

Cultivated Meat

prospects and
opportunities for
Brazil in **2022**



Catalog sheet

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Presentation

This document contextualizes the challenges for the development of cultivated meat in Brazil, the country's current condition as a major player in the supply of animal proteins, its conditions to assume an important role in the sector, the motivations for its development, and the role of different agents in the complex and competitive scenario that evolved in recent years.

Cultivated meat is obtained by using animal cell culture technology. Cultivated meat is a genuine meat produced from animal stem cells rather than raising and slaughtering them. Starting from a single stem cell, successive multiplications and subsequent differentiation and maturation increase the number of cells and cell density in a sequence of progressive bioreactors until an adequate amount is reached, with or without the combination with other support materials, i.e., scaffolds.

Meat consumption

Meat consumption is expected to increase by around 80% in developing regions by 2029, when it is projected to reach 366 million tons, an increase of 40 million tons in global meat production.

Source: OECD and FAO (2020)



Cultivated meat. Image by [Aleph Farms](#).

These cells comprise the same types of those found as three-dimensional structures in animals, which form the tissues and, therefore, can replicate the sensory and nutritional profile of beef, chicken, seafood or other conventional meat products.

Cultivated meat technologies have been proposed and developed by startups in their laboratories, seeking investments to go beyond the research and development (R&D) stages.

Few startups have reached the pilot plant stage already, where investments are high, achieving tens of millions of dollars. They currently face the challenges of scaling up to reach competitive commercial production by the end of this decade.

In Brazil, the announcement of 2.5 million dollars in investments by BRF in the Israeli startup [Aleph Farms](#) alerted the market to the imminence of having a commercial product in the short term (“BRF faz aporte”, 2021). Aleph’s technology to produce cultivated meat from non-genetically modified bovine cells will be available in Brazil in 2024. However, the interest and need to develop national technology exists, as well as possibly transferring technology from foreign companies. The need to encourage innovation and entrepreneurship, properly regulate production and commercialization, and promote research and training of human resources for the sector is also present.

The Good Food Institute (GFI) has been an important catalyst of this entire process, subsidizing the development of the alternative protein sector in the world. Brazil could not fail to be an agent of transformation and support, as it is a country where meat is a first-rate product, of indisputable economic relevance, inciting desire and consumption like few other places in the world.

The following text seeks to draw attention to relevant points for a proper introduction to the subject and some technological, economic and social aspects, which can be used to guide the development of cultivated meat in Brazil.

The GFI hopes that this document will be a helpful source of introductory technical information or assist in decision making, establishing R&D and investment policies and strategies in the cultured meat sector in Brazil. As this document contains a lot of technical terminologies on the theme “Cultivated Meat”, we recommend that you access the Cultivated Meat Glossary ([Berti e Porto, 2021](#)).



Cultivated salmon. Image by [Wildtype](#).

Introduction

The idea of producing cultivated meat is at least a century old, since then British Prime Minister Winston Churchill declared in 1931 that “We shall escape the absurdity of growing a whole chicken in order to eat a breast or a wing, by growing these parts separately under a suitable medium”, in his essay entitled “Fifty Years Hence” ([Churchill, 2022](#)). Churchill was certainly ahead of his time, but what he said is no longer science fiction. In recent years, this idea shifted from imagination to become a promising alternative to meat production from the slaughter of animals. The technological and economic challenges are enormous, but scientific and technological development, potential gains in scale and automation of industrial processes can accelerate the development, maturation and sustainability of technologies as groundbreaking as this one.

This context requires the careful evaluation of the alternatives on the market, its main players and stakeholders, potential partners, competitors, as well as gaps and scientific and technological bottlenecks in Brazil.

While predicting the growth rate of an early-stage industry such as cultivated meat is a challenge, projections so far indicate extremely promising scenarios.

Brazilian meat production in the world scenario

Brazil, China, the European Union and the United States are expected to produce almost 60% of global meat production by 2029. Production growth in Brazil will continue to benefit from an abundant supply of natural resources, animal feed, availability of pastures, productivity gains and, to a certain extent, the devaluation of the Real.

Source: OECD and FAO (2020)

¹ Winston Leonard Spencer Churchill (1874-1965)

In the McKinsey report, for example, it is estimated that, by 2030, cultivated meat could account for up to 2.1 million metric tons of annual meat production and become a \$25 billion industry (Brennan et al., 2021). Estimates from the AT Kearney report for 2040 indicate that cultivated meat will occupy around 35% of the global meat market and will be worth about 630 billion dollars (AT Kearney, 2019). The growth of this market is not only based on increased demand due to population growth. It is also related to the general perception and concern that urgent actions must be taken regarding animal rights, energy and water consumption, agricultural land resources and environmental impacts associated with “natural” sources of animal protein.

A sense of opportunity already exists when we see companies like Cargill (“Protein innovation”, 2022) and Mitsubishi investing in startups and acting to participate in this huge market.

Soy production

The Latin American and Caribbean region will continue to be the largest producer of soy, with its share in global production increasing to over 54% by 2029.

Source: OECD and FAO (2020)

Export potential

Abundant in land and water, Latin America and the Caribbean together account for 13% of the global production of agricultural and fisheries commodities and 25% of exports of these products, underscoring the importance of trade liberalization at a global level for the region. Export demand will therefore be the critical source of growth for the sector in the medium term.

Source: OECD and FAO (2020)

There is consensus that alternative proteins, including cultivated meats, are an important part of the solution to the global supply chain. This sector encourages the development of more sustainable protein-derived foods and supports feeding an increasingly discerning population that demands safe, nutritious, and tasty meat.

Brazil could maintain its leading position in the global animal protein market and be a leader in the new protein economy. However, the advanced technology for cultivated meat around the world and the lack of attention given to this area in Brazil may lead us to miss important opportunities. So far, the main players in the sector have not been prominent, including academics and industry researchers, large food/meat/protein producers, entrepreneurs and capital investors, local agribusinesses, government agencies, and policy makers.

Agricultural and fish production

Agricultural and fish production in the Latin American and Caribbean region is expected to grow by 14% over the next ten years. Almost two thirds of this growth (65%) can be attributed to the growth of agricultural production, around 28% is due to livestock and the remaining 7% is due to the expansion of fish production.

Source: OECD and FAO (2020)

Brazilian meat production in the world scenario

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Source: OECD and FAO (2020)

Regulatory agents in the Executive and Legislative branches can be facilitators of this integration process among various actors. Delayed introduction in the cultivated meat sector can result in economic and social deficits beyond profit margins and loss of market share. The consequences may affect the overall goals related to mitigating the effects of climate change and create dependencies related to developing this emerging technology.

Overview

The first cultivated meat burger was produced from bovine cells grown in a laboratory in 2013 by Professor Mark Post's team at Maastricht University in the Netherlands. As a result of the technological process developed, [Post's beef muscle hamburger](#) cost 200 thousand euros at the time (van Dinther, 2011). In 2019, the same hamburger cost around nine euros. Despite representing a significant price reduction, the production technology of cultivated beef hamburgers continues to be optimized, seeking to reach the market at an affordable price for all. The startup Mosa Meat is currently working on the automation phase and expanding its production scale to [reach the commercial scale of cultivated meat production](#).



Mosa Meat is one of the numerous startups that have emerged in recent years. Industrial scale production remains a common challenge for all startups working in the development of a proprietary cultivated meat technology.

These new technologies require extensive knowledge and integration of advanced techniques in cell culture, molecular biology, engineering (tissue, chemical, food, mechanics, materials, control and automation), biochemistry, bioinformatics, and biomaterials science and technology. Technical complexity is present in the production of all cultivated meats from cell culture, whether to obtain cultivated meat of bovine origin, poultry, fish or even other exotic and unconventional animals.



Cultivated burger. Image by [Mosa Meat](#).

To overcome current challenges, scientists, entrepreneurs and investors create new companies (startups) focused on the development of new proprietary and scalable technologies to produce commercial-scale cultivated meat and/or any of its ingredients and components. The companies [Mosa Meat](#), [Upside Foods](#) (formerly Memphis Meats), [GOOD Meat](#) (Just Foods), [Aleph Farms](#), and [BioTech Foods](#) are examples of startups that have received significant and growing contributions over time to develop proprietary technologies. These new technologies can have a major impact on the supply chain and essential services in several sectors, which must be prepared to sustain new bio-manufacturing industries, such as cultivated meat.

To meet the emerging demand of the sector, suppliers of new formulations of **cell culture media**, new designs of **bioreactors**, new biomaterials for the production of **scaffolds**, new molecules that add flavor, odor and texture, and so arise new companies focused on the production chain, including the development of new ingredients, supplies and equipment. The startups [Matrix Meats](#) and [Geltor](#), for example, focus on the development of technology for the manufacture of scaffolds based on nanofibers and collagen, acting as suppliers of these inputs for the cultivated meat industries.

Cell culture media

A mix of nutritive substance, usually dissolved in an agar gel or liquid medium, in which cultures of bacteria, fungi, animal cells, or plant cells are grown. Also called growth media.

Bioreactors

System developed to carry out a bioprocess, which presents an ideal environment to growth cells and synthesis of a bioproduct of interest. A simple glass flask can be considered as a bioreactor, but this term is normally applied to more complex equipment, which allow the homogenization of the culture medium with cells, keeping controlled (or sometimes just monitored) process variables such as temperature, pH and dissolved oxygen.

Scaffolds

A structure on which animal cells are grown to make them form muscle tissue that resembles structured cuts of meat. They can be made from many materials, including plant polymers and even extruded soy protein.

The Indian company [Laurus Bio](#) (formerly Richcore Lifesciences) and the [Merck Innovation Center](#) work on the development of new **recombinant proteins** of non-animal origin and other components of the culture medium, reagents and new bioproducts for the maintenance of **stem cells.**

The company [OSPIN Modular Bioprocessing](#) is another example of operations in this sector, focusing on the automation of scalable bioprocesses and the design of tissue bioreactors, supporting [important aspects of the cultivated meat production process.](#)

In Brazil, the actions are still at a slow pace. In 2021, a new startup, [Ambi Real Food](#), received [R\\$ 200,000.00 in funding](#) from the approval of an R&D project from Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS), a modest amount for the necessary investment standards (“Pesquisadora brasileira”, 2021). Another important agent in the development of new technologies for cultivated meat is the [Cell Bank of Rio de Janeiro \(BCRJ\).](#)

Recombinant proteins

Proteins made from biotechnological processes.

Stem cells

Cells that have both the capacity to self-renew (make more stem cells by cell division) and to differentiate into mature, specialized cells.

Big market but big investments

Much needs to happen for cultivated meat to become a major industry—at least tens of billions of dollars must be spent to scale it to even 1% of the global protein market.

