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# Introduction to cultivated meat

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“Fifty years hence, we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium”

~ Winston Churchill, 1931



# Motivation

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# Motivation

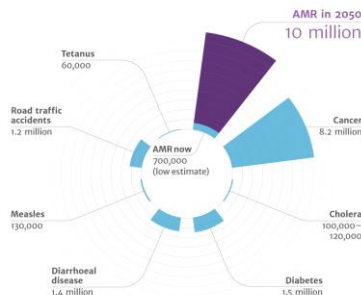
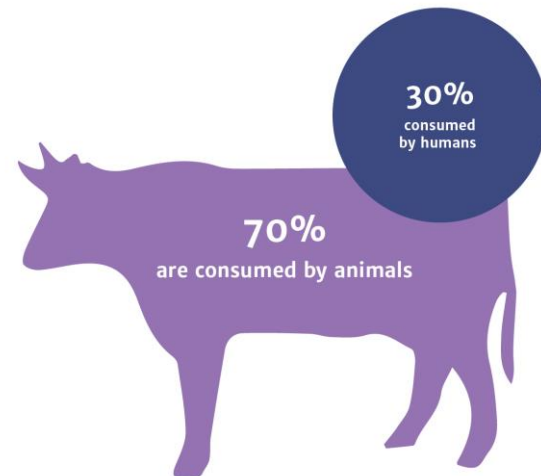
## ▶ Food safety

- ▶ Annually in the US: 76 million cases of foodborne illnesses, 325 thousand hospitalizations, **5,000 deaths**, a third of which is attributed to meat.
- ▶ WHO: “Of all human diseases, 60% originate in animals”



# Motivation

- ▶ Food safety
- ▶ **Antibiotic Resistance**
  - ▶ US: 70% of the antibiotics is used for animal agriculture.
  - ▶ \$2.9 trillion annually to the OECD countries by 2050
  - ▶ Kill more than cancer by 2050



Avesar et al, PNAS (2017)  
Chen et al, Morb. Mortal. Wkly. Rep (2017)  
Tang et al, Lancet Planet Health (2017)  
Nguyen et al, Appl. Environ. Microbiol. (2016)  
Friedman et al, Clin. Microbiol. Infect (2016)  
Elliott et al, CGD Policy Paper (2015)  
O'Neill, Rev. Antimicrob. Resist (2014)  
Kümmerer et al, J. Antimicrob. Chemother. (2003)

Source: Animal consumption figure of 8,893,103kg from FDA, 2012. Human consumption of 3,379,226kg in 2012 based on calculations by IMS Health. The figures are rounded from 72.5% used in animals and 27.5% used in humans.

# Motivation

▶ Food safety

## ▶ Antibiotic Resistance

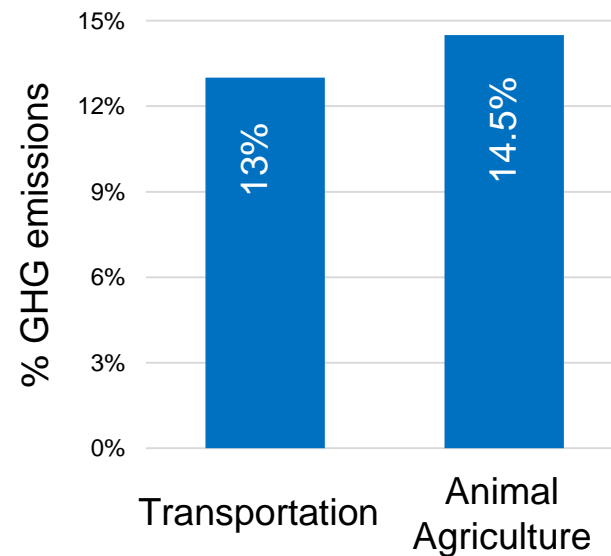
- ▶ US: 70% of the antibiotics is used for animal agriculture.
- ▶ \$2.9 trillion annually to the OECD countries by 2050
- ▶ Kill more than cancer by 2050



Chen et al, *Morb. Mortal. Wkly. Rep* (2017)  
Reardon, *Nature News* (2017)  
Monte et al, *Antimicrob. Agents Chemother* (2017)  
Nguyen et al, *Appl. Environ. Microbiol* (2016)

# Motivation

- ▶ Food safety
- ▶ Antibiotic Resistance
- ▶ **Environmental impact**
  - ▶ 14.5% of GHG emissions
  - ▶ UN:
    - ▶ 78% for terrestrial biodiversity loss
    - ▶ 80% soil acidification and air pollution
    - ▶ 73% for water pollution



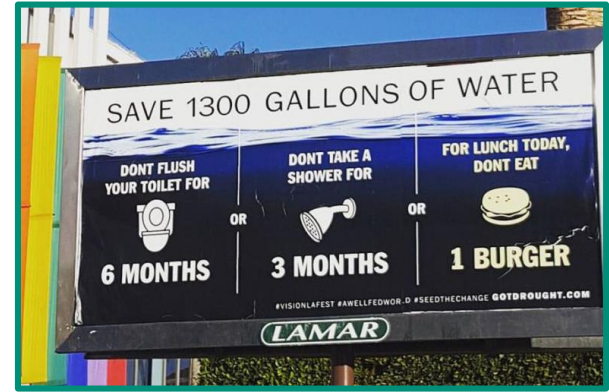
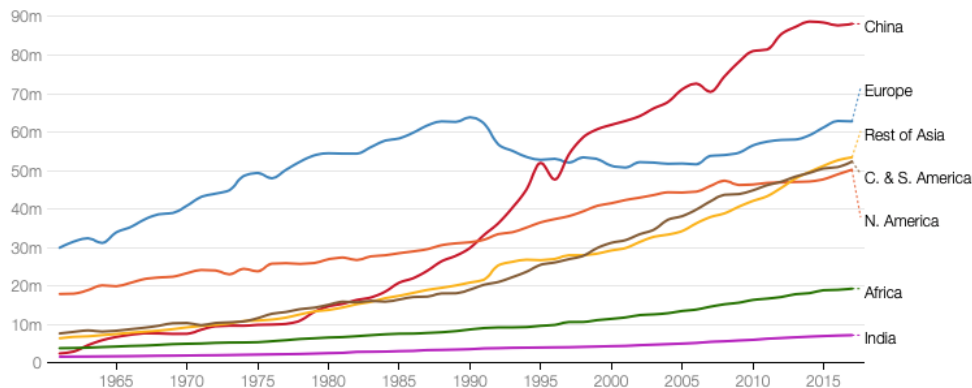
# Motivation

- ▶ Food safety
- ▶ Antibiotic Resistance
- ▶ Environmental impact

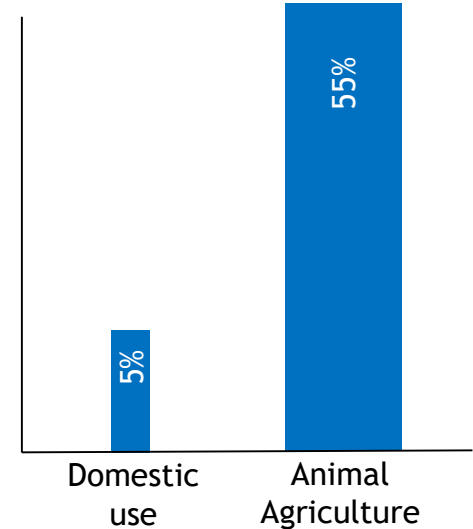
## Resource use

- ▶ **15,000 liters** of water for 1 kg of beef
- ▶ **40% of arable lands** is used for meat production.

Global meat consumption by region



water consumption





# Motivation

- ▶ Food safety
- ▶ Antibiotic Resistance
- ▶ Environmental impact
- ▶ Resource use
- ▶ **Animal welfare**
  - ▶ **150 billion** animals are slaughtered annually for meat.



