مؤسسة دبي للمستقبل
DUBAI FUTURE FOUNDATION

MISSION POSSIBLE **FOOD SECURITY**

A ROLE FOR ALTERNATIVE PROTEINS

DUBAIFUTURE.AE

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ACRONYMS

AFS	agri-food systems
CAGR	compound annual growth rate
CDMO	contract development and manufacturing organisation
CO_2	carbon dioxide
COP	Conference of the Parties
DFF	Dubai Future Foundation
FAO	Food and Agriculture Organization of the United Nations
GCC	Gulf Cooperation Council
GFSI	Global Food Security Index
GHG	greenhouse gas
IFAD	International Fund for Agricultural Development
IoT	Internet of Things
IRENA	International Renewable Energy Agency
MENA	Middle East and North Africa
MMT	million metric tons
NCD	non-communicable disease
OECD	Organisation for Economic Co-operation and Development
TRL	Technology Readiness Level
UN	United Nations
UNICEF	United Nations Children's Fund
WFP	World Food Programme
WHO	World Health Organization

EXECUTIVE SUMMARY

Contemporary food systems are in the spotlight because they are found to be polluting, highly carbon intensive, and potentially unfit for the future. Amid discussions on mitigating the human impact on climate change and ensuring food security for the growing global population, there is an increasing push from the international community to rethink our global food systems in a sustainable manner.[1]

The topic has been regularly addressed by the UN at its Climate Change Conference of the Parties (COP) and was central at COP28 in Dubai.

Traditional animal farming is especially attracting much criticism for its alleged impacts on the environment, as well as on the health and safety of humans and animals alike. As a remedy to some of these challenges, technology-based alternatives to animal proteins are being investigated.

This report assesses three areas of the alternative proteins' ecosystem – plant-based, cellular cultivation, and precision fermentation – to understand their potential benefits and imagine their possible development.

Building on the UAE National Food Security Strategy 2051, developing a national system based on sustainable food production by using modern technologies and enhancing local production, together with Dubai's visionary and forward-looking leadership, this paper has the ambition of encouraging all actors in Dubai's food value chain, from public sector to private companies and consumers, to dig deeper into the opportunities and challenges connected to the alternative animal protein sector.

Contemporary food systems are in the spotlight because they are found to be polluting, highly carbon intensive, and potentially unfit for the future.

INTRODUCTION

Agri-food systems (AFS) form an important economic sector that employs 1.23 billion people worldwide, supporting 3.83 billion individuals in households linked to AFS.[2] In 2021, the Food and Agriculture Organization of the United Nations (FAO)[3] **revealed that around 31% of human-caused greenhouse gas (GHG) emissions in 2019 originated from the world's AFS.**[4]

31%

OF HUMAN-CAUSED GREENHOUSE GAS EMISSIONS IN 2019 ORIGINATED FROM THE WORLD'S AGRI-FOOD SYSTEMS

The contribution to GHGs of animal farming alone is currently calculated to be somewhere between 11% and 14.5%,[5] depending on the methodologies used. The global consumption of animal proteins is projected to increase by 14% by 2030 compared with the base period average of 2018–2020. According to the Organisation for Economic Co-operation and Development (OECD) and FAO data, the global meat supply will reach 374 million tons by 2030 because of rising average income and a growing global population that by 2050 is projected to reach 9.7 billion[6] from the 8 billion of today.[7]

Mitigating the effects of animal protein production and consumption on our environment and ensuring the security of and access to healthy proteins for the global population are globally recognised priorities. Developing alternatives to animal proteins, such as plant-based meat, cultivated meat and seafood,[8] and precision fermentation products, might help to achieve these priorities.[9]

> Agri-food systems (AFS) form an important economic sector that employs 1.23 billion people worldwide, supporting 3.83 billion individuals in households linked to AFS.

