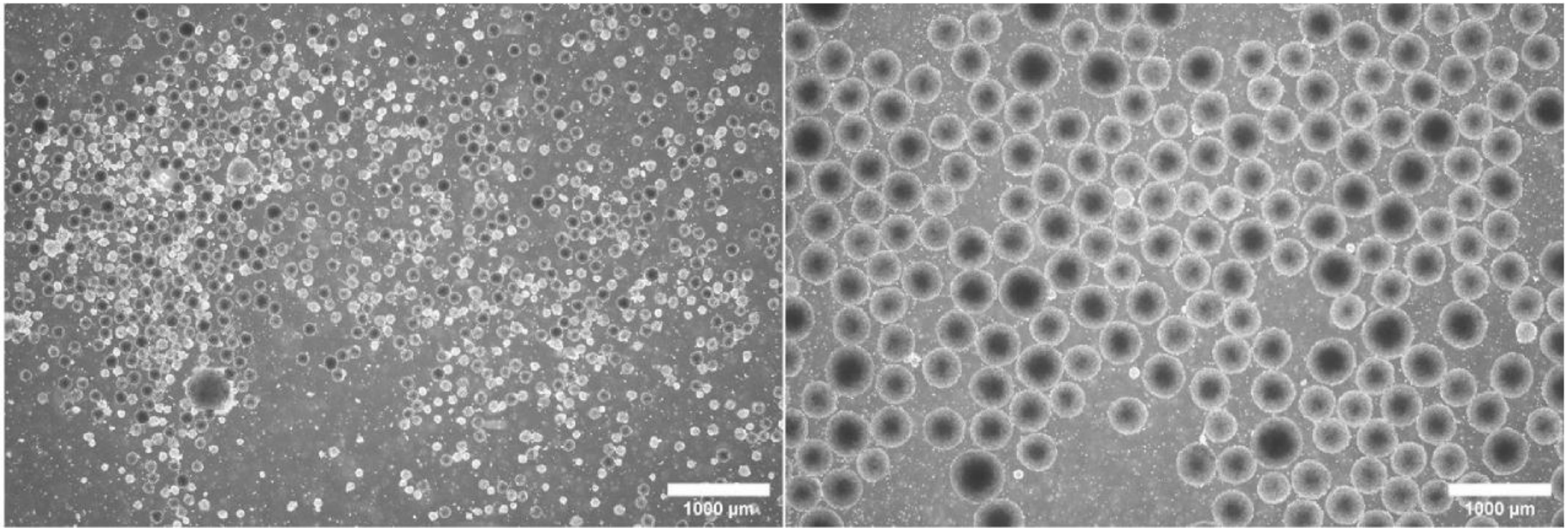
Volume Required
eTeSR™+ AX= **~15 L**
Published = **~40 L**

Media launched in 2025 (Q1)