Herzog, *Psychol. Today.* (2016)  
Schröder and McEachern, *Int. J. Consum. Stud* (2004)  
Verbeke and Viaene, *J. Agric. Environ. Ethics* (2000)  
Hopkins and Dacey, *J. Agric. Environ. Ethics* (2008)  
Sharma et al, *J. Food Sci. Technol.* (2015)  
van der Weele and Driessen, *Animals (Basel)* (2013)  
FAO (2003)

# Solutions

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Plant-based meat



Cultivated meat

# The global plant-based meat market is projected to reach at least \$100b if not \$370b by 2035

U.S. plant-based meat market projections

Source	Projected market size	By year	Projected share of U.S. meat market
Grizzle	\$34b	2030	10%
Bernstein	\$41b	2030	12%



Global plant-based meat market projections

Source	Projected market size	By year	Projected share of global meat market
UBS	\$85b	2030	6%
J.P. Morgan	\$100b	2035	7%
A.T. Kearney	\$370b	2035	23%



## CREATING NEW MEAT

## PLANT-BASED MEAT



## CLEAN MEAT



## SUPPORTING NEW MEAT

## INCUBATORS



## NONPROFITS



## ACADEMIA

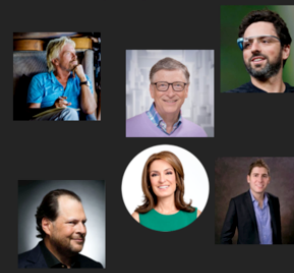


## FUNDING NEW MEAT

## VENTURE CAPITALISTS



## INDIVIDUALS



## COMPANIES





**BEYOND MEAT**

**3D PRINTED**  
SavorEat, Jet-Eat, Novaprotein, Clean Research, BlueNalu, JShiok Meats, Finless Foods, SeaFuture, Multi, Just, Mission Barns, Memphis, Eggs, Biofood, Meatable, Mosa Meat, FM Technologies, New Culture, Perfect Day, Integriculture, Cubio Foods, Geltor, Novacea, WILD EXPR, Because Animals

**SEAFOOD**  
Clean Research, BlueNalu, JShiok Meats, Finless Foods, SeaFuture, Multi, Just, Mission Barns, Memphis, Eggs, Biofood, Meatable, Mosa Meat, FM Technologies, New Culture, Perfect Day, Integriculture, Cubio Foods, Geltor, Novacea, WILD EXPR, Because Animals

**MILK**  
New Culture, Perfect Day, Integriculture, Cubio Foods, Geltor, Novacea, WILD EXPR, Because Animals

**FOIE GRAS**  
Supreme, Integriculture

**OTHER**  
Cubio Foods, Geltor, Novacea, WILD EXPR, Because Animals

**BEEF**  
Biofood, Meatable, Mosa Meat, FM Technologies, New Culture, Perfect Day, Integriculture, Cubio Foods, Geltor, Novacea, WILD EXPR, Because Animals

**PB PROTEIN\***  
Hilona, Night (treat), Green Wisp, Alpha, Wicked Healthy, How On Earth, Vegans, Hilarys, Daring, F8W, Lites, Polska Foods, Santa Fe, Bova, BIAN, Jivera, Veg, Cauldron, Willaross, New Wave Foods, LIKE, Field Roast, Meat Co., The Vegetarian Butcher, MorningStar, Hungry Planet, Unmeat, Garden Gourmet, Gardinier, Wesson, Gusto, Zero Egg, Tofurky, Naturli, Frys, Upton, Olus, Quick Lifes, Impossible

**HEARTBEST**  
Alpha, Wicked Healthy, How On Earth, Vegans, Hilarys, Daring, F8W, Lites, Polska Foods, Santa Fe, Bova, BIAN, Jivera, Veg, Cauldron, Willaross, New Wave Foods, LIKE, Field Roast, Meat Co., The Vegetarian Butcher, MorningStar, Hungry Planet, Unmeat, Garden Gourmet, Gardinier, Wesson, Gusto, Zero Egg, Tofurky, Naturli, Frys, Upton, Olus, Quick Lifes, Impossible

**BEFORE THE MEATLESS FASHION**  
IKEA, Gold & Green, Vegan Cartel, Beyond Meat, R/Bite, Lightlife, Dharma, Veggie, Sophie's, Damhart, Bandwelle, Vegafit, No Evil, Nutritio, Nature, Heritage, Schouten, Heura, Samhoud, Mighty Meat, Spero, No Cow

**ALGAE**  
Odontella, Fungi, Quorn, Moku, Biftek, Deep Foods, Jewels of the Forest, Nudize, Quagga

**INGREDIENTS\***  
Arbom, TerVivo, Kiverdi, DSM, MycoTechnology, protera, BioscienceZ, Givaudan, Energy Labs, Deep Branch, NutraNova, Solar Foods, Noonutrients, MycoWorks, Burcon, Magellan, Salt of the Earth, Emsland Group, Mane, Puris, Naturex, J.M. Smucker, Aruttenberg, Kerry, Firmenich, Improved Nature, Fuji Oil, Glanbia, Sotexpro, Hifood, Inalve, Tereos, Chr Hansen, Novacea, Soussana, Lesaffre, Hinoman, Plantible, Nutriati, Equinor, Roquette, Cosucsa, Wilmar, Hydrosol, Ginkgo Bioworks, Flavorcan, Vestern, Ingredion, Tate & Lyle, Ecovative, Triton, Algorithm, GreenFood50, Biomimetic, The Lupin Co., Meatless, Agri, Pevesa, Calysta, IFF, Symrise, Chinoval Bioworks, Seattle, InVivo, Duplaco, Beneo, Alkermes, Innovations, Adam, Algom, Synthesics, Plantix, Nutriati, Lentein, ABC Kroos

## Supporting

<p><b>MANUFACTURING</b></p> <p>omev IMPROVE</p> <p>BUHLER CLEXTAL WENGER</p> <p>BRECKS Nove foods ThermoFisher</p> <p>VAN HEES BIOREALIZE BLACK&amp;VEATCH</p> <p>VERBUFA SOURCE   TECHNOLOGY copernio</p> <p>R&amp;S BLUMOS   PAN BIOTECH CNOPY</p> <p>AGULUS SUNP BIOTECH EXTRACTIS</p>	<p><b>INCUBATORS &amp; ACCELERATORS</b></p> <p>BLU1877 BLUE OCEAN INCUBATOR PROVE9</p> <p>SHAKEUP FACTORY Combinator BITSxBITES</p> <p>FOOD-X wework labs</p> <p>INDIE BIO FORWARD KICKSTART ACCELERATOR</p> <p>SEEDS OF CHANGE BIG IDEA @ VENTURES MISTA SparX PLUG&amp;PLAY</p> <p>The Kitchen VILLAGE OUTERMOST ATLANTIC LABS GFood StartUpbootcamp</p> <p>KITCHENTOWN PlantStation -ivoro brinc FoodFORWARD Leave a Nest EATABLE ADVENTURES</p>	<p><b>NONPROFITS</b></p> <p>PLANT-BASED FOODS (ST. CATALINA)</p> <p>GOOD FOOD INSTITUTES NEW HARVEST</p> <p>FOOD FRONTIER VEGAN FRANCE The Modern Agriculture Foundation</p> <p>BAL Pro FAIRR Hemp Food Association</p> <p>blue horizon foundation PATH PROTEINS food SHOJIMNET BETTER EATING</p> <p>THE Protein Cluster FIAL PHILANTHROPIES PLANT BASED FOODS ASSOCIATION</p>	<p><b>RESEARCH &amp; ACADEMIA</b></p> <p>WAGENINGEN Maastricht University</p> <p>TEL AVIV UNIVERSITY TECHNION</p> <p>THE HEBREW UNIVERSITY OF JERUSALEM KENISIALE NC STATE UNIVERSITY</p> <p>UNIVERSITY OF BATH CANTA CEFT-ING</p> <p>UNIVERSITY OF TORONTO WPI</p>	<p><b>GOV'T</b></p> <p>SINGAPORE GF</p> <p>Israel Innovation Authority</p>
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## Funding

**VC FIRMS**

Ⓢ Tyson Ventures

PeakBridge

ROOT/VENTURES

NEXT WAVE VENTURES

MEDSTRADA

powerplant

TEMASEK

eighteen94

JVP

BITB\*BITES

DFJ

khosla ventures

SUSV

COLLER FOUNDATION

green Monday

Vegan Capital

MOIRA

Beyond

SPARK CAPITAL

QOO creation capital

KALE INVEST

Mission Bay Capital

CLEAR CURRENT CAPITAL

HATTON

BIG

aiim

Amhrosia

Oakhouse

StrayDogCapital

Nessel

50 Fifty Years

anterra capital

OBVIOUS VENTURES

CULTIVIAN SANDBOX

FIVE SEASONS VENTURES

GOOD SEED VENTURES

The Next Branch

Impact Ventures

Unovis Partners

ARIA BASE CAPITAL

KBW ventures

Horizons Ventures

P.O.V.