1. FOOD-TECH TRANSFORMATION

1.1 WHY ARE WE TALKING ABOUT FOOD?

Food is a fundamental human need:[10] it provides energy, supporting physical growth and mental development. It plays a vital role in people's social lives, religious practices, and cultural traditions.

Throughout history, food has been central in shaping our societies and communities. From the earliest human settlements, not only did food ensure survival and protection, but it also fostered social bonding through the sharing and provision of nourishment. As early as 3000 BCE, in Sumerian society, food was established as a cornerstone of a thriving economic sector.[11] Global food trade routes[12] have existed for thousands of years, paving the way for the current interconnected global food value chain.

In recent years, food systems have faced various shocks ranging from geopolitical tensions to pandemics, affecting animals and humans, and the effects of climate change. These, combined with urbanisation,[13] the increased digitalisation of food systems and the consequent pressure on energy needs, bring into play complex new changes to the whole value chain.[14]

While formulating food policies that prioritise security,[15] sustainability, and affordability of food systems, governments and organisations worldwide[16] are adopting holistic approaches including investment in more innovative food systems and technology development.

There is a growing interest in new technologies such as plant-based meat, cultivated meat and seafood, and precision fermentation to meet the population demand for animal proteins.[17]

> There is a growing interest in new technologies such as plant-based meat, cultivated meat and seafood, and precision fermentation to meet the population demand for animal proteins.

1.2
THE TECH ON OUR PLATE

Science and innovation have kept modernising food systems.[18] In today's world, which is filled with uncertainties relating to food access, safety, and security, technological innovations are spreading in all segments of the value chain (e.g. production, distribution, packaging, consumption, and disposal).[19]

The scientific community has begun to seriously consider alternatives to proteins derived from traditional animal farming in order to address the needs of a growing population and to tackle the carbon footprint of the animal livestock industry.[20]

COMPANIES DEVELOPING ALTERNATIVE PROTEINS RECEIVED

$5bn

IN INVESTMENT IN 2021

Alternative proteins – derived from plants, cell cultivation, and precision fermentation – are coming to our plate from processes whose objectives are to create a more sustainable and resilient system that could provide food to all, irrespective of unforeseen shocks. **Companies developing these processes have experienced a substantial surge in investment from both public and private sector over the last decade reaching a total of $5 billion in 2021, with a slight decline in 2022 amid a global downturn in investment, with the next 20 years projections hinting at an expanding market.**[21]

However, across plant-based meat, cultivated meat and seafood, and precision fermentation the levels of technological maturity and social acceptance vary greatly. This is why policies and regulations worldwide are also very diverse. In the following paragraphs, we will describe the state of play of commercialisation and regulation, market evolution, and (estimated) costs and prices, as well as potential benefits and hindrances per technology.

> 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)**[22]

> Plant-based meat is a widely recognised and readily available alternative to traditional meat that has been gaining popularity for over two decades but has been around for longer.

Table 1. Alternative protein investment summary, 2010–2021

Category	Invested capital			1-year growth
	2021	2020	All-time (2020–2021)	2020–2021
Total alternative protein	**$5.0bn**	**$3.1bn**	**$11.1bn**	**+60%**
Plant-based	$1.9bn	$2.1bn	$6.3bn	–
Fermentation	$1.7bn	$600m	$2.8bn	3x
Cultivated	$1.4bn	$400m	$1.9bn	3x

Source: Good Food Institute[23]

1.2.1 PLANT-BASED MEAT

Plant-based meat is a widely recognised and readily available alternative to traditional meat that has been gaining popularity for over two decades but has been around for longer.[28] These products, made from plant or fungus sources, are specifically designed to mimic the taste and appearance of animal-based meat.[29] The target consumers for plant-based meat extends beyond just vegans and vegetarians as meat-eaters are increasingly drawn to these options for both health and environmental reasons. Plant-based meat is also largely recognised as having a far smaller impact on the environment, primarily attributed to the reduction of GHG emissions associated with livestock farming.[30]