Source: Brennan et al., 2021.

BCRJ offers its advisory and consulting services for the establishment of cell lines and cell banks for companies operating in this sector. In the same period, **BRF**, a Brazilian multinational company in the food industry, the result of the merger between Sadia and Perdigão, announced a partnership with the Israeli startup Aleph Farms to produce and market beef grown in Brazil in 2024. Also in 2021, JBS, a multinational Brazilian company, global leader in animal proteins, and largest food

company in the world, has become the majority shareholder of BioTech Foods (developer of cultivated meat), announced the construction of the first **R&D center** focused on the study of **alternative proteins in Brazil (Souza, 2021)**.

More recently, in the first weeks of 2022, the first startup focused on the development of cultured fish meat, Sustineri piscis, was presented (Setti, 2022). Cultivated meat is arriving in Brazil.



However, the movements and investments dedicated to the development of new technologies based on meat grown in other countries are expressive and disproportionate when compared to Brazil. In 2020, the United States became one of the countries to receive the largest investments in the sector, a position achieved due to the investment of more than US\$ 160 million in Upside Foods (formerly Memphis Meat).

Another country that stands out in this scenario is Israel. By 2020, the country had secured US\$37 million in investment, which rose significantly in 2021 with US\$105 million raised in a Series B funding round from Aleph Farms. Europe also stands out, with [investments from the Spanish Government in the company BioTech Foods](#). Brazil, as one of the largest meat exporters in the world, has internationally renowned companies, very well positioned when it comes to conventional meat. [JBS](#), for example, is committed to helping address the global challenge of responsibly feeding a growing population.

As part of its internal policy, [the company intends to achieve zero greenhouse gas emissions by 2040, in addition to other environmental, social and governance actions \(“Sustentabilidade”, 2021\)](#).

Given the scenario of huge investments in cultivated meat worldwide, the question remains whether Brazil will be able to guarantee its prominent position in the meat sector over the next few years.

The level of maturity and speed of development of new technologies in cultivated meat in developed countries draws attention. The integration of the scientific community, entrepreneurs and investment funds has accelerated the development of these new technologies. The integration of agricultural, industrial, economic, scientific and technological policies, in addition to pro-investment and pro-innovation regulatory policies, are necessary conditions for these new products to enter the market in the shortest possible time.

The natural consequence of the synchrony between the actors of this global ecosystem was the [announcement of the commercialization of the first chicken \(GOOD Meat™\) manufactured by the company Eat Just, initially presented at the restaurant 1880, in Singapore.](#)

Important ecosystem movements have taken place in Brazil. Recently, the Department of Inspection of Products of Animal Origin of the Ministry of Agriculture, Livestock and Supply ([DIPOA/Mapa](#)) and the Food Management of the National

Health Surveillance Agency ([GGALI/ANVISA](#)) participated in the [first workshop on cultivated meat promoted by GFI Brasil.](#)

The event intended to gather and discuss with Brazilian regulatory agents the technical aspects and relevant information for the definition of guidelines on the implementation of actions to develop cultivated meat in Brazil. The proactiveness of regulatory agents is essential to encourage and strengthen the ecosystem of bio-farmed meat in Brazil and worldwide.



Cultivated chicken. Image by [Good Meet](#).



Cultivated fish maw. Image by [Avant Meats](#).

As in the entire ecosystem, the role of innovation centers, incubators and accelerators working in the biotechnology and life sciences area is crucial. These agents of innovation are known to be fundamental for the transformation of ideas into products, for the training of scientist-entrepreneurs and promotion of synergistic connections between the developers of technological solutions and investors.

In Brazil, we have some established innovation agents working in biotechnology and life sciences, such as the [Center for Innovation, Entrepreneurship and Technology \(CIETEC\)](#), the [SUPERA innovation park](#), the [AgTech Garage Hub](#), Lyfeli VC and the [accelerator State](#), in the state of São Paulo, and the [Innovation Hub BiotechTown](#), in Minas Gerais. These are just a few examples of important players in biotechnological innovation in the Brazilian ecosystem.

A small slice at the beginning

By 2030, cultivated meat could supply up to half a percent—million tons—of the world's meat supply, with implications for multiple sectors.

Source: Brennan et al., 2021.

In the wake of venture capital, [Enfini Ventures](#) is an investment fund active in the cultivated meat sector, positioning itself with strong interest in cultivated meat startups in Latin America, for example.

The Brazilian cultivated meat ecosystem is starting its structuring, organization and integration phase and should position itself as an important player in this sector in the coming years, given the country's existing conditions and the sense of opportunity that the topic offers.

Cultivated meat technology



Meat cultivation room. Image by [UPSIDE Foods](#).

The challenge of producing cultivated meat is the need to replicate the physiological animal muscle growth environment under controlled conditions (bench scale) or in a factory (industrial scale). The engineering of animal muscle tissue is only possible from a deep biological, chemical and physical understanding of the development of animal tissue and cells.

The technical and economic principles must be well established throughout the evolution process of the new technology for the production of cultivated meat, so that the final product is accessible and becomes a commodity.

The cultivated meat manufacturing process has been developed by a number of biotech innovation companies. [By 2020, there were over 70 startups focused on cultivated meat \(GFI, 2021\)](#). The website [newprotein.org](#) compiles some maps of this ecosystem (The Ket Maps),

giving an idea of the variety of companies, large and small, and their areas of operation. Most companies working in the development of technology are in the R&D phase, both on a laboratory scale and on a pilot scale, aiming at the technological maturity of the [process to reach the industrial scale at competitive prices by 2030 \(OECD & FAO, 2020\)](#).

It is estimated that the cost of manufacturing cultivated meat today is 100 to 10,000 times higher than that of conventional meat.

These values depend mainly, but not exclusively, on the costs associated with the ingredients used in cell culture media and their prices in each country (Vergeer et al., 2021b). In fact, reducing the production cost of growing media is critical so that cultivated meat can be marketed at competitive prices in the future. Mosa Meat, for example, has been working to solve this problem, with recent reports of encouraging data on cost savings from its growing media ([“Milestone: over 80x”, 2021](#); [“Milestone: over 65x”, 2021](#)).

The methodologies adopted at each stage of the cultivated meat production process depend directly on the type of meat to be produced, the production route adopted at each manufacturing stage (i.e., process flowchart), the use of renewable energy

and the capacity adapting the process to new advanced and disruptive technologies available or to be developed in the near future.

We present, in **Figure 1**, the conceptual flowchart of the macro steps that make up the cultivated meat production process so it can be better visualized.

The stage that involves what we call “On the farm” here concerns the collection of data about the animal, such as its genealogy, genomic profile, breed, age, diet and vaccination cycles or medicines in general; it precedes the laboratory and industrial stages. The choice of the individual donor of the cells must be judicious, aiming to meet the characteristics of the meat that is intended to be produced at the end of the process.



Bioreactors in cultivation room. Image by [UPSIDE Foods](#).

At this stage, it is fundamental to define the methodology adopted to obtain the tissue and from which part of the animal the sample will be collected under aseptic conditions, following strict quality control, handling and fundamental criteria related to health and well-being of the animal donor. Usually, the methodologies used to collect a tissue sample are very similar to the techniques used in exploratory biopsies.

Cell isolation is done via animal cell culture techniques in the laboratory, where the tissue obtained from the animal is processed to obtain target cells for the beginning of the cultivated meat production process (See **Figure 1**).

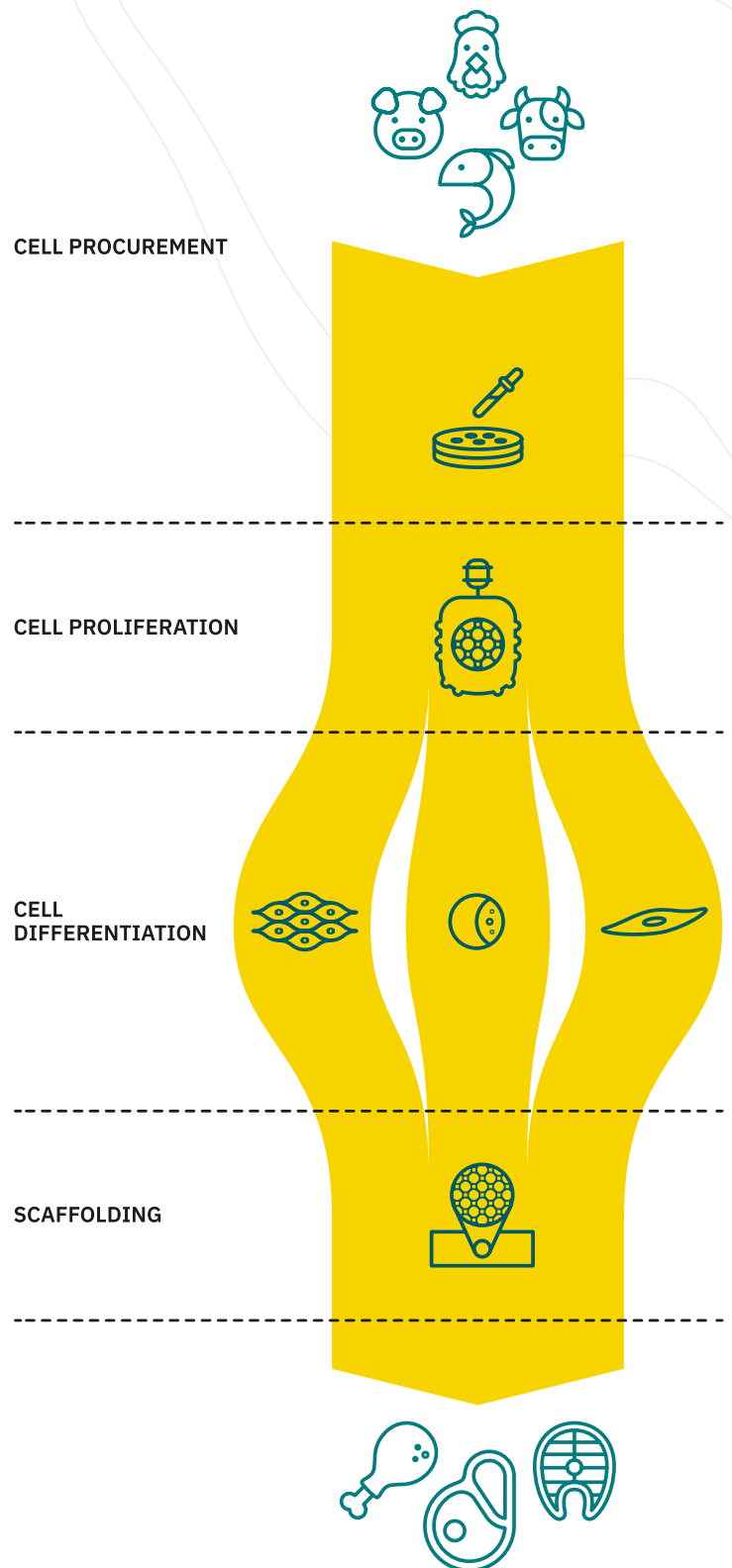


Figure 1 – Conceptual flowchart of the cultivated meat production process.