Karner Blue Capital

NEW TECH FUND

PRO TEIN

AIWYN | CAPITAL

Cleveland Avenue

evolve ventures

RHAPSODY

GlassWall

G/ B37

VegInvest

VENTURES

ARACUS

blue horizon

GOA VENTURES

GERMIN8

Beyond

moonspire ventures

inevitable Ventures

BRAN INVESTMENTS

Felicitas Ventures

ATOMICO

SINAI

FOUNDERS FUND

encore\*

radicle impact

NEW CROP CAPITAL

trueVentures

BABEL VENTURES

EDITION

Breakthrough Energy

AG FUNDER

1955 CAPITAL

STRIPES GROUP

VC FIRMS

**CORPORATE PARTNERS**

TESCO KERRY PEPSICO

P/H/W ALDI sodexo Tyson Sainsbury's Nelo

MARS STARBUCKS Dalco Campbells Kellogg's

neXtfoods DANONE Cargill Kraft/Heinz Nestlé

Unilever DANISH CROWN SOGLOWEK MTG Strauss

TARGET Rabobank Monde Nissin freedom HILTON

MAPLE LEAF KALE UNITED Mondelēz DFDAO FOODS

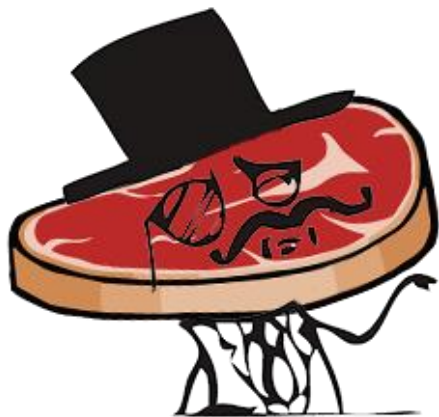
WHOLE FOODS BELL FOOD GROUP foods General Mills Dean Atlantic Natural Foods

# Cultivated meat

Cultivated meat

# Cultivated meat (CM)

Cultured meat  
בשר מתורבת



AKA

Cell-based meat  
בשר תאים

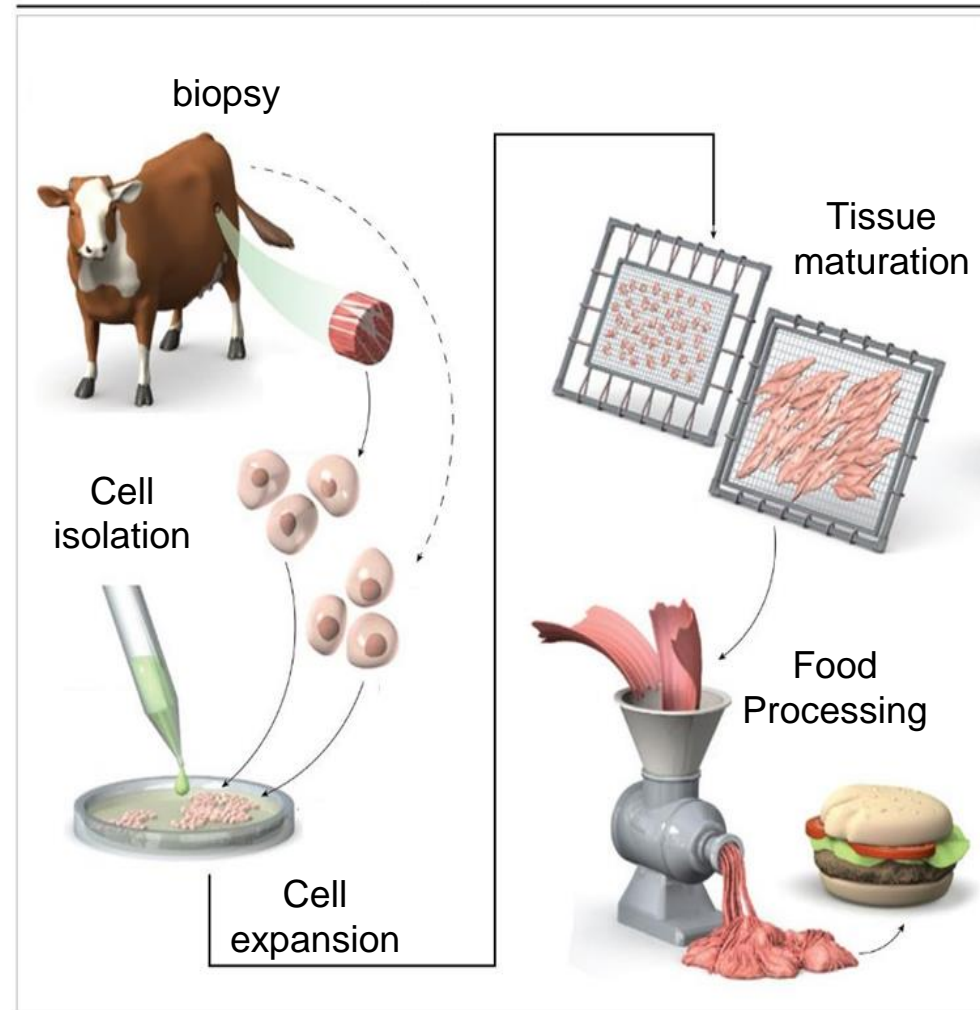


# Cultivated meat prototypes





# Cultivated meat overview



Adapted from Scientific American

## Current companies (>70)



Aleph Farms

Future Meat Technologies

Supermeat

MeaTech

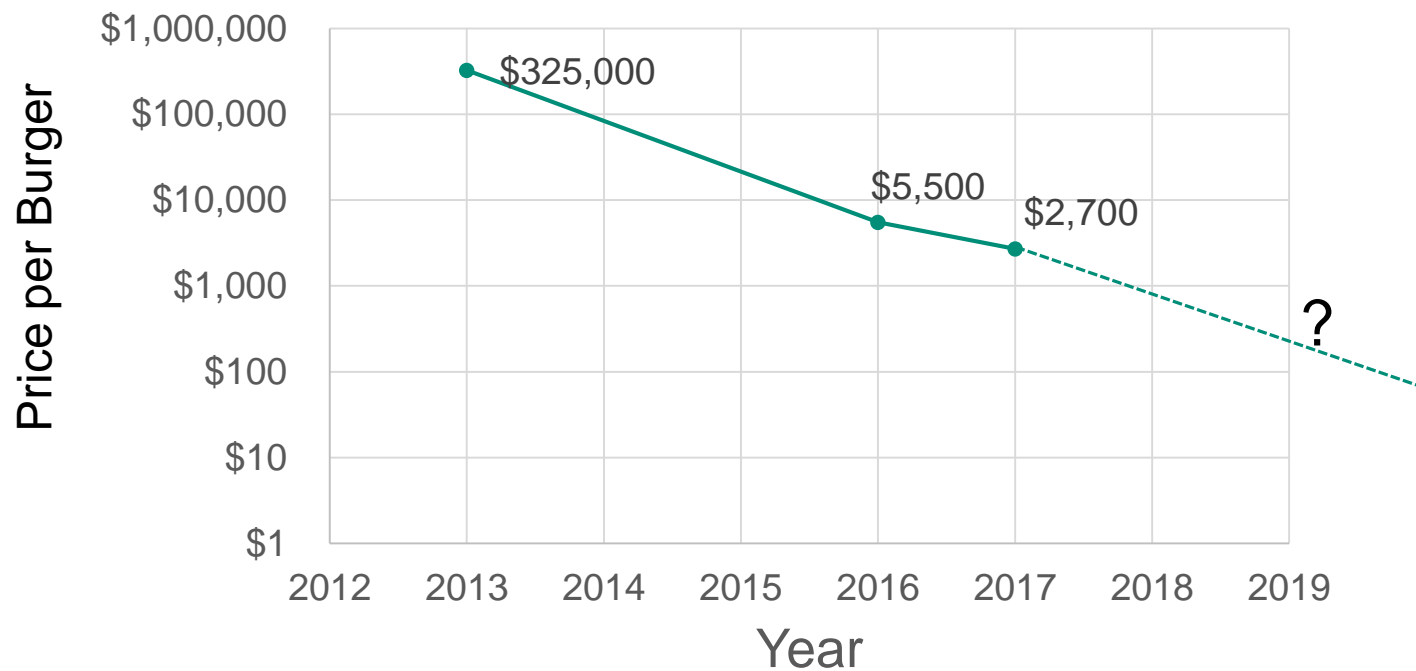
Mosa Meat

Memphis Meats (Upside Foods)