Commercialisation and regulation

Plant-based meat is globally available on the market and fully accessible to consumers in the UAE.[31] Investors and plant-based manufacturers believe that the UAE market for these products will grow steadily as more and more consumers are substituting plant-based alternatives for meat and the COP28 meeting in Dubai encouraged people to reflect on more sustainable lifestyles.[32]

In 2023, two plant-based meat manufacturers opened their doors in the UAE;[33,34] others, including food-tech venture capital companies, are gravitating to the country, which is seen as an unexploited market vis-à-vis the growing interest in plant-based meat alternatives in the Gulf Cooperation Council (GCC) region.[35]

Plant-based meat production techniques are undergoing refinement[36] and new companies are entering the market globally. A primary focus for these emerging companies is to address consumer concerns regarding the raw materials and ingredients used in plant-based meat production.[37] To enhance transparency, these companies are streamlining their ingredient lists, enabling consumers to gain a clearer understanding of the composition of these products. ‘The foundational elements in plant-based meat are a protein of some sort (like tofu, tempeh), plant oils (like sunflower or canola oil) and a vegan binding agent (like gluten, aquafaba or beans).’[38]

Market evolution

The market share of this sector has been steadily increasing, with a projected CAGR of 20.6% up to 2030.[24] But in the past year there have there been some indications of a slowdown: flagship companies have experienced a decline in market share, plummeting stock prices, and concerns about potential bankruptcy,[25] leading to doubts about the sustainability of these innovative alternatives.[26] The causes behind this slowdown have been attributed to factors such as taste preferences, growing awareness of the effects on health (pros and cons), pricing considerations, and the impact of high inflation.[27]

Decline and the Gartner Hype Cycle

The slowing trend in the sector and the failure of some major plant-based meat companies might be explained by the theory of the Gartner Hype Cycle,[39] which has in the past affected numerous innovative[40] technologies such as electric vehicles and the metaverse. After an initial surge of interest, these technologies enter a plateau phase, which should not be mistaken for a complete halt in progress. According to the Gartner Hype Cycle, this phase represents an opportunity for the development of more refined technologies that are appearing on the horizon.

Despite this slowdown, plant-based meat production is projected to grow, in accordance with the forecasted decline of prices of the products, as soon as production at scale is achieved and with health and sustainability elements increasingly affecting consumer choice. **The global plant-based meat market was valued at $19 billion in 2019, with the MENA region accounting for $176.5 million.**[41] This figure is expected to grow in the next few years in the MENA region, with **some analysts estimating it will reach around $380 million.**[42]

> The market share of this sector has been steadily increasing, with a projected CAGR of 20.6% up to 2030.

Costs and price

Plant-based meat production is expensive as it still done at small scale and is not eligible for any subsidy such as those that animal farming companies might receive. The result is that plant-based meat is sold at premium prices on the market,[43] for example in the UAE.[44]

Table 2. Average market price per product in Dubai

Type of product	Average market price (AED)	Quantity (g)	Price per 100g (AED)	Delta price vs. plant-based (%)
Plant-based burger*	33.50	216	15.51	Datum
Organic chicken burger	23.85	300	7.95	–49
Organic beef burger	19.20	300	6.40	–59
Regular chicken burger	17.00	500	3.40	–78
Regular beef burger	13.20	400	3.30	–79

* 'Burger' throughout this report refers only to the meat (or equivalent) and does not include bread
AED = Emirati Dirham
Source: Organic Foods & Café, Choithrams and Carrefour (on site research carried out in August 2023 in Dubai).

With the rising price of meat worldwide and the increased production of plant-based products, the gap is forecast to narrow.