Stem cells are normally the target in this phase of isolation because of their ability to self-renew, in addition to differentiating into other cell types in the subsequent steps of the process. A rigorous characterization of the cells chosen to start the process, which includes provenance, authenticity, viability, functionality and **phenotypic and genotypic** analyses is crucial for an assertive execution of the first phase of the process. A wrong, incomplete or incorrect identification at this stage could compromise the future of its commercialization.

Phenotypic and genotypic

Phenotype

The observable character (including both physical appearance and behavior) of a cell or organism.

Genotype

Genetic constitution of an individual cell or organism. The particular combination of alleles found in a specific individual.

Cell density

Refers to the number of cells in a volume specific.

Cell proliferation is essential for maximum **cell density**, o que garante which guarantees the progression of the process to the **differentiation** of those cells.

Differentiation

Process by which a cell undergoes a change to an overtly specialized cell type.

Succeeding in this step is crucial for the advancement in the process' scalability. At this stage, the cells are normally grown in bioreactors where culture media rich in ingredients necessary for the maintenance of cell viability and proliferation are used.

When progressing to the cell differentiation phase, stem cells are grown in a culture medium containing specific ingredients capable of stimulating differentiation for each target cell type. Conventional meat is a multicellular tissue that includes support cells, skeletal muscle cells, vascular and fat cells, for example.

In the search for the mimicry of conventional meat, the differentiation phase is important to define how many cell types will compose the intended final product.

After obtaining different cell types, a structuring step of the final product, known as “scaffolding,” may be necessary. In this phase, the cells are cultivated, grouped or seeded on a scaffold of edible biomaterial, depending on the technological strategy adopted. Several methodologies can be used and developed at this stage, including 3D printing of bioinks composed of cells and biomaterials, aggregation of cells and biomaterials and extrusion, among others.

Meat product

Meat products are preferably obtained from meat that undergoes one or more types of process, including cooking, salting, curing or even just the addition of seasonings.

meat product

The finalization phase of the involves its sensory evaluation. This stage may comprise the addition of new ingredients that enhance the consumer’s sensory perception of the product and that expand or even customize the nutritional characteristics of the cultivated meat. The addition of these ingredients must, like all other stages of the production process, meet the food safety requirements and the relevant legislation. Critical steps such as packaging, storage and quality control of the final product are also aspects to be considered at this stage.

For a better understanding, we describe, in greater detail, some relevant items involved in the development of a technological route for the production of cultivated meat.

The large-scale production challenge

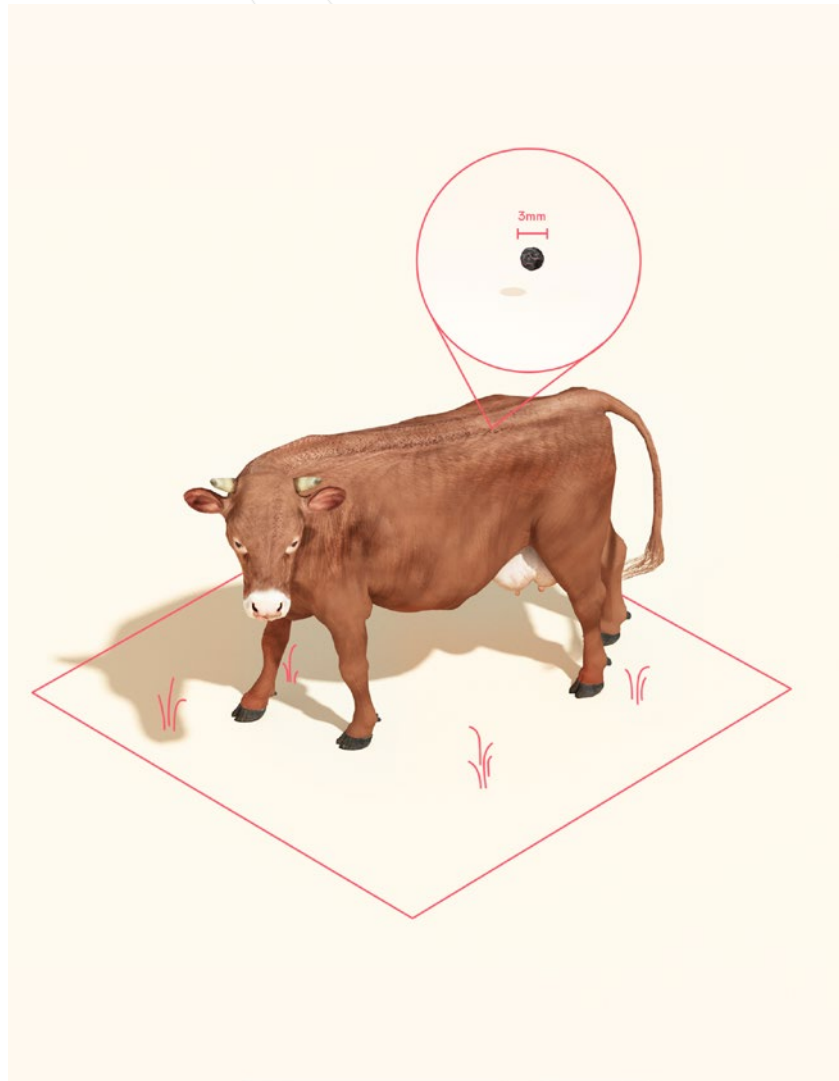
Transforming cultivated meat into a \$25 billion global industry by 2030 presents opportunities within and beyond today’s food industry, but this will require an annual production of 1.5 million tons of cultivated meat.

Source: Brennan et al., 2021.

Source of stem cells

The cultivated meat manufacturing process can start with one or more cell types. The isolation and selection of the initial cells (starting cells) that will be used at the beginning of the cultivated meat production process is undoubtedly one of the most important steps in the first phases of the process. Although a certain variability of cell types is present in conventional meat, the process assumes that musculoskeletal cells and adipocytes are the minimum components to produce cultivated meat (Post et al., 2020).

From a technical point of view, the selection of initial cells requires the fulfillment of certain evaluation criteria regarding replicative capacity (self-renewal).



Bovine cell extraction illustration. Image by [Mosa Meat](#).

It allows reaching a sufficient number of cells for the success of the process, lifespan of the cell type², ability to differentiate into other cell types in a culture medium where the other animal components are reduced or eliminated – as is the case with **fetal bovine serum** and the absence of contaminating microorganisms –, for example, **mycoplasmas**, viruses, fungi and bacteria.

Fetal bovine serum

Fetal bovine serum (FBS) is the liquid fraction remaining after the blood drawn from bovine fetus coagulates. Through centrifugation, cells, coagulation fibrinogens, and proteins are removed to produce serum.

Mycoplasmas

Refers to a genus of bacteria that lack a cell wall, and it is a common contaminant in cell cultures.

The initial cell population can be homo- or heterogeneous, but the variability between samples usually impacts the behavior of cells in the subsequent stages of cultivated meat production. The selection of cells depends directly on the new technology to be developed, the operational strategy and the type of meat to be grown. Therefore, properly characterizing the cells and sizing the cryopreserved cell stocks is essential in the initial phase of the process.

² Hayflick's empirical limit: number of cell passages without significant changes in cell behavior.

In this phase, the selected cells are grown in 2D culture systems, followed by volumetric expansion for further cultivation in bioreactors of different scales (Post et al., 2020; Specht et al., 2018; van der Weele & Tramper, 2014). Several animal tissues from which initial cells can be collected exist, but there is still much debate about which cell types would be ideal to use in the production of cultivated meat depending on the animal species, breed and tissue of origin.

Stem cells have been indicated as the main candidates for initiating cells in cultivated meat production since they meet the requirements of proliferation and differentiation (Post, 2012; Post et al., 2020; Stephens et al., 2018). From a biological point of view, stem cells can be obtained from various animal tissues, whether embryonic or adult (Pavlović & Radotić, 2017).

Major investments needed

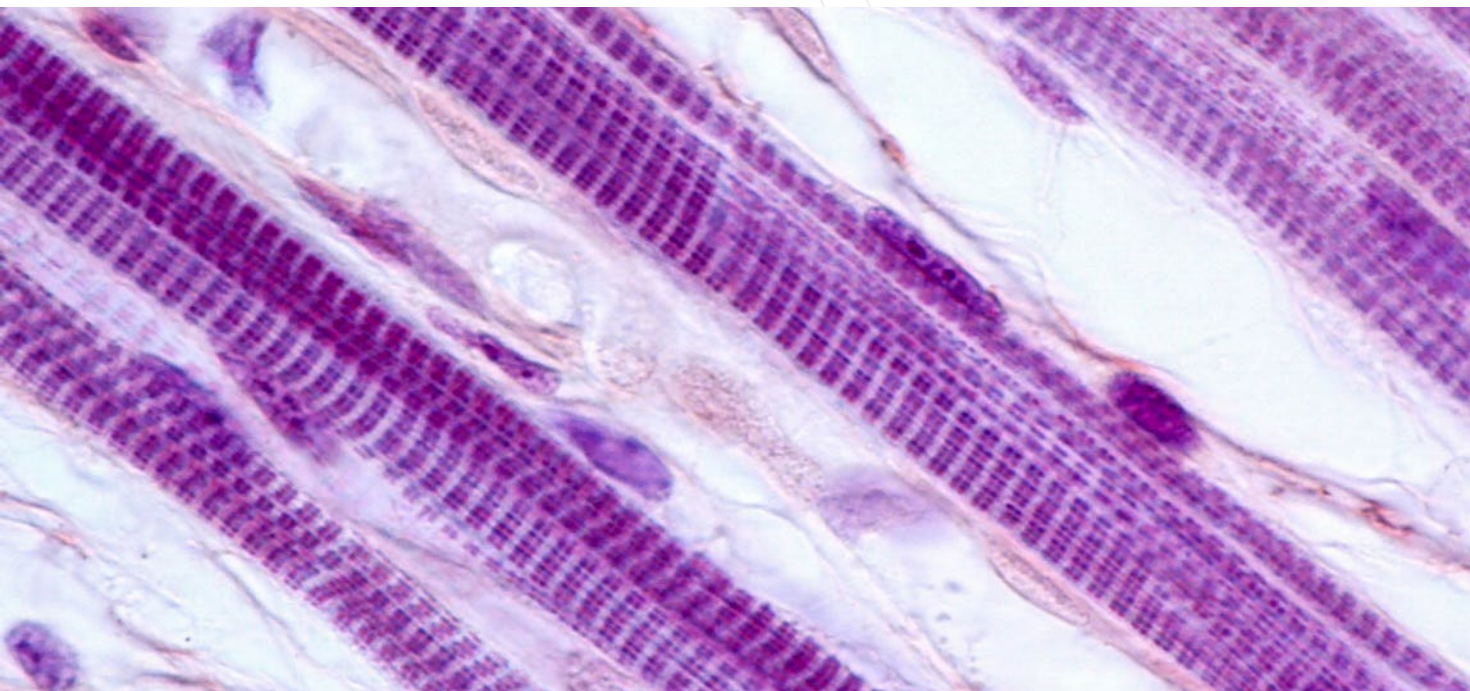
The current cell culture capacity of the pharmaceutical industry is estimated at between 10 million and 20 million liters (less than ten pools). It will take a large capital increase just to reach 1% of the protein market.