Optimization of eTESR formulation yields suspension culture growth in pEpiSC

eTeSR + AX

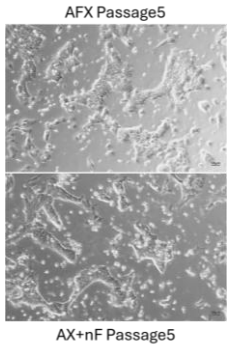
eTeSR + AX 3D



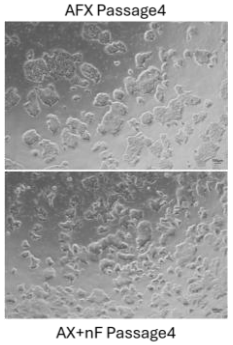
pEpiSC Day 4

Plant-derived bFGF

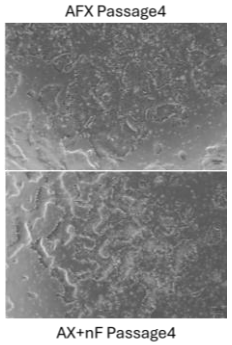
bEpiSC99.1



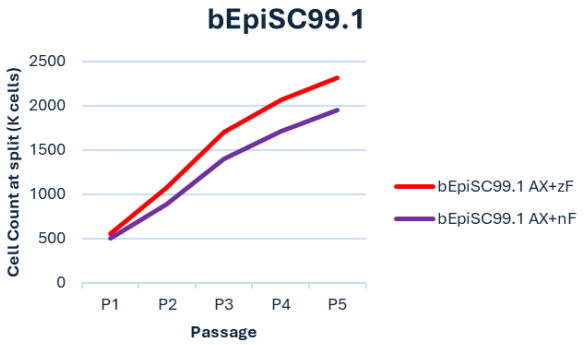
sEpiSC21

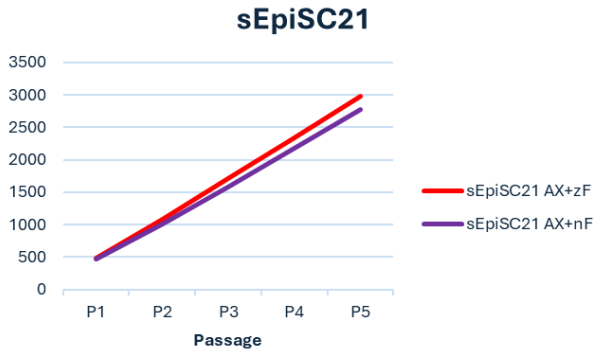


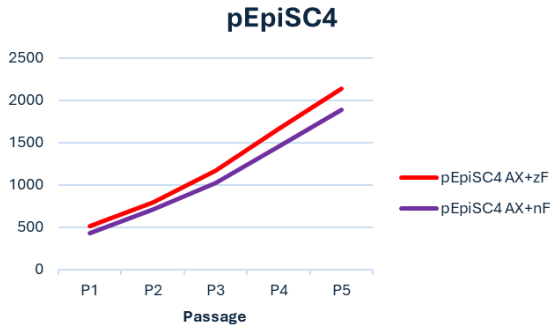
pEpiSC4



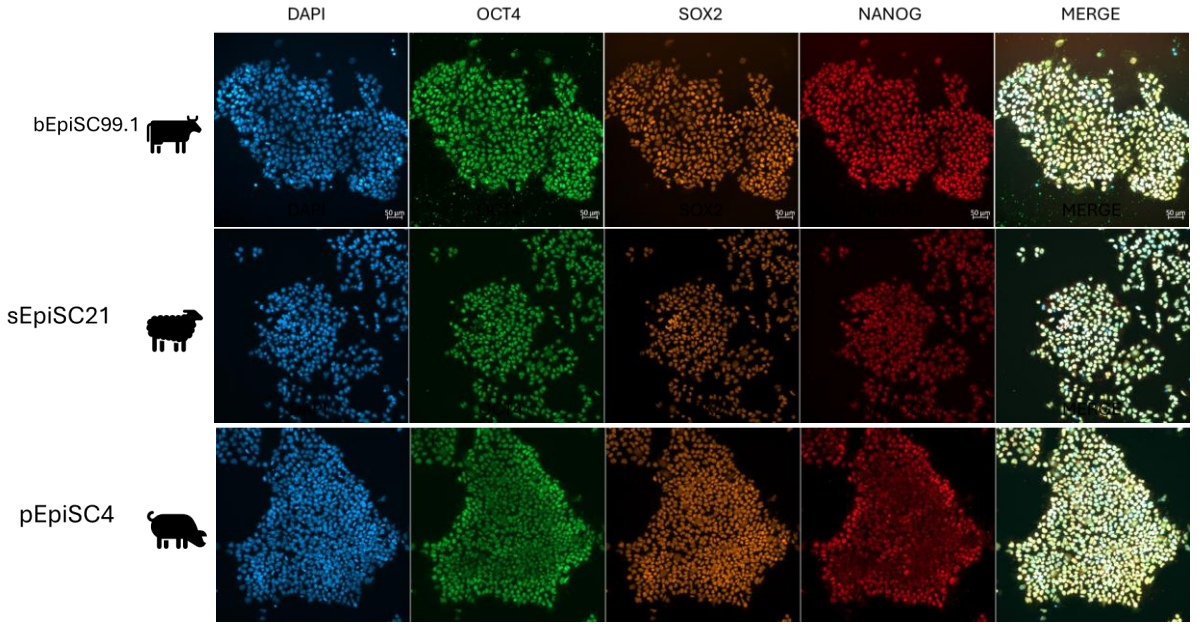
Cumulative Cell Counts





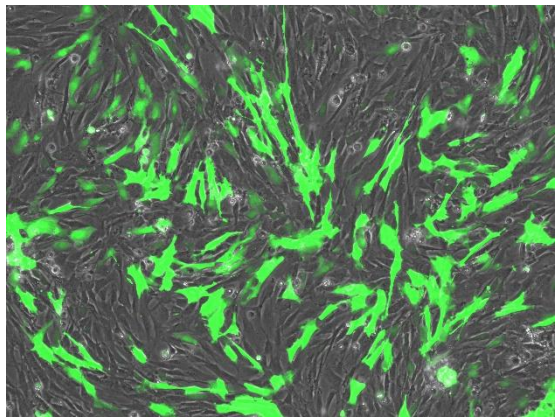


Plant-derived FGF is considerably more economical and currently we are testing a stabilized form which requires 50% less media changes.