According to the Good Food Institute, 'Industrial animal agriculture has been operating and optimising at a global scale for decades. Yet it is still inherently more efficient to make meat directly from plants rather than feeding our crops to animals and then eating a part of the animal. It's all but inevitable that the plant-based meat industry will eventually be cost-competitive with conventional meat.'[45]

> **The global plant-based meat market was valued at $19 billion in 2019, with the MENA region accounting for $176.5 million.**

Benefits

- Positive environmental impact (reduced carbon emissions and GHGs)
- Positive for human health (reduced non-communicable diseases (NCDs) linked to high consumption of meat and food high in sugar, fat, and salt)
- Better use of land resources, water, increased biodiversity
- Projected to be economically sustainable for consumers
- Possible manufacturing localisation by using endemic crops (e.g. faba beans, peas)
- Meets sustainability requirements[46] of some consumers

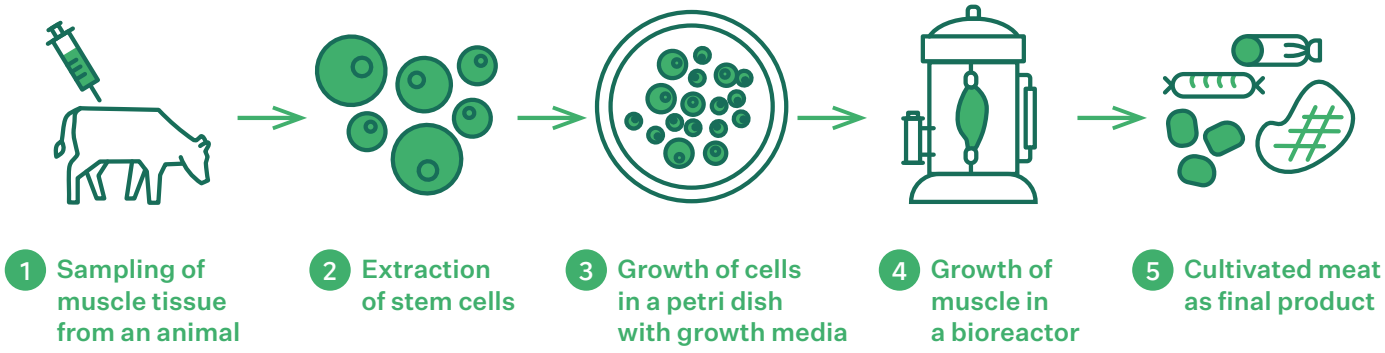
Hindrances

- Lack of consumer awareness on products' nutritional value compared to traditional meat (e.g. content in protein and essential nutrients such as vitamin B12 and iron)
- Funding still limited (both in research and infrastructure)
- Some consumer resistance (linked to price, texture, taste, and unclear lists of ingredients)
- Still largely based on a few crops cultivated in a minority of countries
- Impact on traditional farming sector (social disruption)
- Insufficient availability in food services and restaurants (critical for food trial)

1.2.2 CULTIVATED MEAT AND SEAFOOD

Cultivated meat, also known as cultured meat,[47] is genuine animal meat (including seafood and organ meat) produced by directly cultivating animal cells in bioreactors. This production method eliminates the need to raise and slaughter farm animals for food. Cultivated meat is made of cell types that can be arranged in the same or similar structure as animal tissues, thus replicating the sensory and nutritional profiles of conventional meat.[48] While the technique of cultivating animal cells dates back to the 1970s, emerging from the fields of tissue engineering, regenerative medicine, and pharmaceuticals, its application in generating edible products such as cultivated meat marks a novel advancement.[49]

Figure 1. Cultivated meat production



Source: Four Paws International[50]

Cellular (cell) cultivation is a method that grows fish or meat directly from cells extracted with a biopsy from an animal, whether obtained from a live specimen, post-slaughter biopsy, or an egg. Once extracted, the cells are initially grown in a suitable growth medium in small batches before transfer to a dedicated bioreactor.[51] 'Similar to what happens inside an animal's body, the cells are fed an oxygen-rich cell culture medium made up of basic nutrients such as amino acids, glucose, vitamins, and inorganic salts, and supplemented with growth factors and other proteins.'[52] Much still needs to be done to perfect the production of cultivated meat and seafood, for example in terms of environmental impact and reducing production costs. Among other areas, research is focusing on how to acquire high-quality cell lines, how to obtain animal-free, cell-cultured media, and how to make more sustainable bioreactors.[53]