Source: McKinsey POBOS Pharma manufacturing benchmark database.

Blastocyst

The modified blastula of a placental mammal having an outer layer composed of the trophoblast.

Embryonic stem cells, obtained from the internal mass of the **blastocyst**, have an “unlimited” ability to proliferate and a potential for pluripotent differentiation; that is, these cells can originate all cell types that make up an organism (Post et al., 2020; Williams et al., 2012).



Muscle tissue micrograph.

The so-called mesenchymal stem cells have limited differentiation capacity but can still differentiate into bone, cartilage and adipose tissue cells.

Adult stem cells may remain quiescent in the tissues and be recruited during tissue development, contributing to the regeneration of parts of the tissue (Díaz-Flores et al., 2006). Satellite cells, which are adult skeletal muscle stem cells, can restart the cell cycle to proliferate and differentiate into myoblasts, having a finite number of duplications, constituting the myogenic progenitor of skeletal muscle tissues, and requiring little manipulation to give rise to myotubes and

myofibers. Musculoskeletal cells are the majority in the composition of conventional meat, and satellite cells were chosen for the production of the first prototype of cultured beef hamburger (Post, 2014). While satellite cells have limited renewal capacity, embryonic and induced pluripotent stem cells (iPSC) have virtually unlimited renewal capacity (Post et al., 2020).

It is worth noting that conventional satellite cell culture protocols and/or other types of stem cells need substantial optimization for their use to be viable in the manufacture of cultivated meat on an industrial scale (Post, 2014).

The huge commercial demand of the animal protein market requires cultivated meat to reach industrial scale, and the success of this depends heavily on the proper propagation of cells, which also greatly promotes the importance of bioreactor engineering. The **immortalization** of cells can extend their replicative capacity, favoring industrial scale expansions. However, new immortalization techniques must be developed and/or current techniques must be perfected, avoiding immortalization by **lentiviral transduction.**

Immortalization

A process that allows cells to multiply indefinitely in culture.

Lentiviral transduction

A method to deliver genes of interest within of a cell.

The fact is that some genetic approaches developed for the functional immortalization of human skeletal muscle cells (Zhu et al., 2007), adapted to cells from traditional livestock species, may be alternative sources for industrial biomanufacturing of cultivated meat (Roberts et al., 2015). It is known that keeping stem cells in their undifferentiated stage is critical, as the cell responds quickly to physicochemical stimuli when in culture (Pamies, 2016). Recent results showed that embryonic stem cells and iPSC from pigs and cows were successfully derived and characterized (Bogliotti et al., 2018; Choi et al., 2019; Ezashi et al., 2009; Gao et al., 2019).



However, the derivation of embryonic stem cells and iPSC from avian species, namely, chickens, resulted in partially reprogrammed cell lines (Pain et al., 2018).

In fact, carrying out genetic modifications in cells used for the production of cultivated meat should be one of the issues addressed by regulatory agencies, given the rapid advance in the development of new technologies. Such modifications have great potential to improve the characteristics of the final product, but they can be interpreted in different

ways by different regulatory agencies worldwide, depending on their current regulatory frameworks (Hanlon & Sewalt, 2021).

Given the rapidly evolving technologies for the production of cultivated meat, it is likely that multiple conceptual paradigms regarding stem cells will find applications in industrial manufacturing based on the inherent advantages of their respective biology. In this context, Brazilian agriculture stands out for its accurate genetics in cattle, poultry and swine.

Cell banks

Animal cells kept continuously in culture, primarily for scale manufacturing of a product or by-product, can become unstable, resulting in changes in morphology and function. The use appropriate freezing or cryopreservation techniques is a way to avoid possible changes in the viability or other characteristics of animal cells, allowing the preservation of cells for prolonged periods (Moraes et al., 2007). Cell bank is the name given to the stock of cryopreserved cells in special flasks and frozen at negative temperatures. In the case of cultivated meat production, the cell bank can be considered the “treasure” of the development of a new technology, whether for scientific research or commercial purposes. Cell banks maintain a consistent and reproducible reserve of identical cells prepared and cryopreserved from the same culture originating from the isolation and selection phases (Moraes et al., 2007).

Cell banks thus guarantee the existence of an adequate supply of equivalent and well-characterized animal cells to produce cultivated meat over the years. In addition to providing a constant supply of initial biological material, cell banks offer the opportunity to carry out a comprehensive characterization of animal cells, minimizing the risk of cell culture being lost due to handling accidents, contamination by adventitious agents or equipment failures in the subsequent stages of production.

Some strategies and methods must be adopted when establishing an animal cell bank. Cell banks are usually established in two phases: the first comprises the Master Cell Bank (MCB) and the second, the Work Cell Bank (WCB).

The MCB is a collection of cells of uniform composition derived from a single source of animal cells prepared under defined culture conditions; the WCB is derived from one or more flasks of animal cells from the MCB, which are expanded by serial subculture. The pooled cells are stored in individual vials and cryopreserved to make up the WCB.

Usually, animal cells used in the cultivated meat production process are first thawed from the WCB and propagated under controlled conditions to verify that cellular functions and characteristics were maintained after freezing. Methods to assess plasma membrane integrity, metabolic activity,

proliferation and the ability of cells to differentiate into different post-thawing lineages are some examples of numerous assays that can be performed. Tests for the presence of adventitious agents after the preparation of MCB and WCB should be routine.

The World Health Organization (WHO) and the Organisation for Economic Co-operation and Development (OECD) provide a series of pertinent information on the characterization of cell banks and cite a series of tests and analyses to verify adventitious agents (Organisation for Economic Co-operation and Development [OECD]; 2018; WHO, 2013).



The implementation of a quality system related to the organizational process and conditions under which a new cultivated meat technology is developed in terms of environmental safety must be planned, executed, monitored, recorded, archived and reported. Therefore, complying with Good Laboratory Practices (GLP)³ and, consequently, with Good Manufacturing Practices (GMP), is fundamental for the development of any new technology based on cultivated meat.

The cell bank can be developed in loco in the cell culture laboratories of universities or companies, but the cells used in the process can be acquired directly from established cell banks, such as the [Rio de Janeiro Cell Bank \(BCRJ\)](#), in Brazil, if designed for that purpose.



BCRJ is a Biological Resources Center, being a repository of human and animal cells; its collection includes cells from different origins, from humans to different types of animals such as swine, goats and cattle, as well as insects, fish, primates, mustelids and birds. The use of these cells in a future commercial application, however, must be planned in advance and follow, from the very beginning, the recommendations of regulatory agents.

³ OECD Series on Principles of Good Laboratory Practice (<https://bit.ly/3yya9vL>) and Princípios das boas práticas de laboratório (BPL) (Instituto Nacional de Metrologia, Qualidade e Tecnologia [INMETRO], 2019).

Cell culture medium



The development of new formulations of culture media is another important demand when it comes to the development of new technologies for cultivated meat. Reducing the cost of the culture media used over the cultivated meat production process has been identified as one of the key points for significantly reducing the costs of any technological production route for cultivated meat via bioprocesses, at any scale (Vergeer et al., 2021b). The fact is that, in addition to requiring culture conditions with parameters related to temperature, oxygen and carbon dioxide concentration, pH, osmolality, etc., animal cells need specific nutrients in appropriate concentrations for each cell lineage.

One of the most important factors in animal cell multiplication is the culture medium, regardless of application. The function of the culture medium is to provide appropriate osmolality and pH for the cell's

survival and multiplication and to provide it with all the required chemical components, that is, those it is unable to synthesize (Moraes et al., 2007).

Currently, basal media supplemented with complex additives such as fetal bovine serum (FBS) are used to cultivate animal cells in laboratories. The main functions of the serum are to stimulate growth, adhesion and various pathways of cellular metabolism via hormones and growth factors, also providing proteins to transport hormones, minerals and lipids (Freshney, 2005; Moraes et al., 2007).

However, the use of fetal bovine (or equine, etc.) serum should be avoided. Pertinent ethical limitations exist—in addition to technical ones—, as serum is extracted from the blood of bovine and equine fetuses by cardiac puncture.

Serum also presents great variability between batches and suppliers, making it difficult to standardize culture media, thus not meeting the need to control the nutrient concentrations of the medium over the cultivated meat production process. Serum is also considered a potential risk component, as it may contain contaminating microorganisms such as fungi, mycoplasmas and viruses, in addition to proteins such as prions.

Possible sources of inputs for culture medium

Average yields are expected to increase over the next ten years and will account for most of the growth in production of cereals, pulses, roots and tubers, and sugarcane. The increase in productivity will account for 75% of the increase in corn production and more than 50% for soybean.

Source: OECD and FAO (2020).

Given the information presented above, it is important to emphasize that the use of fetal bovine or equine serum or any serum from animals should be avoided in the development of new technologies such as cultivated meat. Therefore, new chemical compositions of culture media for animal cells containing defined concentrations of each ingredient added to the culture medium must be developed (van der Valk, 2017). The use of chemically defined culture media presents many advantages in relation to process control and traceability, in addition to the search for a significant reduction in the cost of the formulation. Some companies point to having managed to move quickly in this direction.

As examples, we can cite the Israeli company [Aleph Farms, which does not use serum and antibiotics to cultivate bovine cells](#) (“Aleph Farms FAQs”, 2021), and [Mosa Meat, a Dutch company that claims not to use any ingredients of animal origin](#) (“Growing beef”, 2020). In addition to these companies, researchers worldwide have also been working to obtain media free of this and other animal-derived components (Das et al., 2009; Chal et al., 2015).