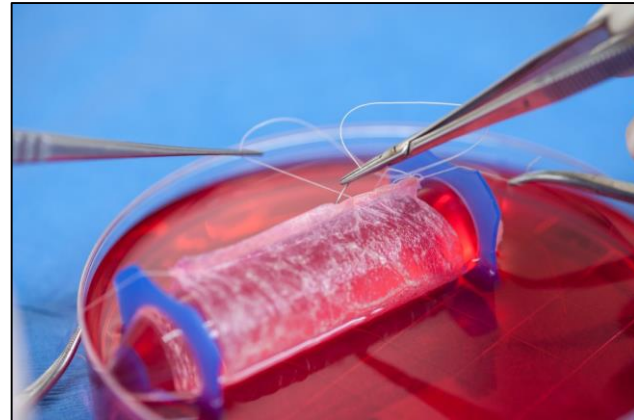
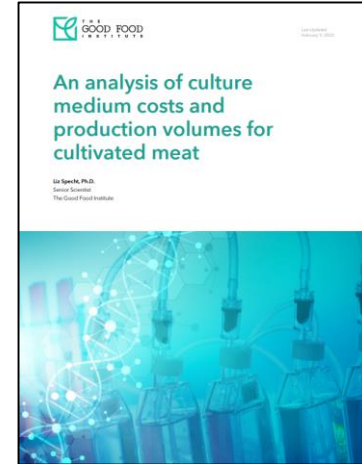


# Cost



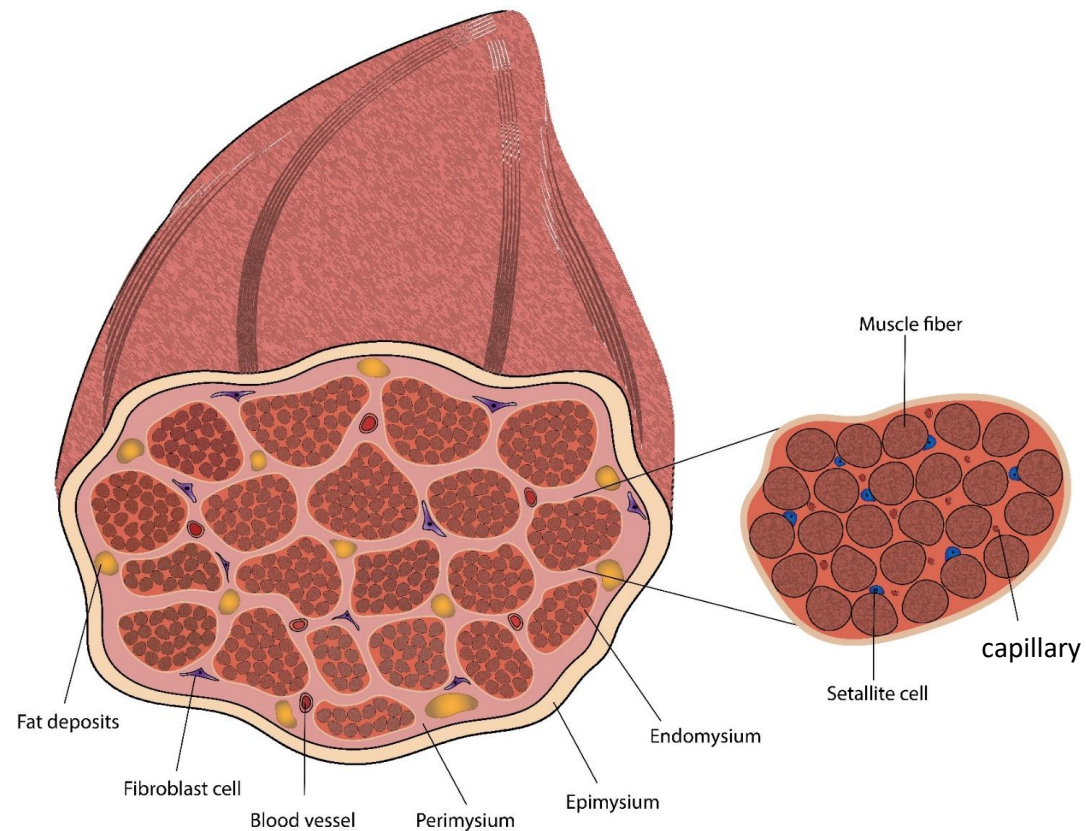
# Cost

- ▶ Medical grade techniques & biomaterials
- ▶ Cell medium
- ▶ Small scale production



# What is meat?

- ▶ Skeletal muscle tissue
- ▶ 80%-90% muscle fibers
- ▶ 5%-10% connective tissue
- ▶ 5%-10% fat
- ▶ 0.3% blood



**CM should recapitulate the main components of skeletal muscle tissues**

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# Questions?