The environmental impact of cultivated meat: an open question

A techno-economic assessment (TEA)[54] was published in 2021 followed, in January 2023, by an *ex-ante* life-cycle assessment (LCA)[55] comparing the environmental performance of commercial-scale cultivated meat production with conventional animal production in 2030. The studies concluded that **cultivated meat has the potential to be more environmentally friendly than conventional meat in several ways, particularly in terms of agricultural land use, air pollution, and nitrogen-related emissions.**

While cultivated meat production and its upstream supply chain require a lot of energy, using renewable energy sources can make it a viable and sustainable alternative to all types of conventional meats. In the most optimistic scenario of the LCA and TEA studies, **cultured meat could even lead to a reduction in the climate change impact of beef by 92% and pork by 44% and it could be competitive with chicken (+3%).**[56] However, researchers investigating the climate impact of cultivated meat based on existing state-of-the-art technology seem to conclude that the environmental benefits are not yet evident, in particular in relation to blue water use, freshwater eutrophication, and energy demand.[57]

Whether cultivated meat production can be or is more environmentally friendly than traditional livestock farming is a vital question for this technology; consumer awareness and acceptance depend on its answer.

Commercialisation and regulation

There are approximately **150 dedicated cultivated meat companies worldwide, none of them based in the GCC to date**, and a growing number of mature food and supply companies (e.g. Nestlé, Merck, Mitsubishi, JBS) involved in this sector.[58] The first country to give a green light to a company to sell worldwide was Singapore in 2020, followed by the United States in 2023 (which remains the reference country for companies because of the size of its consumer market) and Israel in early 2024.[59]

Other countries (e.g. the Netherlands, Japan, Australia) allow for public tastings of cultivated meat and seafood but have not yet permitted their commercialisation.[60] In the GCC, the Saudi asset management company KBW Ventures contributed to three rounds of financing for a cultivated seafood company and a round of financing for a cultivated meat company,[61] and, in 2021, Qatar announced its intention to allow a cultivated-meat company to build a factory in the Qatar Free Zone, considered to be outside the administrative borders of the state.[62]

The commercialisation of cultivated meat has pushed FAO and the World Health Organization (WHO) to issue a report addressing the growing questions regarding the health and safety standards of cultivated meat.[63] In short, the report finds that edible products can be produced if their production is aligned with the required health and safety standards.

Table 3. A glimpse from around the world[64]

Country or group of countries	Regulatory approval (commercialisation)	Tastings	No. of cultivated meat companies (approximately)
United States	As of July 2023	YES	33
European Union[65]	NO	YES	27
Israel[66]	As of January 2024	YES	16
Singapore[67]	As of January 2021	YES	6
The Netherlands[68]	NO[69]	YES	4
Japan	NO	YES	4
Switzerland	In July 2023, one submitted application for regulatory approval[70]	NO	2
Gulf Cooperation Council[71] Members	NO	NO	0

Is cultivated meat halal or kosher?[72]

The introduction of cultivated meat has raised ethical, philosophical, and religious considerations in the Islamic community. The crucial question is whether cultivated meat is halal, compliant with Islamic laws. **In February 2024, the Islamic Religious Council of Singapore (Muis) issued a *fatwa* saying that cultivated meat is to be considered halal 'if the cells are sourced from animals that Muslims are allowed to consume,** and there is no mixing of non-halal components in the production process'.[73] In September 2023, the company Good Meat consulted Shariah scholars in Saudi Arabia for an opinion on the way its cultivated chicken is produced. The Islamic scholars confirmed that Good Meat cultivated meat can be halal if it meets specific requirements, such as: the cells are from an animal that is permissible to eat, and it has been slaughtered according to halal principles.[74]

The halal status of cultivated meat hinges on the source cell and culture medium used in its production.[75] In Indonesia and Malaysia,[76] religious authorities have recently stated that, to be considered halal, the stem cell must come from a (halal) slaughtered animal, and no blood or serum should be used during the culturing process. By adhering to these requirements, halal cultured meat can be obtained. However, not all companies envisage the slaughtering of an animal at the beginning of the process – cells could be extracted from living animals, with minimal pain.