In fact, chemically defined media without the presence of animal origin components must be developed, and their composition is directly related to the cell lineage used in the process, to the process stage (maintenance, proliferation, differentiation, among others), and to the characteristics of the final product.

The main components of any animal cell culture medium are water, a carbon source, essential and non-essential amino acids, vitamins, salts and highly complex molecules usually found in serum, namely growth factors, hormones, lipids, among others. Despite advances in the development of new culture media for animal cells, a universal culture medium that can be used in the cultivation of all cells is yet to be discovered, as each cell line has a particular metabolic profile and requires different ingredients to maintain its functions and viability.

Brazil holds great advantages in this sector due to its advanced agribusiness actions. The richness of Brazilian biodiversity is a great ally for the formulation of culture media especially developed for animal cells in the most diverse stages of cultivated meat production. Molecules with diverse applications can be prospected from native plants, such as cellular signals, aromas, colors and flavors.



The importance of agriculture, agribusiness and agroindustry in the development of **cellular agriculture**, with a focus on cultivated meat, is represented in Figure 2.

Cellular agriculture

Cellular agriculture focuses on the production of agriculture products from cell cultures. It uses a combination of biotechnology, tissue engineering, molecular biology, synthetic biology, biomaterials (scaffolds), and bioprocess and bioreactor engineering to create and design new methods of producing proteins, fats, and tissues.

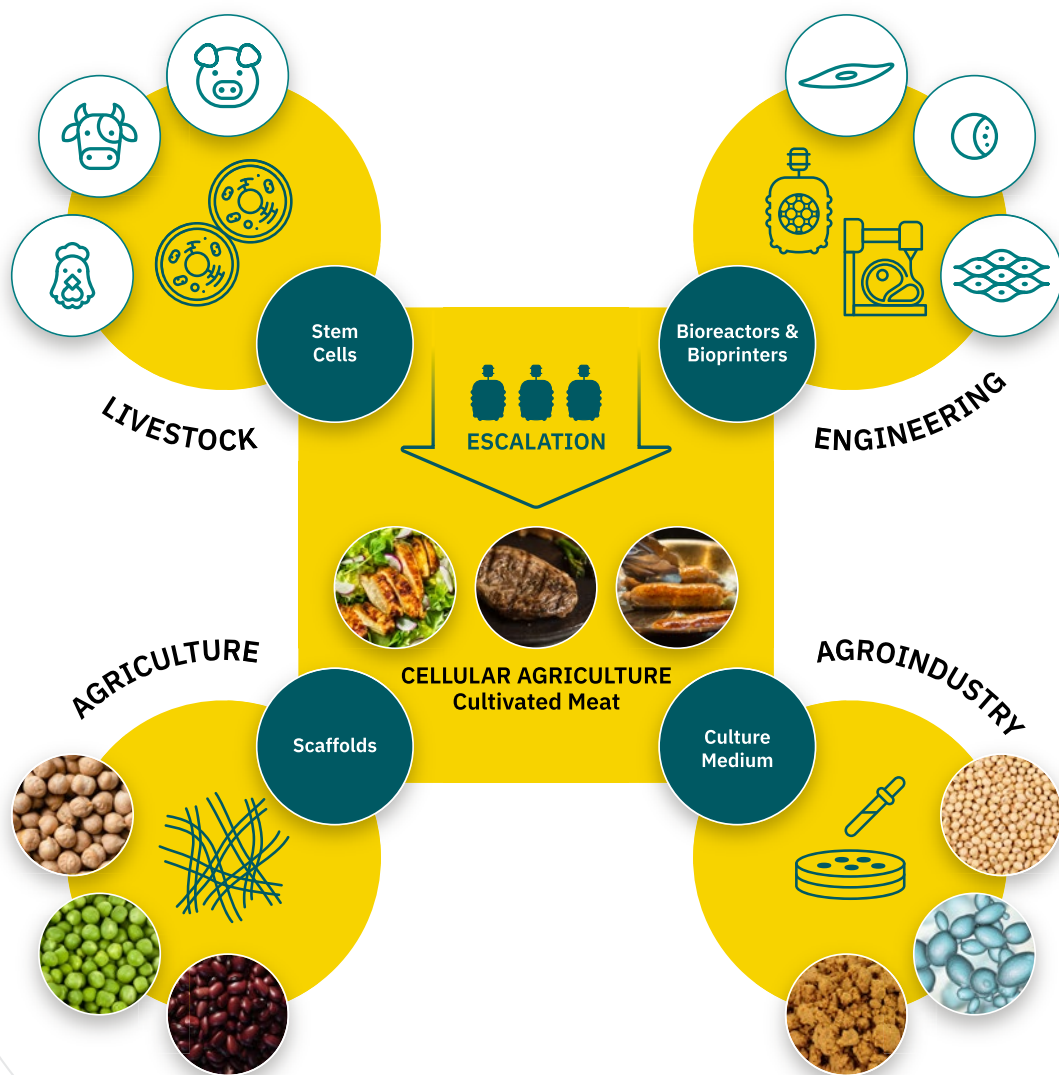


Figure 2 – Elements of the cultivated meat chain and their interrelationships. Look at the tissue engineering and bioprocess processes required for large-scale commercial product development and the interaction among key industry players.

Scaffolds



Animal cells are, as a rule, associated with tissues, whose extracellular matrix (ECM) contributes to their structuring, intercellular communication and the development of their functions. The cellular microenvironment is determinant, from which the necessary signaling for cell and tissue differentiation, maturation and function arises.

At a slightly higher level, organs combine different tissues to establish complex systems that support multicellular organisms. Although animals have cells that perform their functions suspended in fluids, such as bloodstream cells, most depend on complex three-dimensional interactions anchored in the extracellular matrix and/or indirect contact with other cells.

In the case of tissue construction by tissue engineering techniques, an important element is the biomaterial used as a scaffold, which supports adhesion, anchoring and substrate where the cell maintains and proliferates itself or adapts its metabolism. The support function is consequently extended to address cellular integration, determine its physiology, and structure the material at macroscopic level.

Good scaffold candidates are rich in edible fiber and hold high protein, or even fat, content. **It is important that these components, scaffolds or food additives, are “generally recognized as safe” (GRAS).** Textured soy, pea and/or other plant-based components may serve this purpose. In the case of bone biomimicry, non-edible biomaterials that maintain the food safety commitment and satisfy sensory requirements can be tested as a structural and functional alternative.

The stage and/or the moment in which support and cells are combined is one of the differential points when alternative technologies can compete favorably, one in relation to the other, depending on the final characteristics of the desired product. **This is a window of opportunity for innovation and the development of new bioprocess technologies to obtain new scaffolds; Brazilian agriculture, both industrial and family businesses, can be a strong ally.**

Bioreactors

One of the technologies that needs the most attention and development in cultivated meat production is the engineering of bioreactors.

Bioreactors are devices or equipment where biochemical reactions and biological transformations are conducted to obtain one or more products of biological nature. These (bio) reactions are usually promoted by enzymes (genuine biochemical catalysts), microorganisms or cells in containers or vessels where the culture media, temperature, pH and other process variables can be properly monitored and controlled.

In the case of cellular agriculture, more specifically in the production of cultivated meat, bioreactors are responsible for transforming an initial stem cell into products that contain differentiated and mature cells of different types. After being tested on bench and pilot scale, bioreactors must be



*Bioreactors in a meat cultivation room.
Image by [UPSIDE Foods](#).*

designed for commercial scale, where much larger volumes must be handled (thousands of liters). This step requires knowledge of the kinetics involved, of relevant mechanisms and mass transfer coefficients, and of the thermodynamic limitations imposed on the bioprocess.

Bioreactors should be made available for the process of stem cell expansion, where the aim is the continuous proliferation of progenitor cells; this would achieve adequate populations for the cell banks that will form the basis for the expansion required to being larger-scale reactors (pilot and commercial scales). The inoculum from such expansion can be carried out and, later, would feed the bioreactors where cellular differentiation will take place. Each specific lineage (or cell type) must have its proper culture medium and process conditions so that, from the original stem cell (pluripotent or adult), its final destination is the mature cell chosen to compose the final tissue, that is, the meat product of interest.

Bioreactors can operate discontinuously (batch), semi-continuously (fed-batch) or continuously. Under large-scale conditions, the process should be continuous, although bench-scale experiments conducted in small bioreactors are usually conducted in batches (in vessels of a few liters). Experiments that require a steady-state operation are an exception, for which the chemostat concept is used, that is, a bioreactor where the operating conditions do not vary during the study period.



Bioreactors in a meat cultivation room.
Image by [UPSIDE Foods](#).

Tissue bioreactors



Although stirred tank reactor (STR) type of bioreactors are used to cultivate animal cells, a particular case that deserves special attention is tissue bioreactors. In this case, there is an interest in increasing the cell density to its maximum point, without, however, losing the properties of the cells and allowing them to form tissues. These tissues can be obtained by combining more than one cell type, coupled to edible scaffolds, in the case of soft tissues, or in the case of meat-on-bone mimicry.

Examples of these bioreactors are wave bioreactors, where the culture medium and the cells are gently agitated, promoting the exchange of gases and nutrients without subjecting them to mechanical stresses that could affect their desired phenotype performance; another case are rotating wall bioreactors, which simulate gravitational forces by moving the cell culture system. Perfusion bioreactors are also particularly interesting, as they can operate continuously.

In this case — but unlike chemostats — the cells are either retained in the bioreactor or fed back into it. The medium passing through the bioreactor, therefore, contains no cells, resulting in higher cell concentrations and product yields in the bioreactor. To avoid the stresses produced by mechanical agitation, other flow systems (e.g., airlift) can be used and/or developed.



Wagyu meat bioprinted by scientists at the University of Osaka, Japan. Image by [Reuters](#).

In any case, it is important to note that these are types of bioreactors that were not developed to produce food but to find ideal conditions to maintain certain cellular properties. **Opportunities for innovation and development of new concepts and types of bioreactors for cultivated meat purposes thus exist.** Bioreactor engineering is an area where technological development can help to advanced products from cultivated meat to be achieved.

Bioprinting

In another line, there are numerous opportunities for the composition of tissues from the bioprinting of cells and other edible components, using bioinks suitable for 3D printing (layer-by-layer or additive manufacturing).

Naturally, commercial-scale bioprinting of meat products will require extensive development and innovative solutions, but this is a technology that can promote the production of biomimetics or analogues of traditional cuts more easily than conventional bioreactor technologies.



Cultured rib filet produced by bioprinting. Image by [Aleph Farms](#).