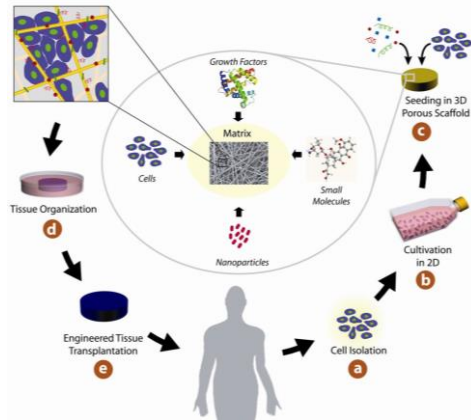


# RESEARCH

## TISSUE ENGINEERING

## FOOD ENGINEERING

## BIOPROCESS



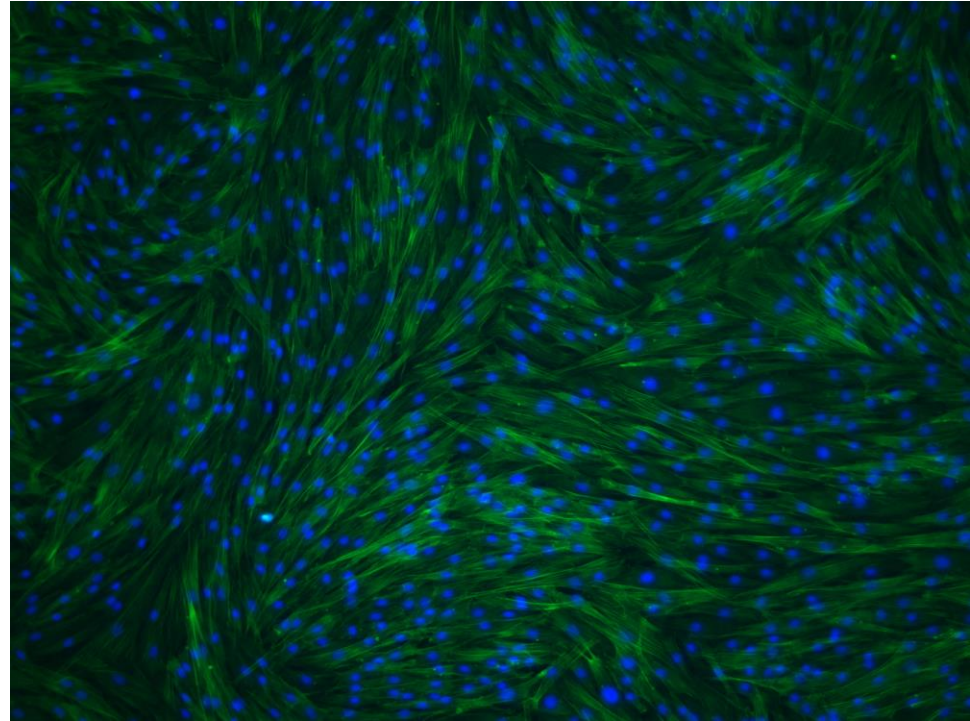


# Tissue Engineering

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## ▶ Cell culture

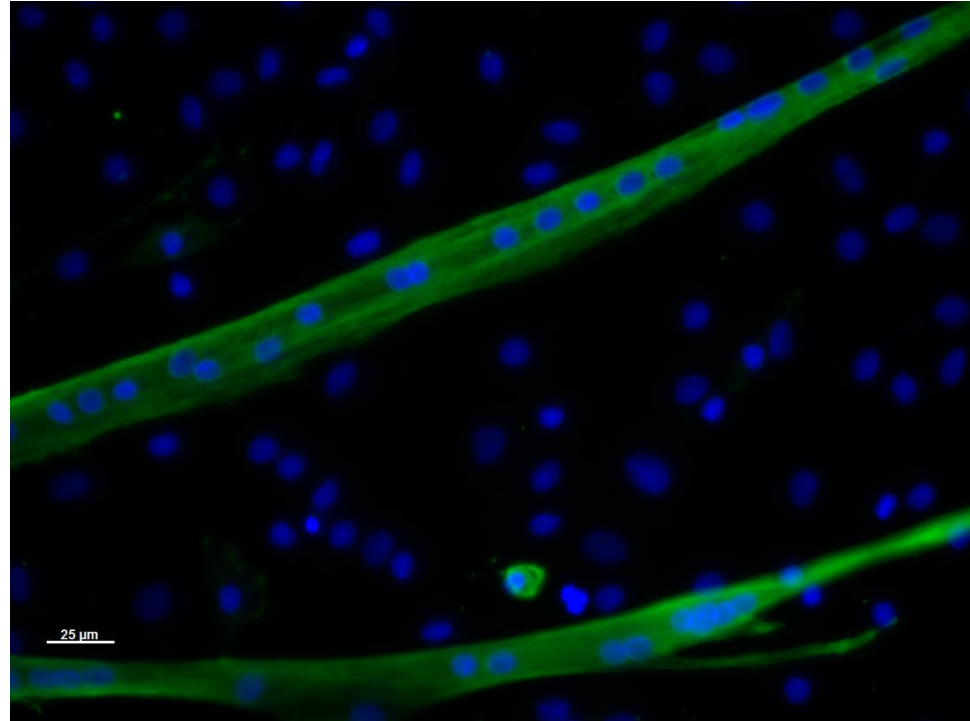
- ▶ Farm-animal cells
- ▶ Cell of origin choice
- ▶ Culture conditions



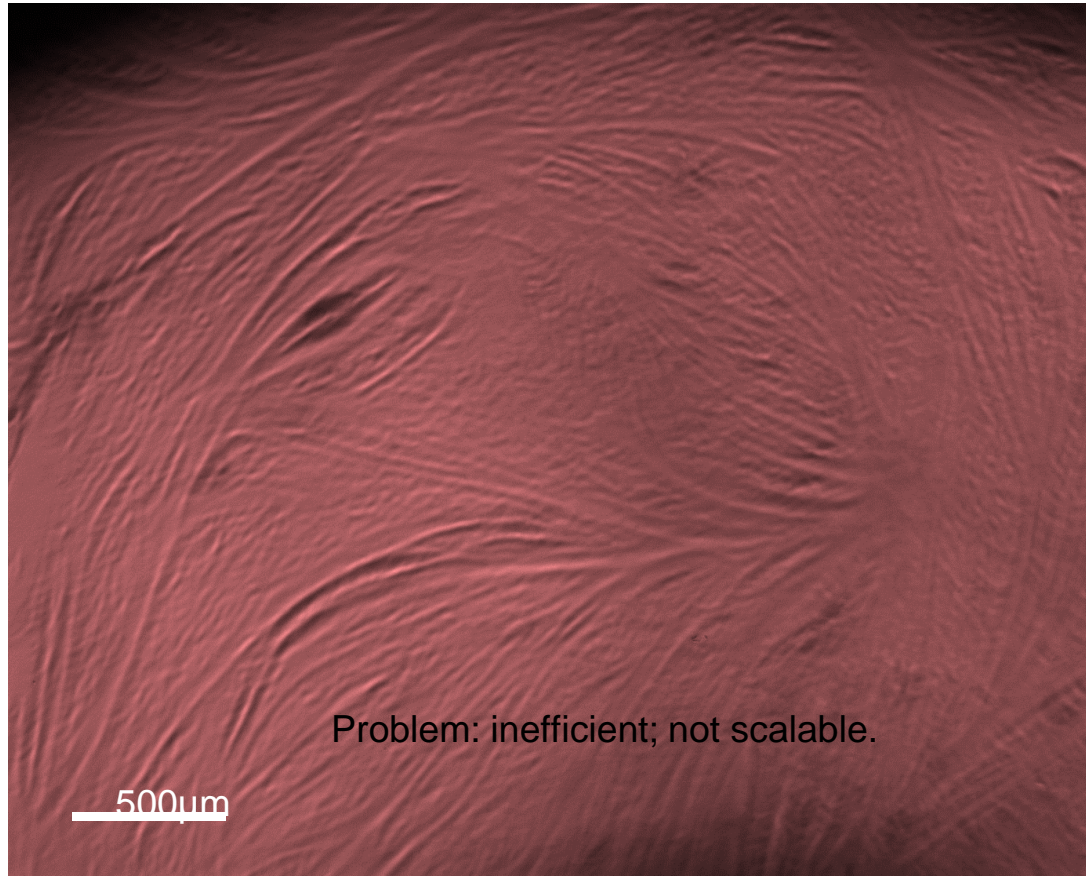
# Tissue Engineering

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- ▶ Cell culture
- ▶ **Cell maturation**



Muscle cells, grown in a dish

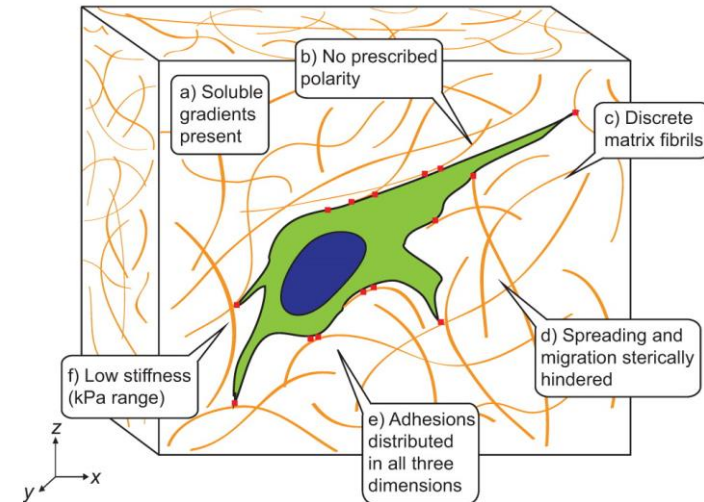
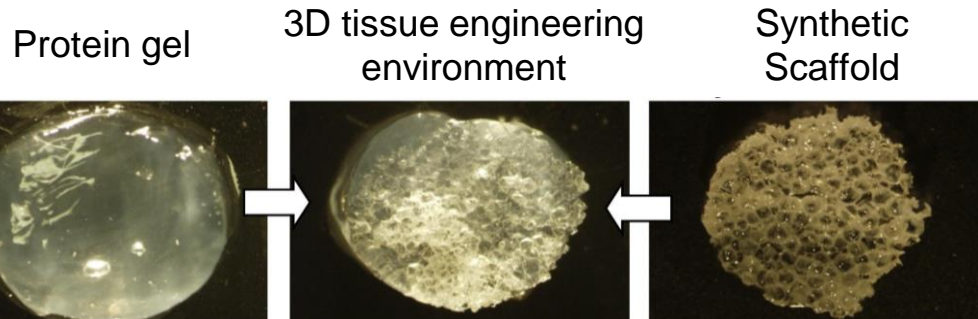


Problem: inefficient; not scalable.