As every company adopts different techniques, the question will most likely have to be addressed case by case. This is what has happened in Israel, where at the beginning of 2023 the Chief Rabbi declared the chicken produced by Aleph Farms to be kosher.[77]

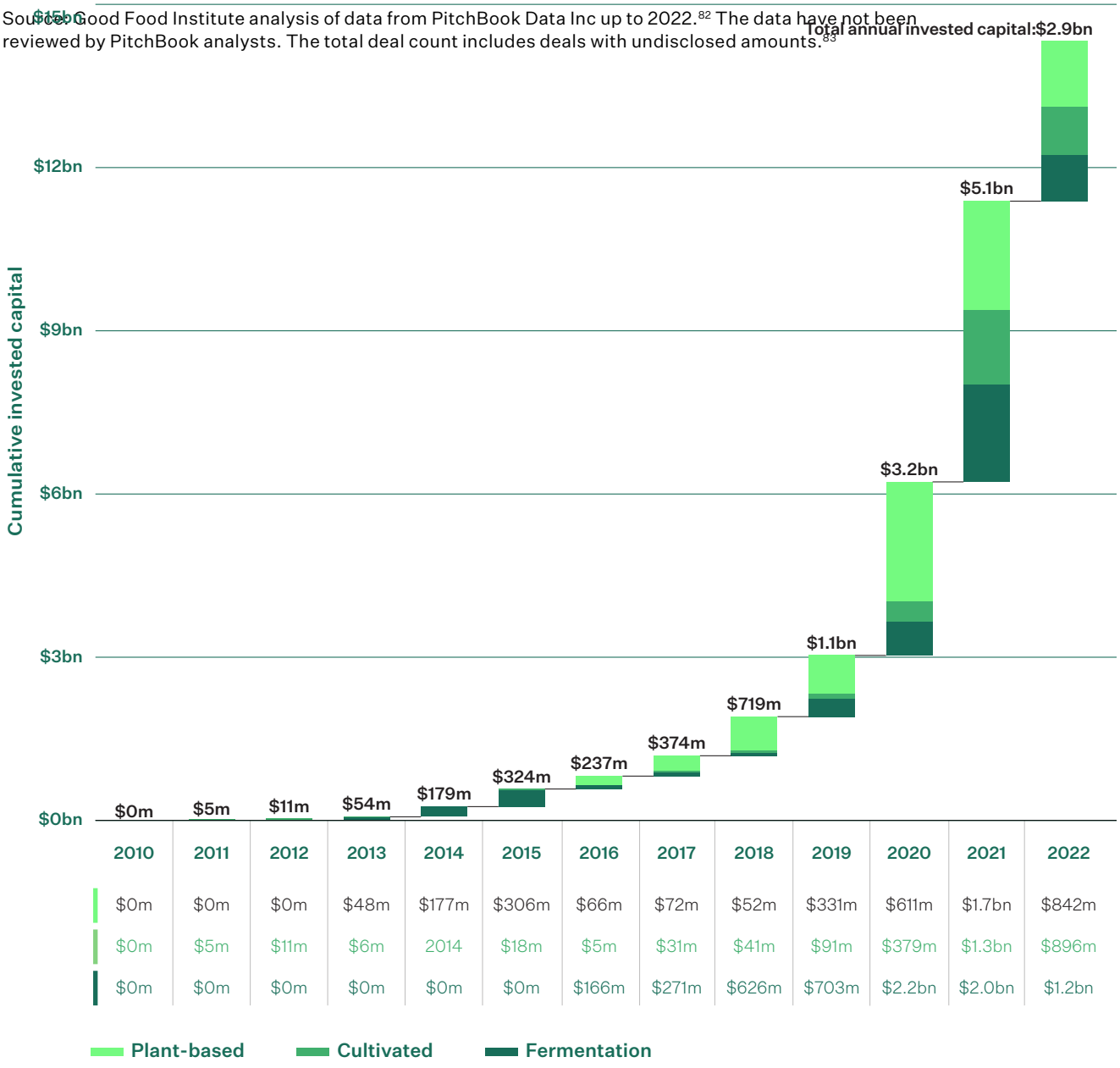
Market evolution

There are various projections concerning the growth of the cultivated meat and seafood sector, with McKinsey estimating that, depending on factors such as consumer acceptance and price, under a high growth scenario (i.e. cultivated meat is able to replicate a wide variety of both processed meats and whole cuts; sales take place in multiple large meat-consuming countries such as China, US, EU, Brazil and India), **by 2030 cultivated meat could account for up to 2.1 million metric tons (MMT), making it a $25 billion market. This is around 0.56% of global meat demand,** which is expected to reach 375 MMT by 2030.[78] Others believe that the cultivated meat sector will never make it to mass-scale production unless governments decide to step in with subsidies.[79]

The Good Food Institute reports that 'following the first disclosed investment in cultivated meat and seafood in 2016, such companies have raised $2.8 billion, with investments on average tripling every year'.[80] The investment levels for 2022 and 2023 have significantly decreased, in line with declining trends for the whole agrifood tech sector. Some experts have indicated that funding for cultivated meat startups has declined by 78% in comparison to 2022.[81]

Figure 2. Cumulative and annual alternative protein invested capital, by pillar

Source: Good Food Institute analysis of data from PitchBook Data Inc up to 2022.[82] The data have not been reviewed by PitchBook analysts. The total deal count includes deals with undisclosed amounts.[83]



> By 2030 cultivated meat could account for up to 2.1 million metric tons, making it a $25 billion market. This is around 0.56% of global meat demand.

Costs and price