Cell performance optimizations



Marketing of cultured meat at affordable prices will depend on several factors, some of them related to the efficiency of the process, including the optimization of the use of culture media and other inputs, operating costs and investments in equipment and infrastructure. From the point of view of bioreactor engineering, they become more compact and, therefore, cheaper when kinetics is favored. In the case of cell growth kinetics (i.e., cell multiplication), interventions in the genotype may allow for higher replication rates and increase the number of passages before critical senescence thresholds are reached.

This can be achieved by evolutionary engineering techniques or by genomic modifications designed for this purpose (genomic engineering). Telomere lengthening, for example (by the action of more efficient telomerases) and other cells “immortalization” techniques could result in cells optimized to produce cultivated meat. Genomic engineering comprises a large arsenal of genomic improvement tools, including methods and techniques from bioinformatics, metabolic engineering, systems biology and synthetic biology. These tools could contribute to the competitiveness of cultivated meat bioprocesses, although the initial perception of both the public and regulatory agents seems unfavorable.

Innovative techniques such as the **CRISPR/Cas9** system and other more recent systems allow genome editing of the initial cells to be carried out with great precision; the control of gene expression by activating or inactivating genes can also be studied and monitored by metabolic flux analysis and control; on the other hand, epigenetic regulation of gene expression influenced by the culture medium, for example, can be done without genetic modification of the cell. Genetic edits performed on post-biopsy cells will affect only the cell lineage derived after the modification.

CRISPR/Cas9

The genomic editing method by the CRISPR/Cas9 method technique started a new revolution in synthetic biology.

Drastic cost reduction

Since the development of the first prototypes, companies have managed to reduce production costs by 99%.

Source: Brennan et al., 2021.

Therefore, the transmission of these modifications to other living organisms or dissemination of these cells in the environment is not expected. Thus, cells optimized to produce cultivated meat will not necessarily be treated as GMOs (genetically modified organisms), as established by the Brazilian Biosafety Law.

Obviously, these and other modifications need to be studied for their effects on both safety and the characteristics of the final product, and duly regulated by the relevant agencies.

The role of the academy



Commercial-scale cultivated meat production is a multidisciplinary enterprise that requires the attention of professionals from different technical areas and understanding of a complex and increasingly dynamic market. The alternative protein market will benefit from competition between technologies—some yet to be discovered—and products that attract the attention and preference of end consumers, bringing continuous demands on the entire ecosystem.

The development of cellular agriculture in Brazil, in particular of cultivated meat, opens up numerous academic opportunities for those who will offer positions for professionals who will work in the sector and for talented young people who are looking for opportunities for their future careers.

As with other multidisciplinary areas, such as nanotechnology and bioinformatics, cellular agriculture will benefit from the introduction of new disciplines in traditional courses, but also from the creation of new undergraduate courses, new specializations and courses for master's and doctoral studies in various educational programs.

However, unlike training courses that explore techniques and methodologies aimed at specific topics, cellular agriculture is not a thematic area but the conjunction of different fields of application, with a view to obtaining tons of a complex industrial product.

In the case of cultivated meat, the challenge comes from a single initial cell, selectively obtained from an animal of interest. This can be an already domesticated animal (beef, pig, chicken, fish, shrimp, etc.), or even a wild or exotic animal, considering nutritional or commercial aspects.



What needs to be domesticated, in this case, is the initial cell, which requires a suitable environment to grow and reproduce at a rate and quantity compatible with the demand imposed on it. Bioinformatics tools and nanotechnologies may be just two of many facets of technology to achieve cultivated meat products. Characterization of genetic profiles can be important to ensure the

desired cell stability from a genomic point of view, as nanofibers and other nanostructured biomaterials can be part of commercial formulations. In other words, the education of professionals qualified to work with cultivated meat should be concerned with subjects as diverse as molecular biology and biomaterials.

How to train professionals to work on cultivated meat?

Cultivated meat technology requires skilled professionals in several areas, and vertical training covering all areas of interest would be appropriate. However, the training time and the efforts necessary for the proper training demand deepening in many concepts, techniques and tools. At the moment, the most reasonable approach is teamwork, with the use of professionals from the relevant areas. Cultivated meat production activities need to be naturally divided among employees with training in molecular biology, cell biology, biochemistry, bioprocesses, biomaterials, food engineering, chemical engineering, tissue engineering, among many others.

When this new industry reaches high levels of maturity, specialization courses or even undergraduate courses with a vocation for cellular agriculture may be necessary to meet the demands of the job market. Anticipating this future gap and certain that the debate on the creation of undergraduate courses focused on the area of cultivated meat needs to begin, the GFI prepared a pedagogical project proposal for a degree focused on cultivated meat. The proposal will be available soon and was conceived considering all the multidisciplinary aspects necessary for a course of this type. It is important to point out that graduate training with a focus on cultivated meat is a reality in Brazil since 2020 due to the [initiative and pioneering spirit of the Federal University of Paraná \(UFPR\)](#).

Opportunity for young researchers



Cultivated meat technology is also a movement toward sustainable technologies, valuing animal welfare, concern for the environment, and food safety. As such, it offers a motivating scenario for young people who want to be part of the history of their time, who seek to contribute to humanity's great challenges and the planet's sustainability.

The education of this new professional, as well as the training of any of the so-called "professions of the future," involves a long and complex interdisciplinary path, but with great possibilities for personal and professional achievements.

Depending on the level of expertise required, it may range from basic biology to advanced bioreactor engineering, genomic engineering, biological engineering, tissue engineering, ; therefore, it offers an excellent opportunity for young professionals to enter a market of promising high employability, in addition to a highly relevant social and environmental role.

New technologies



It is known that there is great overlap between medical technologies and those that are or will be used to develop and produce cultivated meat, in particular those related to tissue engineering and regenerative medicine techniques. What may not be so obvious is the possible development synergy for both sectors: what is discovered in one sector can very well be transferred to the other. **We must be aware of new methods and techniques in areas as diverse as organ printing, biophotonics and nanotechnology.** For applications focused on meat production, fat marbling can be added by advanced bioprinting techniques, for example, promoting structure and flavor (Lanza et al., 2020).

[Aleph Zero](#), Aleph Farms's program to create space meat.

The use of lasers to move particles of matter to form organized structures is not only of interest to medicine—for example, for cell separation, or delivery of drugs or microencapsulated substances into cells—, it may also be of interest in tissue production, including in meat products. Among additional possibilities, the use of nanotechnologies and nanomaterials can be of great value to produce scaffolds and to the structuring of biomaterials for the composition of remarkable new bioproducts.

Research opportunities

Scientific research opportunities encompass projects that investigate from the establishment of cell lines—with a strong bias toward the use of stem cells, supporting their use at industrial scale—, to the formulation of specific culture media for each stage of the cell fate process, mapping of biologically active molecules derived from biodiversity or from the cells themselves; these can be indispensable ingredients in culture media or as flavor and odor aggregating molecules, by-products or products of agriculture that can be transformed into fibrous substrates, tasty and rich in nutrients that favor the structuring (scaffolds) of products, design of tissue bioreactors, efficient bioprinters for 3D printing, among other opportunities raised by the bio-manufacturing industry.

It is known that the Brazilian National Council for Scientific and Technological Development (CNPq), as well as the country's Coordination for the Improvement of Higher Education Personnel (CAPES) and the Financing Agency for Studies and Projects (FINEP) are fundamental for stimulating technological development in Brazil. Actions by a government of entrepreneurial spirit (Mazzucato, 2011) are also fundamental in leveraging disruptive high-tech sectors. In the case of the cultivated meat sector, State actions such as those seen in Israel and Singapore, for example, corroborate this statement. **In Brazil, a synergistic integration between agricultural, economic, industrial and science and technology policies can ensure that Brazil is a protagonist in the global scenario of cultivated meat.**

Simple and agile mechanisms that encourage public-private partnerships can be extremely helpful so that the relationship between researchers, industry and investors is effective and supports projects in their different degrees of uncertainty and risk. In this scenario, universities and research institutes must be the driving force of innovation and their internal intellectual property and technology transfer structures must be in line with the demands and challenges of the cultivated meat sector.



On the other hand, innovation habitats such as incubators, accelerators and public and private innovation centers are also important actors, as they are the locus where entrepreneurial initiatives by startups focused on the cultivated meat sector receive the necessary support to build and validate its value propositions, qualifying its access to the investment market in entrepreneurial capital.

The transformation of a scientist into an entrepreneur and the transformation of innovative ideas into technological solutions depend on the synergistic action of all these agents of the [Brazilian National Innovation System \(“A importância do Sistema”, 2019\)](#). As observed in other countries, such as the Netherlands, Israel and the United States, the role of universities is extremely relevant in supporting startups in biotechnology and life sciences.

The industry challenge and investment opportunities

The Brazilian animal protein industry is one of the most important in the world. JBS and BRF are larger producers of animal meat and giants in the sector, which does not prevent small companies from getting along perfectly well with large ones, according to the [Brazilian Association of Animal Protein \(ABPA\) \(Benetti, 2020\)](#). Brazil reached this position for several reasons, but the country's vocation for the production of animal protein is undeniable.

Contributing to this is the Brazilian taste for meat consumption, especially beef—as well as that of our Argentine neighbors—, the size of arable land, the technological advances in the agroindustry, the training of human resources for the sector, and the incentive to research by development and government agencies.

The country's food industry has shown great flexibility and adaptability.



Cultivated duck. Image by [UPSIDE Foods](#).

Retailers fill supermarket shelves with ever-increasing quality and creative products. The meat industry has adapted to external demands, exporting products that not only comply with Brazilian legislation but also adhere to the protocols of other countries, cultures and religious practices.

From field to port, our products are exported all over the world, with a well-established cold chain, distribution and logistics. All this potential should motivate the productive sector to adhere to the new scenarios and challenges posed by the new cultivated meat industry. Numerous investment opportunities are available, both for current market players and for investors of all levels.

The challenge for the national industry is to maintain its global competitiveness and to quickly adapt to new technologies and markets. The Brazilian business community in the sector is audacious and has already proven its competence in the production of animal protein.

Now is the time to use the accumulated knowledge and expand it to ensure a leading role on the world stage also in the field of alternative proteins.

Startups and investments in the sector

The industry, which currently comprises less than 100 startups, has attracted around US\$350 million in investments in 2020 and around US\$250 million by June 2021 from some of the biggest animal protein players, including Tyson and Nutreco, and well-known investors, including Temasek and SoftBank.

Source: Brennan et al., 2021.

The country is starting a little late, but we have the strength to recover and surpass our competitors. For this, investments in the development of the country's own technology – and not just absorbing external knowledge – is crucial. If Brazil also wants to be a leader in the cultivated meat sector, it must bet its chips on the new market, as it has done in the recent past in sectors that are now considered traditional and consolidated.