500μm

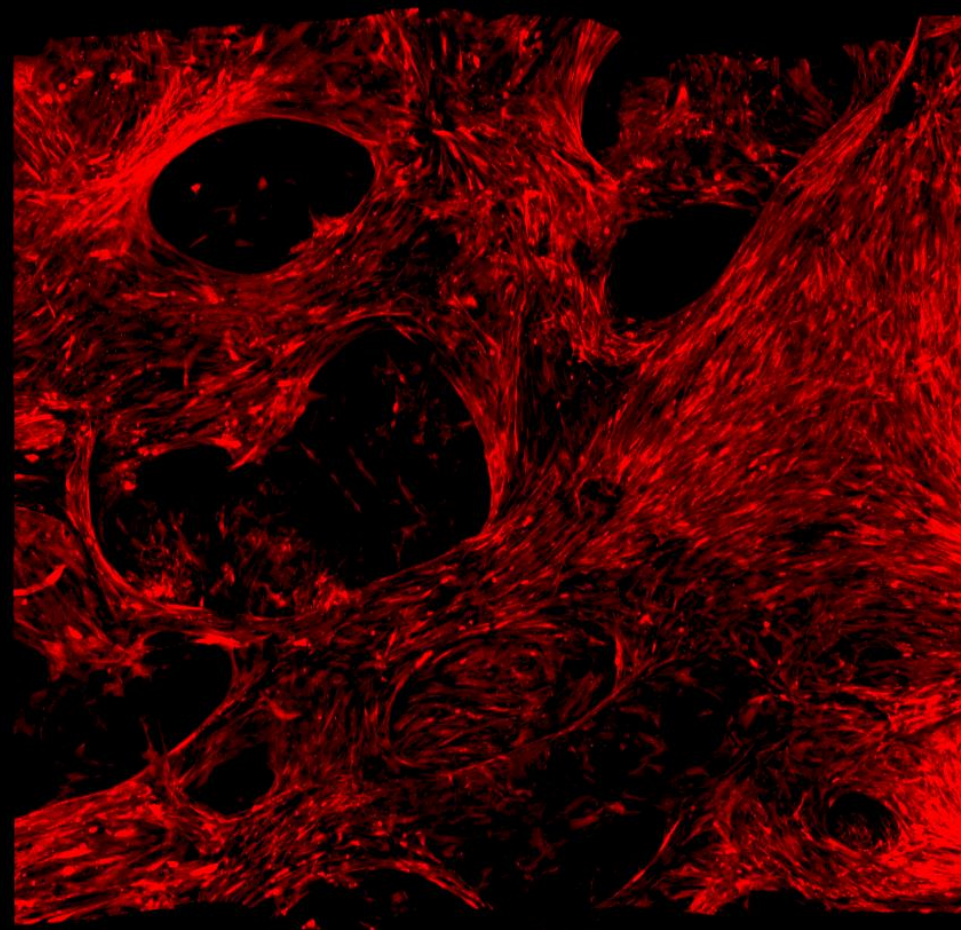
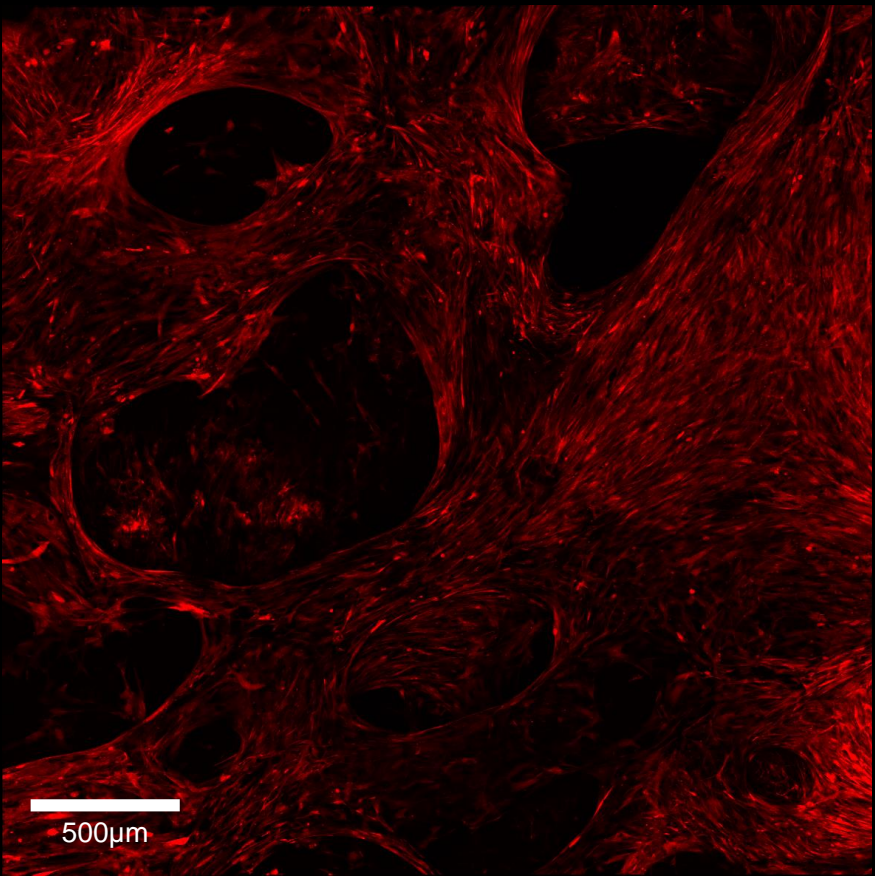
# Tissue Engineering

- ▶ Cell culture
- ▶ Cell maturation
- ▶ **Scaffolds**
  - ▶ Mechanical strength
  - ▶ Biological environment











5'