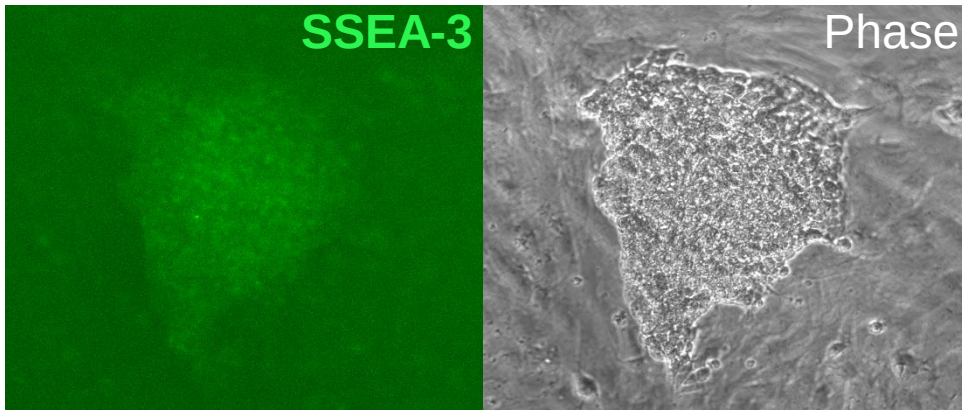


Pig iPSCs production using non-integrative vectors

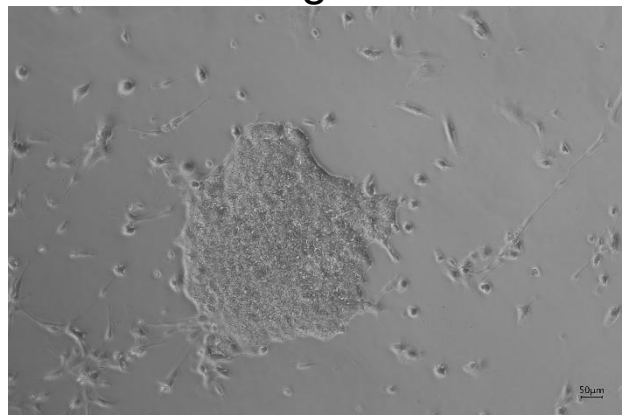
Pig fibroblasts



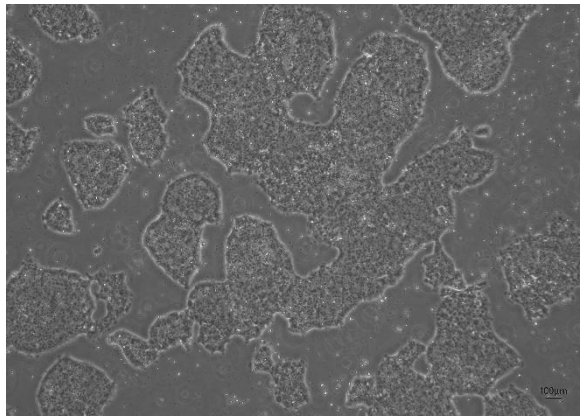
After 12 days



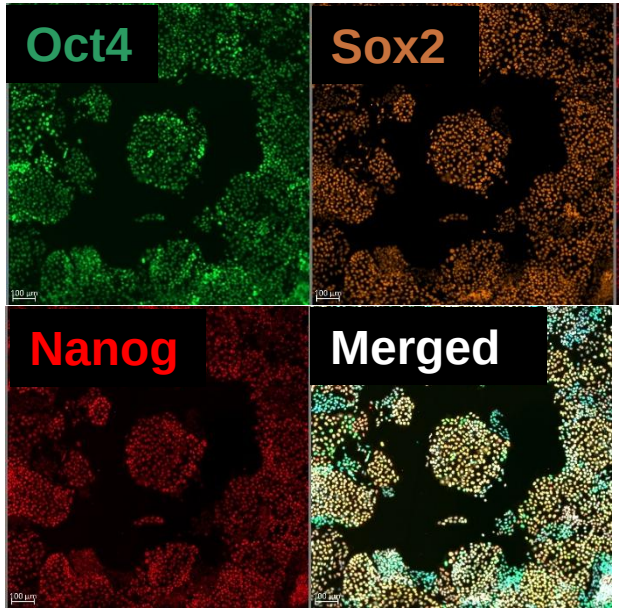
Passage 1



Passage 25



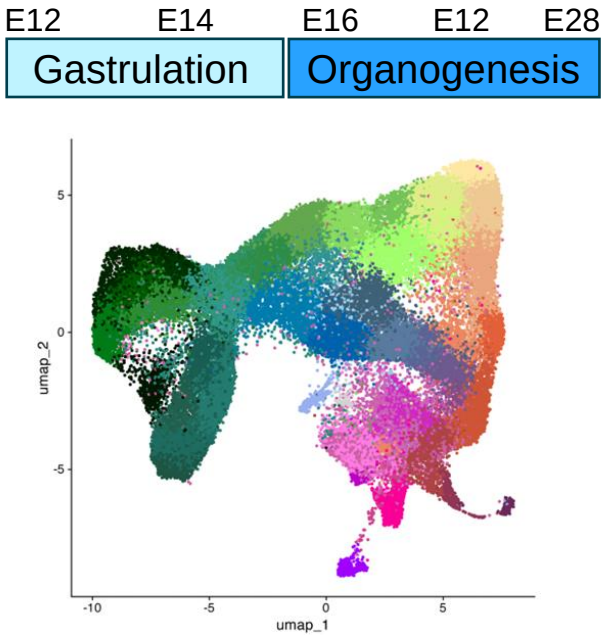
Pluripotency markers

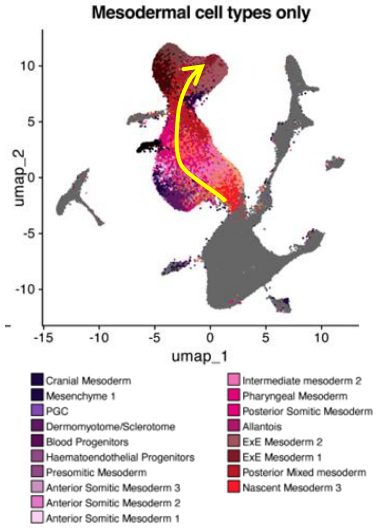


Key Features of pig iPSC:

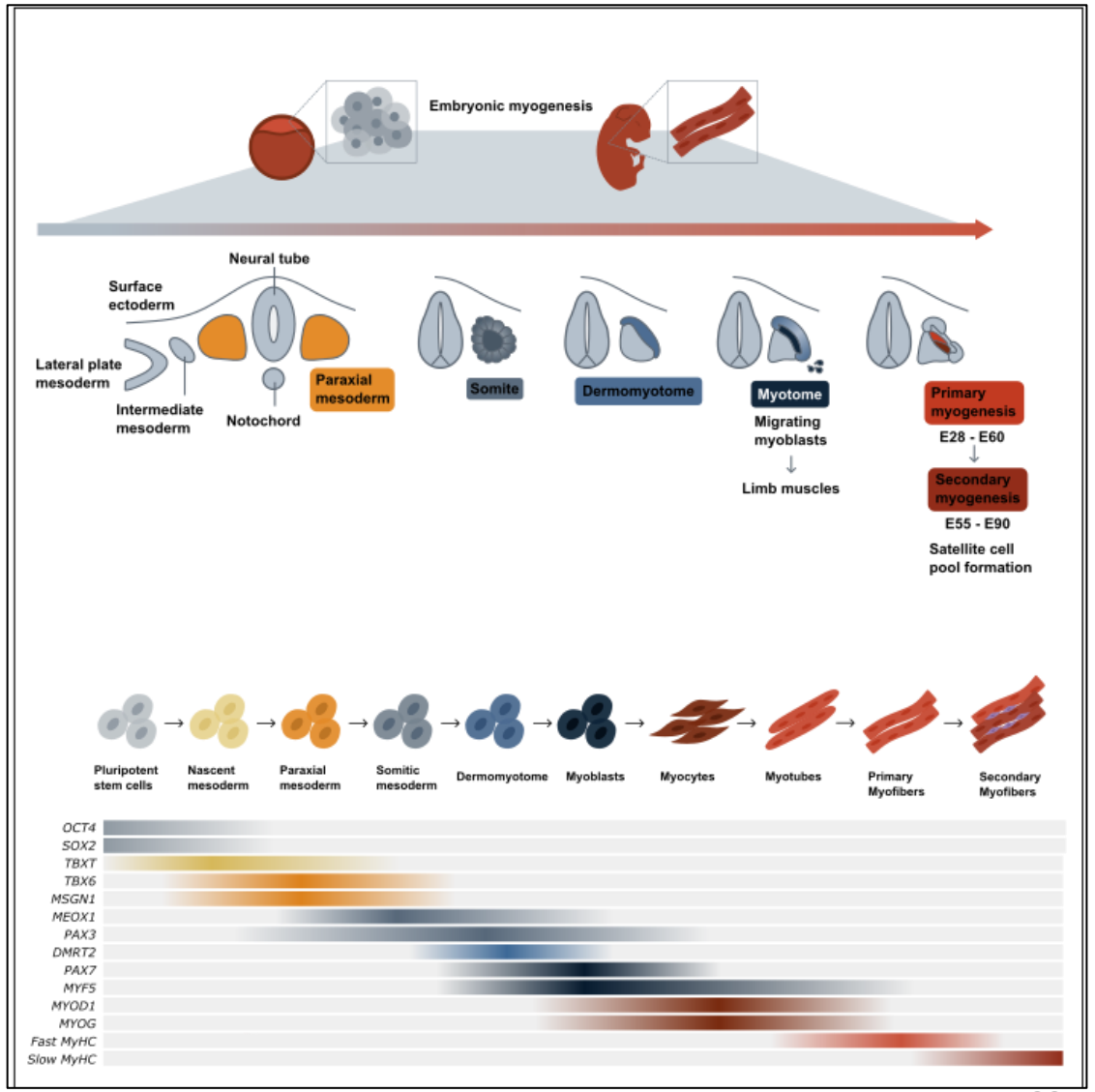
- ✓ **Chemically defined medium**
- ✓ **Feeder-free**
- ✓ **Long term self-renewal**
- ✓ **Rapid proliferation (~16 hrs)**
- ✓ **Phenotypic stability**
- ✓ **Amenable for GM**
- ✓ **Fully traceable**
- ✓ **High efficiency**
- ✓ **Multiplineage differentiation capacity**

A single cell atlas of pig myogenesis





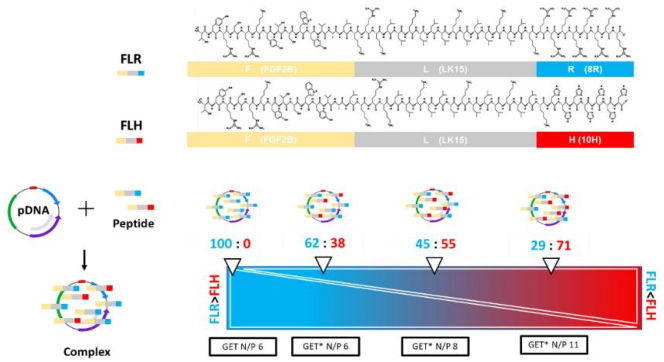
Forward programming strategies for the differentiation of Stem cells into myoblasts