Market forecasts

The [FAIRR initiative](#), established by the Jeremy Coller Foundation, is a collaborative network of investors that aims to raise awareness of environmental, social and governance (ESG) risks and opportunities brought mainly due to intensive livestock production. In partnership with investors and important players in the animal protein market, FAIRR offers market analysis tools to assist investors and the industry in their positioning and in reducing investment risks in the face of long-term environmental, social and regulatory trends. The ability of companies to successfully anticipate and navigate these changes is crucial to ensure their positioning in the world market.

As of May 2021, FAIRR's projection estimated that the cultivated meat industry will move about \$572 million in 2027, representing a compound annual growth rate of 15%. Considering that the year [2020 ended with around US\\$ 360 million invested \(Swartz, 2019\)](#), capital flows to the cultivated meat industry reached over US\$ 1 billion by September 2021.

Diversifying the protein portfolio is an opportunity for the industry to offset the non-financial risks associated with over-reliance on animal-based proteins. The increase in animal protein production for human consumption via the intensification of traditional livestock activity brings with it significant challenges in terms of sustainability and the use of finite natural resources. **Therefore, protein diversification is crucial for risk mitigation and cultivated meat presents itself as a potential solution to several environmental issues.**

Increase in world meat production

Developing countries are expected to account for 81% of the additional beef produced in the 2021–2029 period. Most of this expansion is expected to take place in Argentina, Brazil, China, Pakistan, Sub-Saharan Africa and Turkey.

Source: OECD and FAO (2020)

Support for research and rural extension

Agricultural research in Brazil is traditionally supported by important State initiatives, working together with the productive sector and promoting innovation. At the national level, the Brazilian Agricultural Research Corporation (EMBRAPA), a public research company linked to the Ministry of Agriculture, Livestock and Supply of Brazil (Mapa), founded in 1972 and with around 10,000 employees, has provided highly relevant services and boosts the sector in different ways, either as a generator and transferor of technologies or in support of large industry and small rural producers. State agencies are also relevant. In the State of Santa Catarina, for example, a similar role is played by the Agricultural Research and Rural Extension Company (EPAGRI), founded in 1991 and having over 2,000 employees.

Government support should also be given to the cultivated meat industry, with the integration of production systems, support for small, medium and large producers, the input and equipment industry, as well as technical assistance and training of researchers.

At GFI, our commitment to expedite the development of the cultivated meat industry includes funding scientific research programs. In particular, we seek to allocate resources to high-impact open access research capable of solving technical challenges and overcoming knowledge gaps. [Between 2019 and 2021, GFI's Research Grant Program](#) awarded over US\$13 million to 82 projects in 17 different countries.

Of this total, 43 projects are focused on cultivated meat, some of which are being conducted by Brazilian scientists.

The adhesion of large producers to the new industry should promote a natural alignment in the sector, especially with the maturation of disruptive technologies in progress, uniting raw material producers, suppliers in general and distributors.

In the case of large companies, the vertical model can give rise to strategic partnerships with small producers of micronutrient-rich inputs, arising from activities that already exist and/or are to be developed.

Demands in Latin America and the Caribbean

The Latin America and Caribbean region comprise about 8.5% of the global population and will add another 60 million people by 2029. Its urban population will increase by 66 million people, bringing the urbanization rate to 83%, the highest among developing regions.

Source: OECD and FAO (2020)



New programs to encourage small producers can motivate innovation in rural and urban areas alike, with new ingredients to be used as raw materials and/or in the formulation of new products, which use cultivated meat as a basis for new protein foods.

Regulatory demands



Regulatory agencies will play a key role in consolidating the cultivated meat sector in Brazil. They are responsible for conducting the [Regulatory Impact Analysis process and defining the sector's operating models](#) (“Análise de impacto”, 2022). The construction of a regulatory framework favorable to innovation and investment and aligned with the regulatory experiences developed in other countries is a determining factor for the speed with which the Brazilian market will develop. In this scenario, the role of the General Management of Food of the National Health Surveillance Agency (GGALI/ANVISA) and the Department of Inspection of Products of Animal Origin of the Ministry of Agriculture (DIPOA/Mapa) deserves to be highlighted.

The [regulatory study developed by the Institute of Food Technology \(ITAL\)](#), commissioned by the GFI, shows that the countries of the European Union, Canada, the United States, Australia, New Zealand and Singapore have started regulating novel foods produced from cell culture. The regulatory agencies of each country determine the guidelines relevant to sanitary controls related to the production process, as well as the permits for the installation of manufacturing units to guarantee the safety of this novel food.

In Australia and New Zealand, the regulation of novel foods is the responsibility of Food Standards Australia New Zealand (FSANZ), the Australian and New Zealand food standards authority.

FSANZ claims that its current food regulation system is sufficient to assess new types of food, including food produced by new technologies. To date, no protein obtained by cell culture has been approved in these countries.

In Canada, the responsibility for regulating food is shared by Health Canada, a federal institution of the Ministry of Health, and the Canadian Food Inspection Agency (CFIA), an agency of the Canadian Ministries of Agriculture, Health and Science and Technology. The CFIA defines novel foods as:

(a) a substance, including a microorganism, that does not have a history of safe use as a food; (b) a food that has been manufactured, prepared, preserved or packaged by a process that (i) has not been previously applied to that food, and (ii) causes the food to undergo a major change; and (c) a food that is derived from a plant, animal or microorganism that has been genetically modified such that (i) the plant, animal or microorganism exhibits characteristics that were not previously observed in that plant, animal or microorganism, (ii) the plant, animal or microorganism no longer exhibits characteristics that were previously observed in that plant, animal or microorganism, or (iii) one or more characteristics of the plant, animal or microorganism no longer fall within the anticipated range for that plant, animal or microorganism (aliment nouveau).

Singapore, the first country to approve the marketing of cultivated meat in the world, has the Singapore Food Agency (SFA) as the body responsible for overseeing food safety and food safety from farm to table. [On December 1st, 2020, SFA approved the sale of cultured chicken meat from Eat Just Inc., branded GOOD Meat™](#), a historic milestone for the new generation of food products. The SFA defines novel foods as foods or food ingredients that do not have a history of safe use.

The definition of novel foods can also include compounds that are chemically identical to substances found naturally in foods but produced via technological advances. With a policy of avoiding procedural delays, companies are encouraged to consult with SFA early in the process to understand the information that must be provided to prove the safety of their new products. SFA estimates a timeframe of three to six months to complete each novel food evaluation application

For the safety assessment of cultivated meat, SFA currently requests the following information from companies: a description of the entire manufacturing process, characterization of cultivated meat, including nutritional composition, and comparison of residual amino acid rates against data from the literature, information related to cell lines used, information related to culture media, information related to scaffolding, information about how the purity and genetic stability of the cell culture are guaranteed during the manufacturing process, safety assessment covering possible hazards arising from the manufacture of cultivated meat and other relevant studies to support safety, such as digestibility assays, allergen profiles, genetic sequencing, etc.



*Cultivated chicken served at Madame Fan's restaurant in Singapore.
Image by [GOOD Meat](#).*

In the European Union, foods obtained from cell cultures are covered by the definition of Novel Foods in the Regulation EU No. 2283, of November 25, 2015. In 2020, at the 108th Plenary Meeting of the Nutrition, Novel Foods and Food Allergens (NDA) Panel, the European Food Safety Authority (EFSA) addressed the topic of Cultivated Meat in the presentation “Insights on novel foods risk assessment” and presented the following points to be considered when assessing safety: identity, which includes information about the biological source; characterization of by-products or residues and biological hazards; production process; nutritional information and allergenicity.

The main EFSA safety assessment criteria for novel foods are described in “Guidance on the preparation and submission of an application for authorization of a novel food in the context of Regulation” (EU 2015/22831, Revision 1 – 26/03/2021).

In the United States, the United States Department of Agriculture (USDA) and the Food and Drug Administration (FDA) have established a formal agreement to jointly regulate cultivated meats. Food products produced from cells from species regulated by the USDA, Federal Meat Inspection Act (FMIA) or the Poultry Products Inspection Act (PPIA) will be regulated by the FDA during cell procurement, selection and cultivation and by the USDA/FSIS during subsequent processing and labeling.

In this context, regulatory agencies in Brazil must work closely with their peers abroad while advancing innovative propositions that put the country in the spotlight.

Singapore’s pioneering spirit should be an inspiration. We must take advantage of our position as a major producer of proteins, of both animal and vegetable origin, to also be protagonists in cultivated meats. Cultivated meat must be seen as a novel food and as such follow the existing paths and those provided for in specific legislation. At the same time, work with the productive sector can be done to guide and mitigate risks, while the technology matures. A protocol for requesting the registration of products and manufacturing facilities can and should be built in this spirit of collaboration, after hearing all the actors involved.

Public perception and consumer acceptance



Several studies conducted in the last decade have attempted to capture public perception and consumer acceptance of cultivated meat (Siegrist & Hartmann, 2020), analyzing issues such as hamburger consumption made from cultivated versus conventional meat. (Slade, 2018), influence of environmental impacts and animal welfare of cultivated meat (Bryant & Barnett, 2018), sustainability of the process (Bekker et al., 2017), and other aspects that draw the attention of the general public. In the last three to four years, technical limitations have also given way to growing public interest in the subject, as some companies begin to reveal their short-term plans to enter the market.

Public perception is, in general, closely associated with the way the subject is presented in opinion polls and popular publications, magazines and newspapers. In particular, terms such as “laboratory meat” or “synthetic meat” bear negative and artificial connotations in their very mention. Even recent studies mention cultivated meat as such, that is, referring to cultivated meat as “artificial meat” (Chriki et al., 2020). Terms such as “in vitro meat” or “lab-grown meat” can be derogatory and do not contribute to a favorable public perception (Bryant & Barnett, 2019). In 2019, the GFI conducted a nomenclature study to verify which words of the shortlisted cultivated meat, cell-based meat, clean meat and non-slaughtered meat would lead to greater consumer acceptance.



Image by [Mosa Meat](#).

The results showed that the name “cultivated meat” was among the most accepted (Bryant & Krelling, 2020). It is important to mention that consumer perception changes when the positive aspects of cultivated meat are presented clearly and without prejudice. There is a great responsibility, not only for scientists, but also for economic and technology journalists to democratize knowledge about technology, its innovations, advances and benefits.

Cultivated meat science can increase acceptability as it introduces ways to improve flavor and texture; behavioral science can increase acceptability by identifying modifiable perceptions; likewise, scholars must communicate the science and technology of cultivated meat to the public in a transparent way (Tomiyam et al., 2020), both in specialized publications and in popular media and social networks, working as scientific disseminators, either in interviews or in reports for specialized journals and websites.