174.4  
0.74

142.9  
0.62

161.5  
0.53

121.8  
0.47

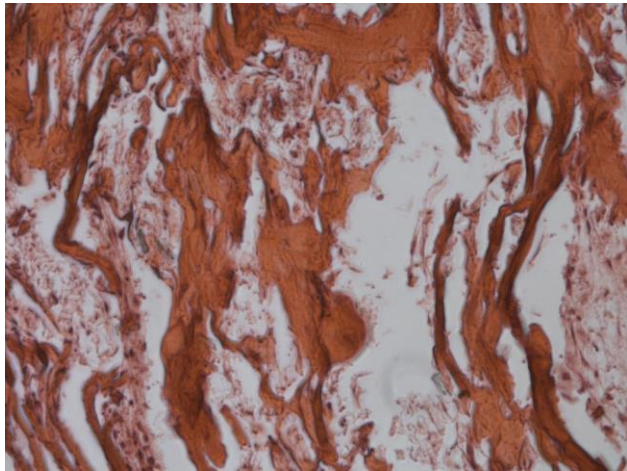
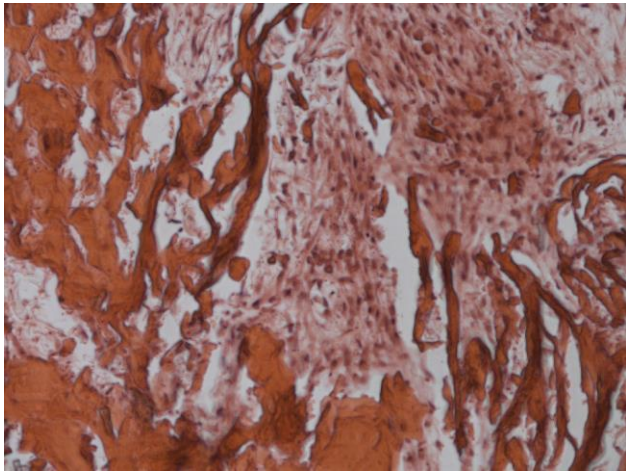
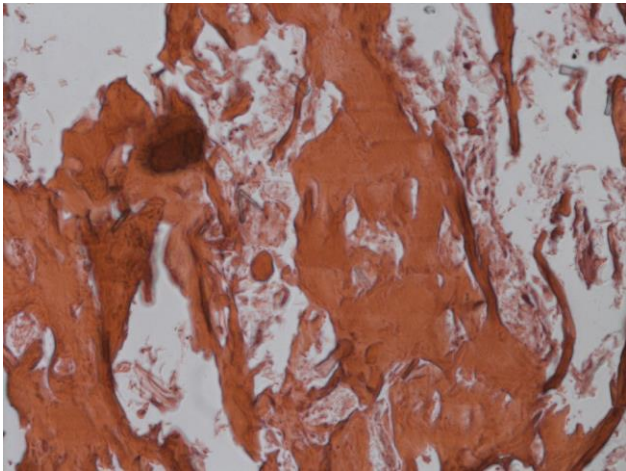
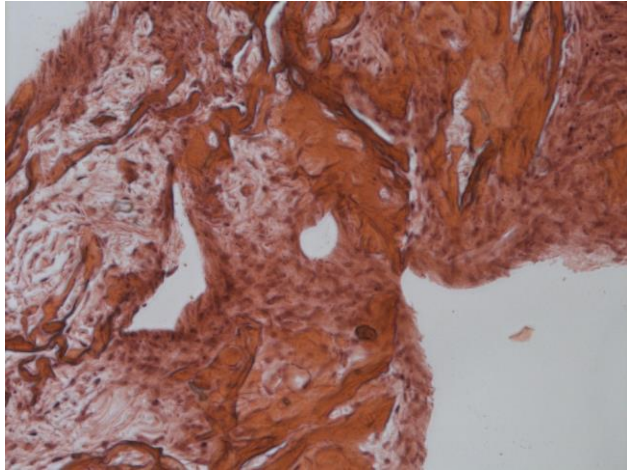
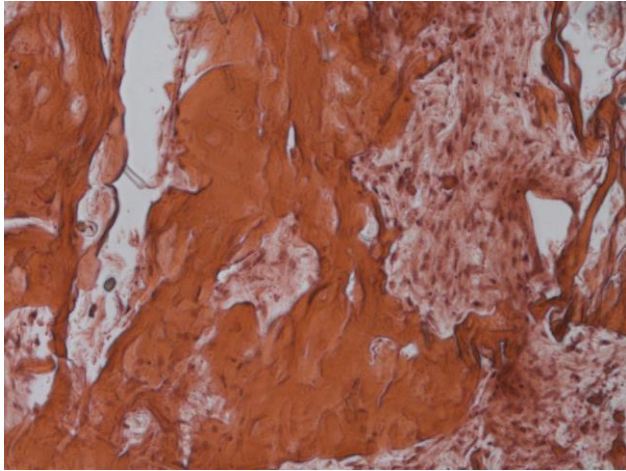
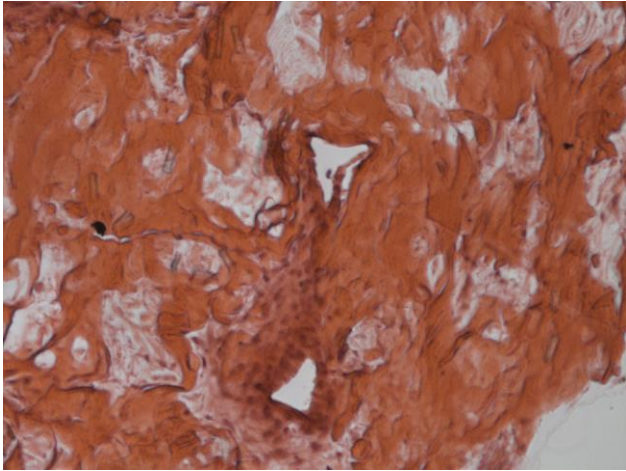
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0.67

146.7  
0.69

exp 101

TBA

252.017

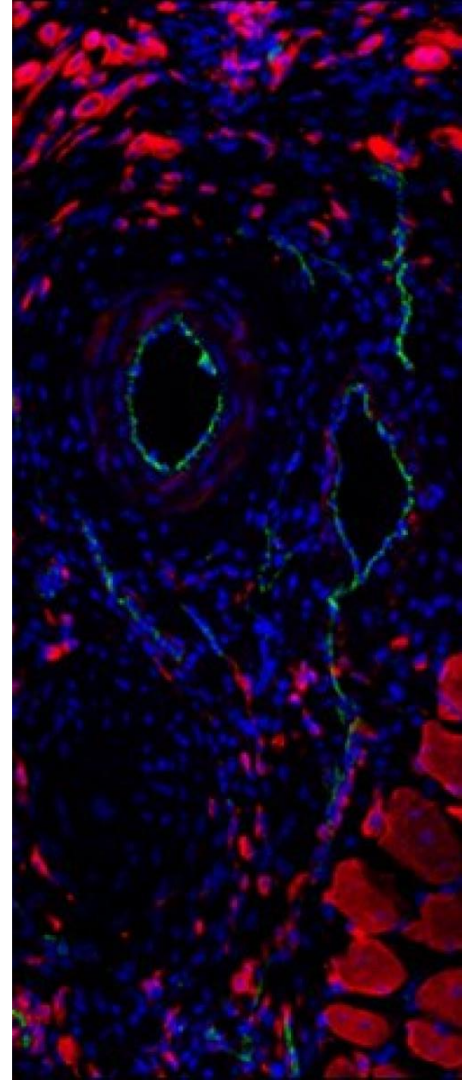




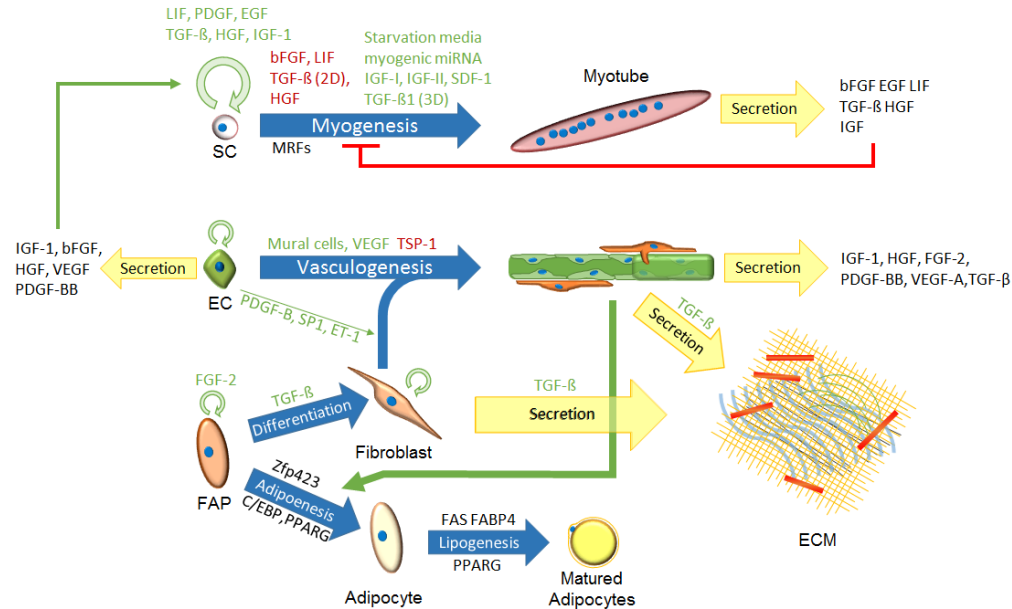
# Tissue Engineering

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- ▶ Cell culture
- ▶ Cell maturation
- ▶ Scaffolds
- ▶ **Muscle tissue - Not just muscle cells**
  - ▶ Adipose cells (fat)
  - ▶ Supporting cells (produce ECM)