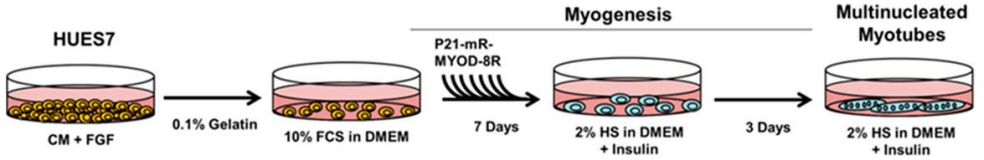
Forward programming of muscle differentiation: delivery of DNA cargoes into bovine ESC using nanoparticles

Glycosaminoglycan-binding enhanced transduction (GET)

Peptides that interact with cell membrane heparan sulfates and promote cell-penetrating peptide-mediated endocytosis into cells.

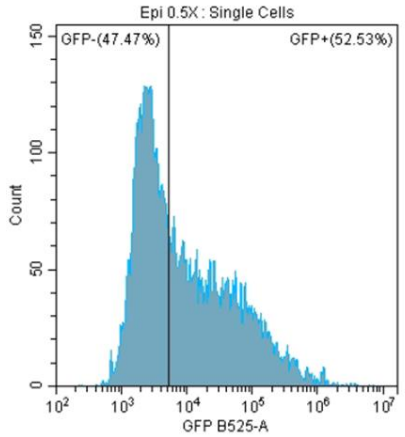


Dixon et al., 2016

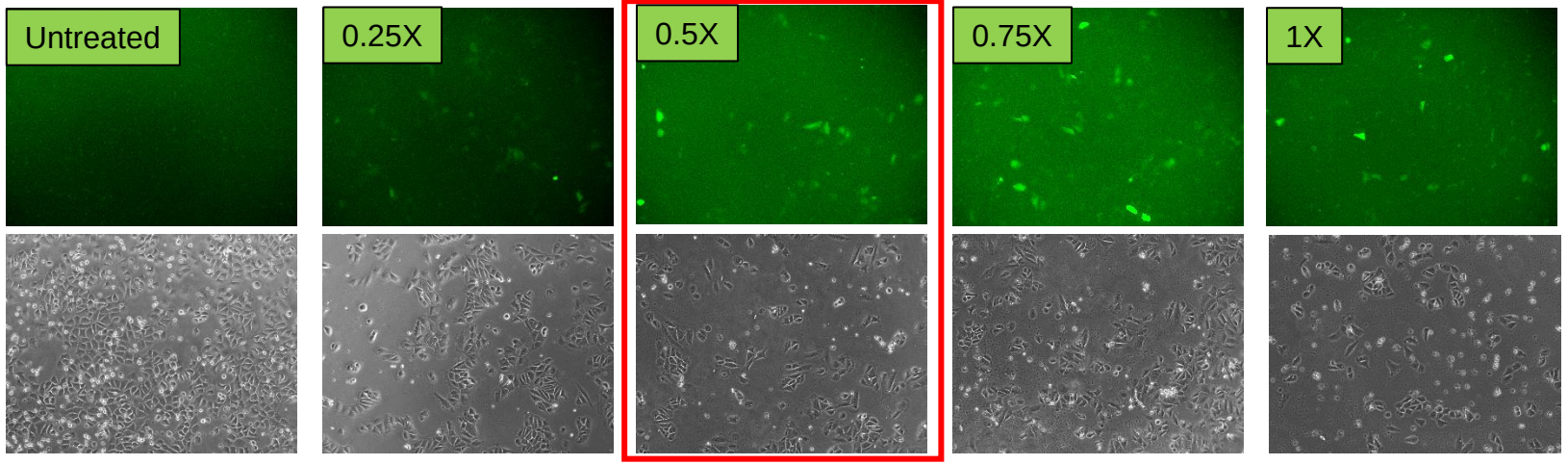


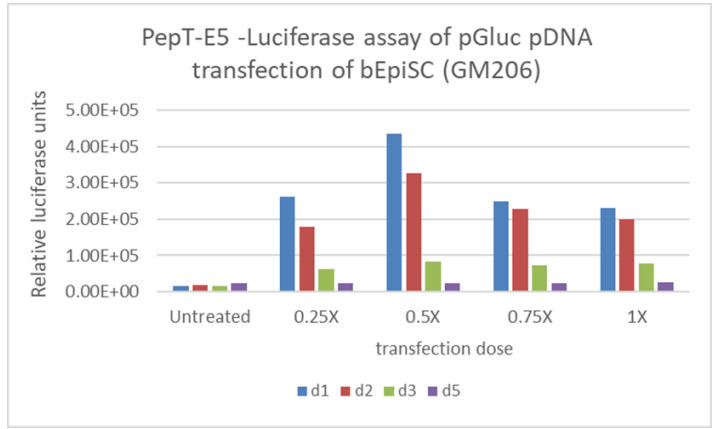