Climate challenges and cultivated meat

The latest Intergovernmental Panel on Climate Change (IPCC, 2021), published on August 8, 2021, reinforces the importance of combating deforestation, promoting forest recovery and the need for changes in agricultural practices. These measures aim to mitigate the environmental impacts caused by human action.

Brazil, host to the greatest biodiversity on the planet, plays a fundamental role in mitigating the effects of climate change by reducing Greenhouse Gases (GHG) emissions from agricultural and livestock activities.

The [Low Carbon Agriculture Plan – ABC Plan](#), sponsored by the Federal Government via the Mapa, in its first phase (2011–2020), was composed of 7 programs:

- Recovery of degraded pastures;
- Crop-livestock-forest integration and agroforestry systems;
- No-tillage system;
- Biological nitrogen fixation;
- Planted forests;
- Animal waste treatment;
- Adaptation to climate change.

The main results were the adoption of technologies recommended by the plan in almost 50 million hectares, with crop-livestock-forest integration, no-tillage and biological nitrogen fixation and, according to Mapa data, more than 26.8 million hectares of degraded pastures were recovered in the program's first ten years.

Still in this first phase, the [ABC Plan developed the Carbon Neutral \(“Marca-conceito”, 2017\)](#) and [Low Carbon Meat \(Embrapa, 2020\)](#) certifications, which guarantee that certified products come from cattle raised with proper pasture management, in addition to providing greater animal welfare. In January 2021, the federal government published Decree 10,606 establishing the Integrated Information System of the Sectorial Plan for Consolidation of a Low-Carbon Economy in Agriculture (SIN-ABC) and the Technical Committee for Monitoring the Sector

Plan for consolidation of a Low Carbon Economy in Agriculture (CTAB), instituted to monitor these actions (New ABC Plan 2021–2030). These are important initiatives, but in the long term, they may not be enough given the growth projections in the demand for animal-derived protein for human consumption. [An estimate by FAO points to 70% increase in global demand for food by 2050 \(“2050: A third more mouths”, 2009\)](#). The infographic in Figure 3 shows how this growing demand will impact animal protein production by species.

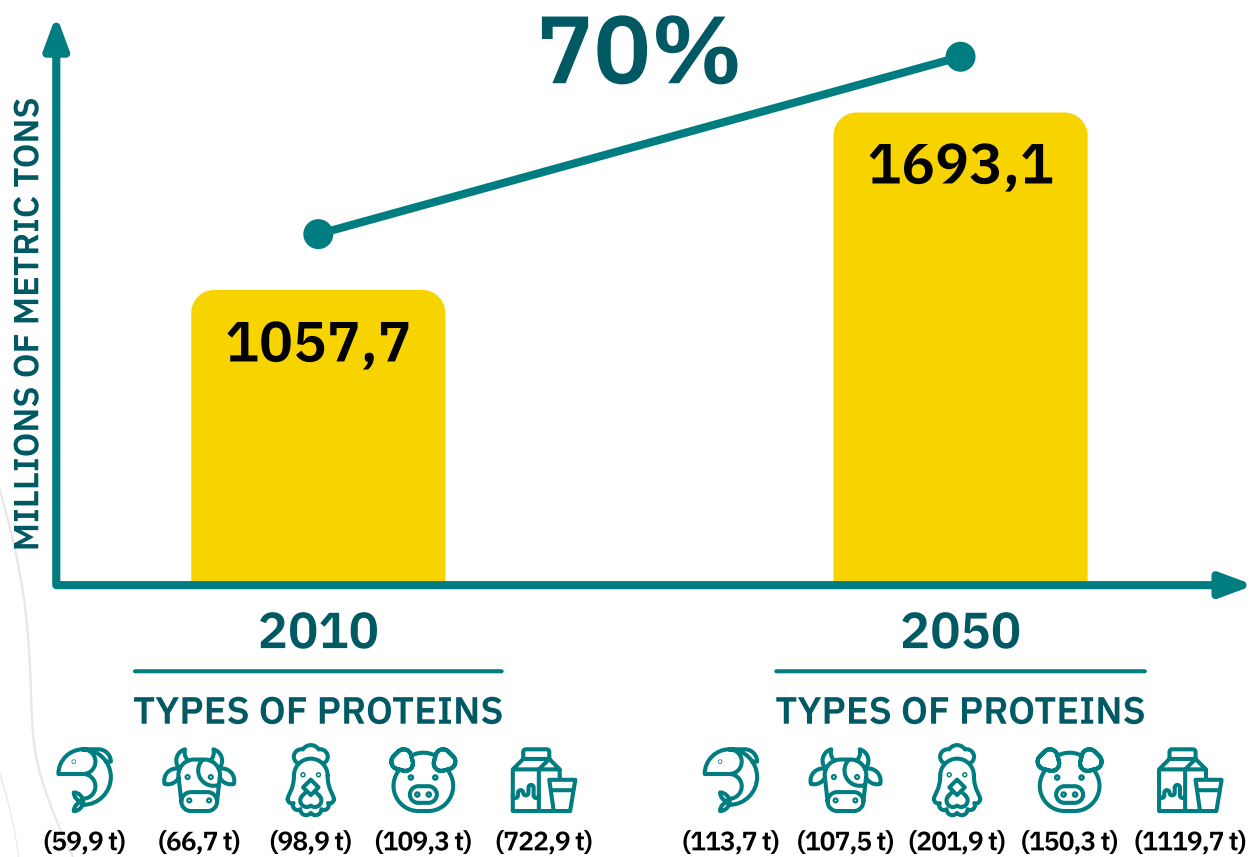


Figure 3 – Increase in global demand in food production forecast for 2050 and its impact on the animal protein production chain, by species.

The introduction of cultivated meat as an alternative option to the consumption of conventional animal protein is estimated to contribute substantially to the optimization of the use of finite natural resources such as water and land and their associated environmental effects. It is taken for granted that land extensions should be reduced when comparing the production of 1 kg of cultivated meat as opposed to raising cattle for slaughter. [The methane emitted by cattle \(flatulence and belching\) is a consequence of their complex digestive tract \(Gibbens, 2019\)](#), used to transform the cellulosic material of pasture into animal meat.


More sustainable, lower environmental impact

A recent life cycle assessment carried out by CE Delft found that cultivated meat is significantly (over 75%) more sustainable in terms of CO₂ and land and water use than beef and has a similar sustainability profile to poultry and pork.

Source: Odegard et.al, 2021.

This is a naturally inefficient process. About only 3% of the energy/material consumed is converted into meat. It is also a fact that the reduction in methane production drops to zero in the industrial process of cultivated meat. It is always good to remember that methane (CH₄) is about 20 to 30 times more harmful as a greenhouse gas than carbon dioxide (CO₂). Therefore, in the long term, the gradual transition from conventional meat production to cultivated meat will contribute to the reduction of methane production associated with the consumption of animal protein.

Other relevant topics and impacts are generally manifested in studies and publications by international organizations and study groups.



Conclusions, reflections and recommendations

In his essay written in December 1931 with reflections and predictions for the next fifty years, originally published in the Strand Magazine, Sir Winston Churchill (2022) not only predicted that chicken breast and wings would be produced from cell culture in suitable growing media, but also that cordless telephones and televisions would unite people in distant places as if they were talking from their windows. Churchill's bets were based on the strength of science and the pace at which it developed in the first decades of the 20th century. The former British prime minister may have been wrong for a few decades when it comes to cultivated meat, but it is undeniable that his vision qualifies him as a prophet of our times. Still from his words, it is also worth mentioning that:

“

Synthetic food will, of course, also be used in the future. Nor need the pleasures of the table be banished [...]. The new foods will from the outset be practically indistinguishable from the natural products, and any changes will be so gradual as to escape observation. (Churchill, 2022).

His remarks on the possibilities of scientific development based on new, abundant and efficient forms of energy, above all of molecular/atomic (nuclear) origin, also advocated technological revolutions. In his day, coal was the main source of energy:

“

But food is at present obtained almost entirely from the energy of the sunlight [...] Many people, of course, prefer food in what the vegetarians call 'the secondhand form', i.e., after it has been digested and converted into meat for us by domestic animals kept for this purpose. In all these processes, however, ninety-nine parts of the solar energy are wasted for every part used. (Churchill, 2022).

It is a pity that the famous English statesman did not have the privilege of also living in the beginning of the 21st century to witness what technological progress has been able to achieve in 90 years, and the transformations that our means of communication, energy generation and food production have undergone. Although the undeniable advances in the way we produce animal protein for human consumption have contributed greatly to the increase in the efficiency of the process, we are fundamentally “behind” the Churchillian possibilities. We have replaced animal traction with modern and efficient gasoline, diesel and electric engines, even if their power is still reported in horsepower, but are yet to replace live animals raised for slaughter as our main source of protein food.

The production of meat cultured on an industrial scale from stem cells from chicken, beef, sheep, shrimp, fish and/or any animal whose cells can be “domesticated” is undoubtedly a major challenge for our generation. The most important initial steps have already been taken, with numerous successful cases on a laboratory scale. Production on a pilot scale and on an industrial scale still mount important challenges, especially regarding the reduction of input costs, including raw materials for the production of culture media free of components of animal origin, and tissue bioreactors.

Ultimately, the ingredients will come from the conversion of energy from the sun into organic material, as inevitable, through the biosynthesis of primary products such as sugars, fatty acids, amino acids and micronutrients. However, unlike the traditional method where we need to

convert pasture/feed into edible protein, using the live animal as a biofactory and keeping all the inefficiencies inherent to the process, the cultivated meat industry method uses only the information written in the DNA of an animal cell for the production of new protein foods, in which we can reduce the cell->meat. Finally, we will be using the most advanced scientific knowledge and our full technological capacity to transform information into food in an intelligent, sustainable, safe and nutritious way. New forms, new products, new formulations and new nutrients will emerge as a consequence of human needs and creativity. And, as Winston Churchill said, “changes will be so gradual as to escape observation.”

Seen from the world stage, Brazil appears to be leaving late. But this is not a sprint or a 100-meter dash; rather, it is a long-distance race, a scientific and technological marathon where the winners are those with the best resistance, greatest breath, correct strategy for the track conditions, planning, anticipation of events. The participation of public agents, with adequate incentives and support, and the joint efforts of the private sector with government agents, especially with science and technology institutions and regulatory agencies, should motivate the flow of capital and stimulate the development of researchers and professionals dedicated to such a strategic area for Brazil.

The establishment of a national program of cultivated meat is not only of business interest but also an opportunity to promote and train human resources. It can come from the collaboration of different agents interested in transforming the way we produce, market and consume meat products—efficiently and sustainably—with the scientific and technological content that our times now allow.

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