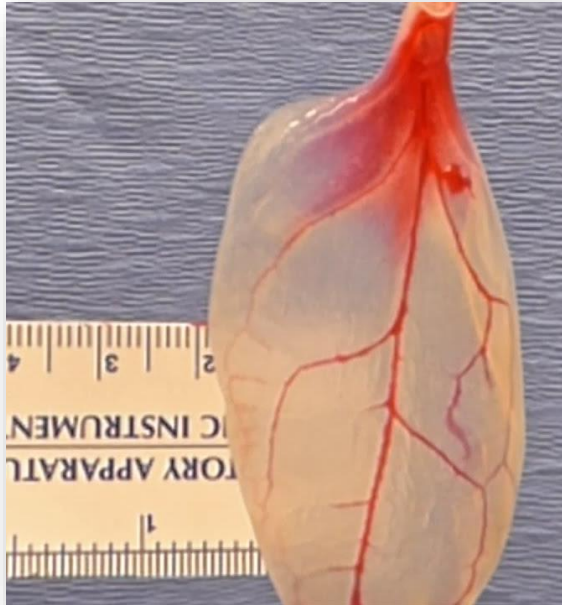
# Meat has complex cell-cell interactions



Cell co-culture is imperative for CM to resemble native muscle tissue

# Food Engineering

## ▶ Edible ingredients



# Food Engineering

- ▶ Edible ingredients
- ▶ **Meat analysis**
  - ▶ Texture
  - ▶ Flavor
  - ▶ Nutritional value

FoodScan™ for meat



# Food Engineering

- ▶ Edible ingredients
- ▶ **Meat analysis**
  - ▶ Fat, moisture, protein, collagen and salt.
  - ▶ Ash, starch, pH, carbohydrates, etc





# Food Engineering

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- ▶ Edible ingredients
- ▶ Meat analysis
- ▶ **Food Regulations**



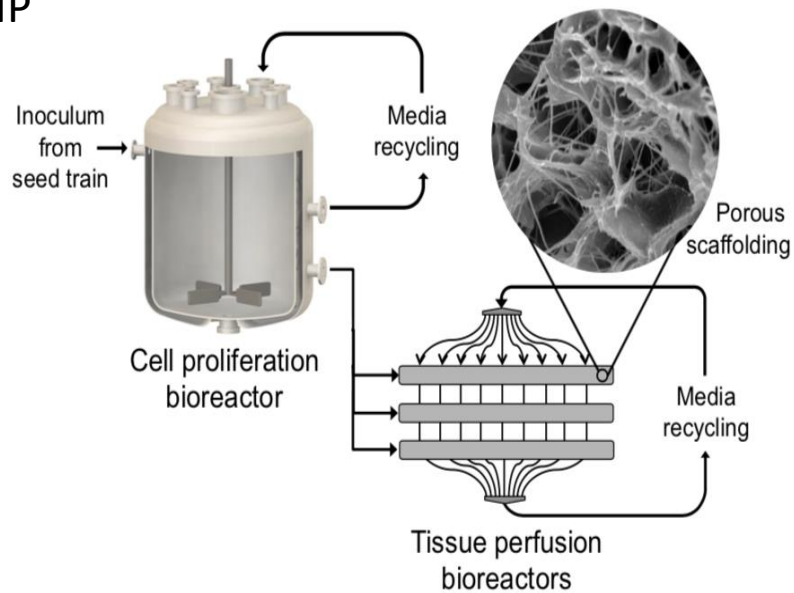
# Food Engineering

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- ▶ Edible ingredients
- ▶ Meat analysis
- ▶ Food Regulations
- ▶ **Additives & Product design**

# Bioprocess

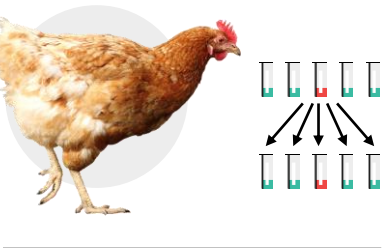
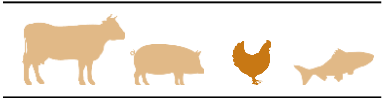
- ▶ Bioreactors
- ▶ Automation
- ▶ GMP



# Cultivated Meat Production at Scale

## SAMPLE

A small sample of cells is obtained from an animal.



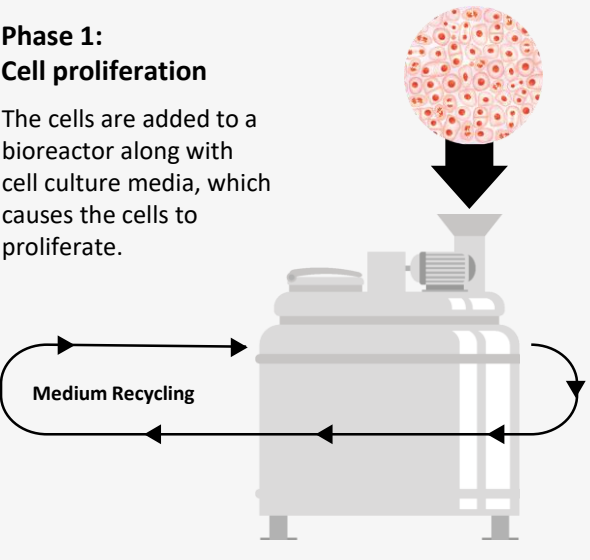
## CELL STARTER CULTURE



## Phase 1:

### Cell proliferation

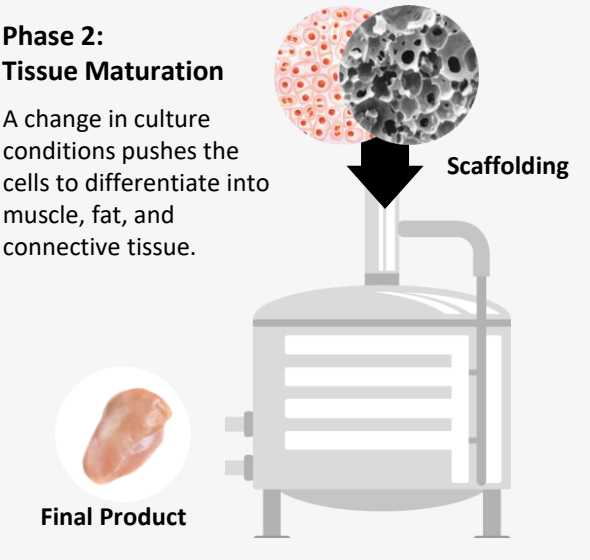
The cells are added to a bioreactor along with cell culture media, which causes the cells to proliferate.



## Phase 2:

### Tissue Maturation

A change in culture conditions pushes the cells to differentiate into muscle, fat, and connective tissue.



## CELLS AT MATURATION

Primarily muscle, fat, and connective tissue.

Fat  
Cell



Muscle  
Cell

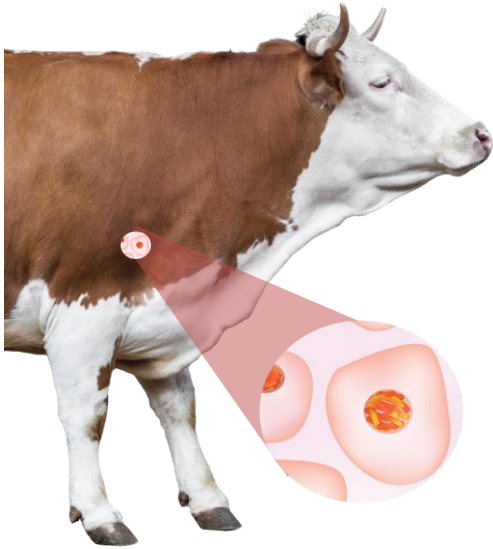


Fibroblast  
Cell



# Novel meat products

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Muscle



Fat



# Longer shelf life, decreased foodborne illness

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- Cultivated meat production is sterile and antibiotic-free
- Potential for decreased foodborne illness
- Potential for longer shelf life
- Impact on transportation, distribution, and environmental footprint

*“left at room temperature the conventional meats were completely spoiled in less than 48 hours; after four days, the lab-grown meats had barely decomposed because there was no trace of bacteria”*

-Uma Valeti of Memphis Meats describing initial testing

<https://newrepublic.com/article/154269/meat-moguls-case-lab-grown-beef>

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# Questions?