40% muscle differentiation

Dixon et al., 2016



Bovine ESC



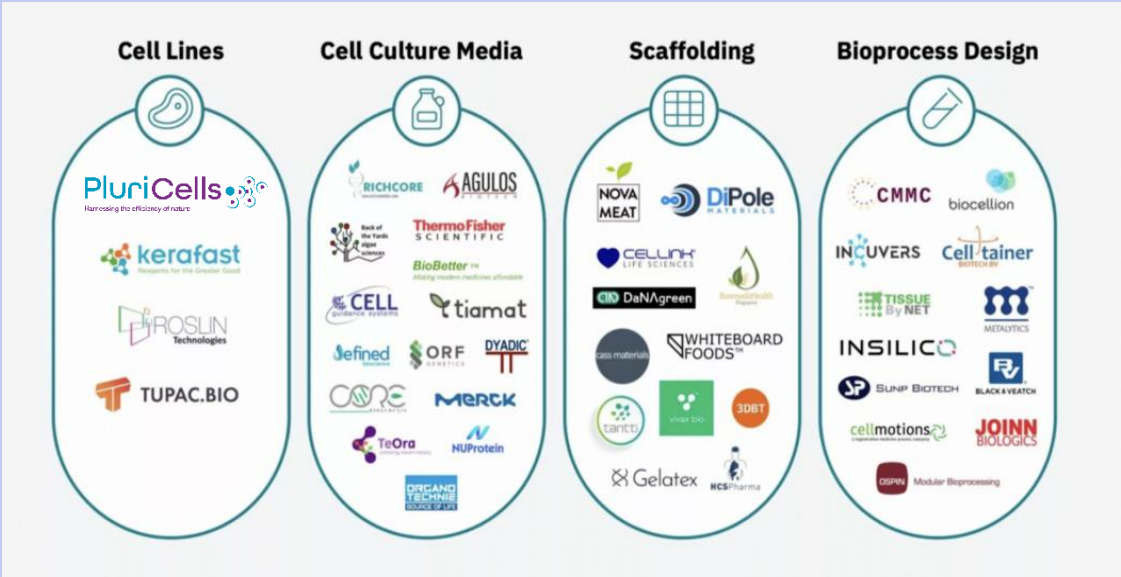


- The challenge of feeding 10 billion
- Cultivated meat: Definitions and processes
- Inputs: cell lines, media, growth factors
- Building a robust supply chain
- **Opportunities for integration with existing industrial capabilities and sectors**

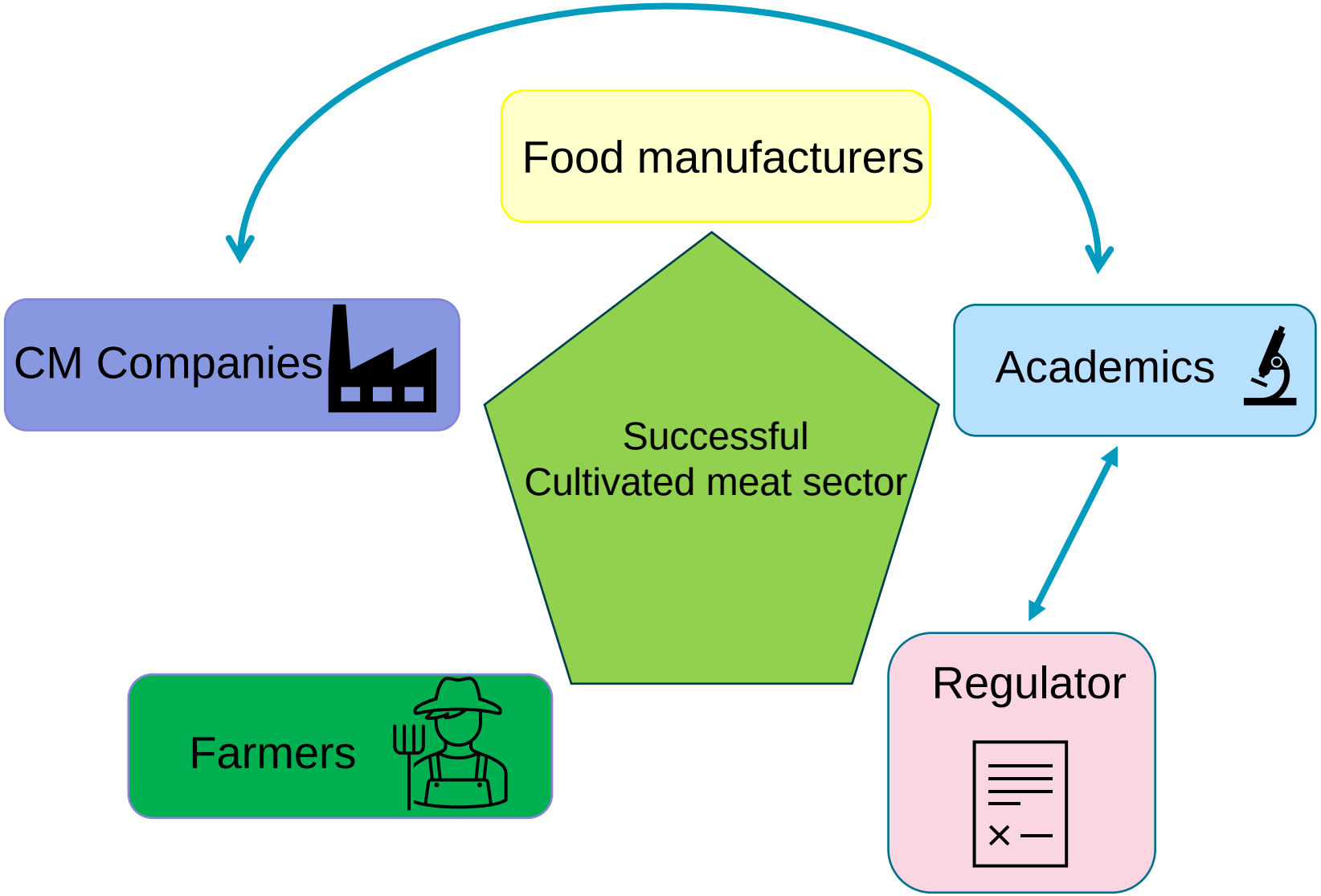
Cultivated meat ecosystem is rapidly growing

Cultivated meat companies

Supply chain



Engaging with stakeholders



Meeting the regulatory requirements

1- Origin: Source of cell, purification steps, pathogen free, microbiological tests, cell banking and adaptations, and transoformation of the cells..

2- Consistency of product: Variability of compositional data between batches (at least 5 batches needed) and includes chemical (heavy metals, pesticides, etc) and nutritional (complete amino acid profile) as well as microbiological.

3- **Genetic modification**: type of GM method and changes caused to cells have to be disclosed.

Guidance on the scientific requirements for an application for authorisation of a novel food in the context of Regulation (EU) 2015/2283 (Sept 2024)

NEWS

FSA launches pioneering regulatory programme for cell-cultivated products

The sandbox programme, funded by the Department of Science, Innovation and Technology's Engineering Biology Sandbox Fund, will make sure Cell-Cultivated Products (CCPs) are safe for consumers before they're sold, whilst supporting innovation in the sector.

March 2025

Cultured meat around the world

Over 174 companies worldwide with more than £3.1 bn invested in F

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Singapore approves lab-grown 'chicken' meat

2 December 2020

Eat Just chicken nuggets

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Technology

Lab-grown chicken safe to eat, say US regulators

17 November 2022 · Comments

By Shiona McCallum

Technology reporter

NEWS

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Lab-grown meat set to be sold in UK pet food

Cultivated chicken is expected to soon be found in UK pet food (file picture)

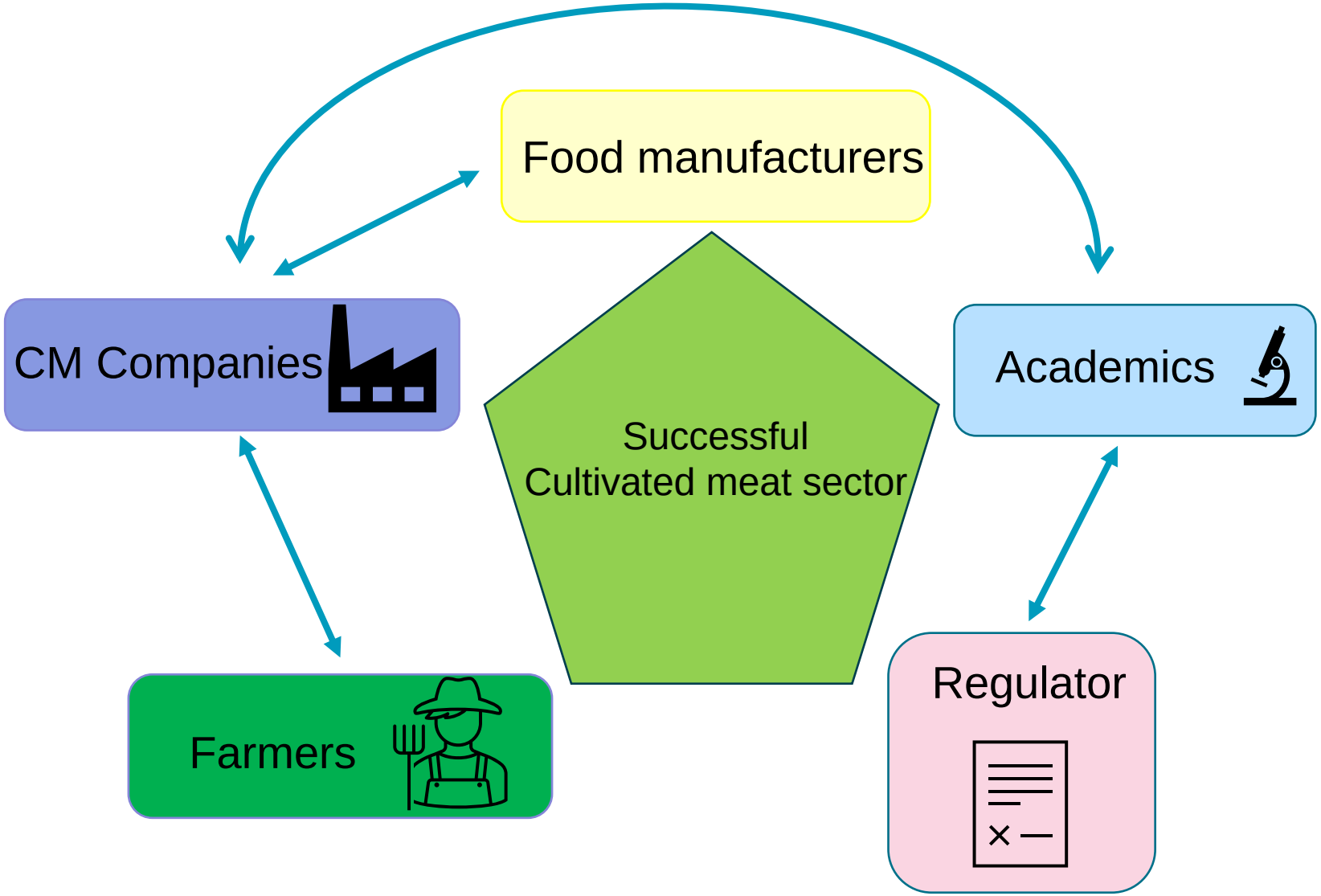
Harrison Jones

BBC News

17 July 2024

The UK has become the first European country to approve putting lab-grown meat in pet food.

Engaging with stakeholders



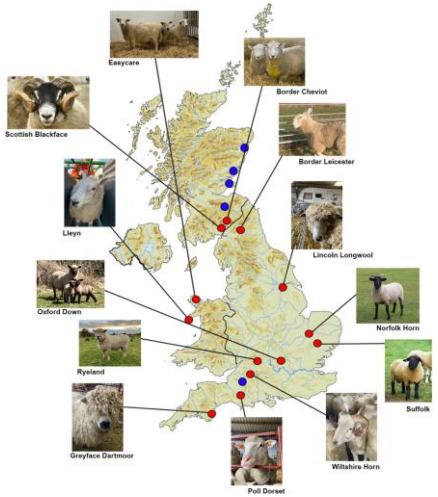
Engaging with farming community

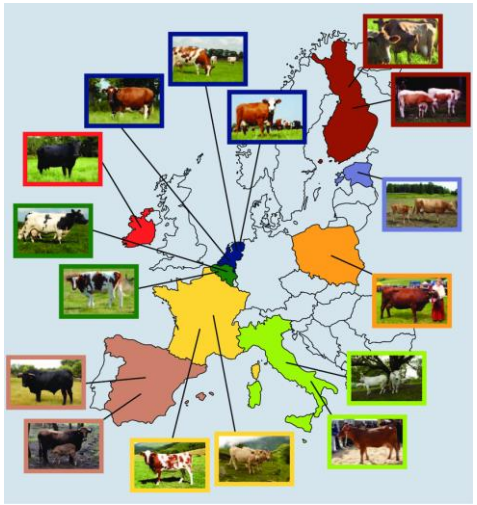
CM Companies

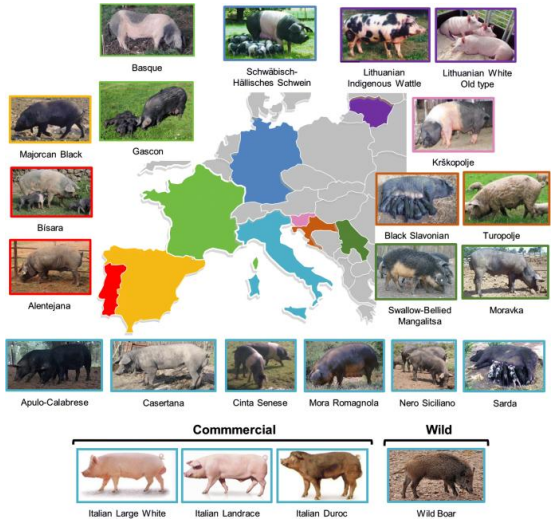
Farmers

1. Develop a panel of cell lines from different breeds and sexes to diversify product development and marketing.
2. Consumers will have more choice and variety of products.

1. Farmers will diversify their income by producing embryos or offering somatic cell biopsies from specific animals of interest.
2. New markets and scalability will become an option not currently available to them.







Conclusions

- **The cultivated meat industry is an emerging sector that will become consolidated as these products become regulated in multiple continents.**
- **Bioprocess optimization using “quality by design principles” are essential to reduce production costs. For example, media costs has decreased by over 75%, but there is more to be done, particularly with the components of the basal medium.**
- **Integration with the food manufacturers, to utilize existing capacity is critical for cost reduction and scalability.**
- **Integration with the farming community will results in more choice for consumers and additional income opportunities for farmers.**

University of Nottingham
UK | CHINA | MALAYSIA

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