Since 2013, when a $300,000 cultivated burger was presented for the first time to the press,[84] the cultivated meat technology has developed and **five companies worldwide have received commercial approval to put their cultivated products on the market:** one in Singapore (GOOD Meat),[85] three in the US (Upside Foods, Good Meat, and Good Meat's manufacturing partner Join Biologics),[86] and one in Israel (Aleph Farms).[87] Today, in Singapore, cultivated meat (mixed with soy) chicken skewers are sold for $3.10; however, there are only few servings available per month.

The cost of setting up mass-scale production is being analysed by researchers and institutions.[88] The main elements impacting on the results are the high price of cell culture media and the production of bioreactors.[89] A recent study tried to determine the cost of producing cell-cultured meat in a large-scale production facility that produces 540,000kg of product annually. The total expected cost of production was $34.9 million per year, $95,685 per day.[90] Projecting the wholesale cost of cell-cultured meat to be as low as $63/kg would make it competitive only in a niche market in comparison with traditional farmed meat. The costs were calculated on the basis of the use of state-of-the-art technology that is largely consistent with pharmaceutical production plants. However, some new companies entering the sector are using technology that utilises brewery methods, resulting in lower costs.

Because of the high capital expenditure costs, many cultivated meat companies are investing in the research and development of refined technology, while just a handful of them are investing in setting up large-scale production manufacturing plants.[91]

As in any nascent sector, life-cycle assessment studies have been carried out based on the limited available data and on the shared recognition that the technology is still under development, with implications for cost and efficiency.

Benefits

- Increasing food security
- Potential reduced carbon emissions and GHGs (thanks to technology development)
- Elimination of animal slaughtering
- Meeting consumer demand for healthy and potentially sustainable food
- Less pressure on land use for animal farming
- Push towards renewable energy

Hindrances

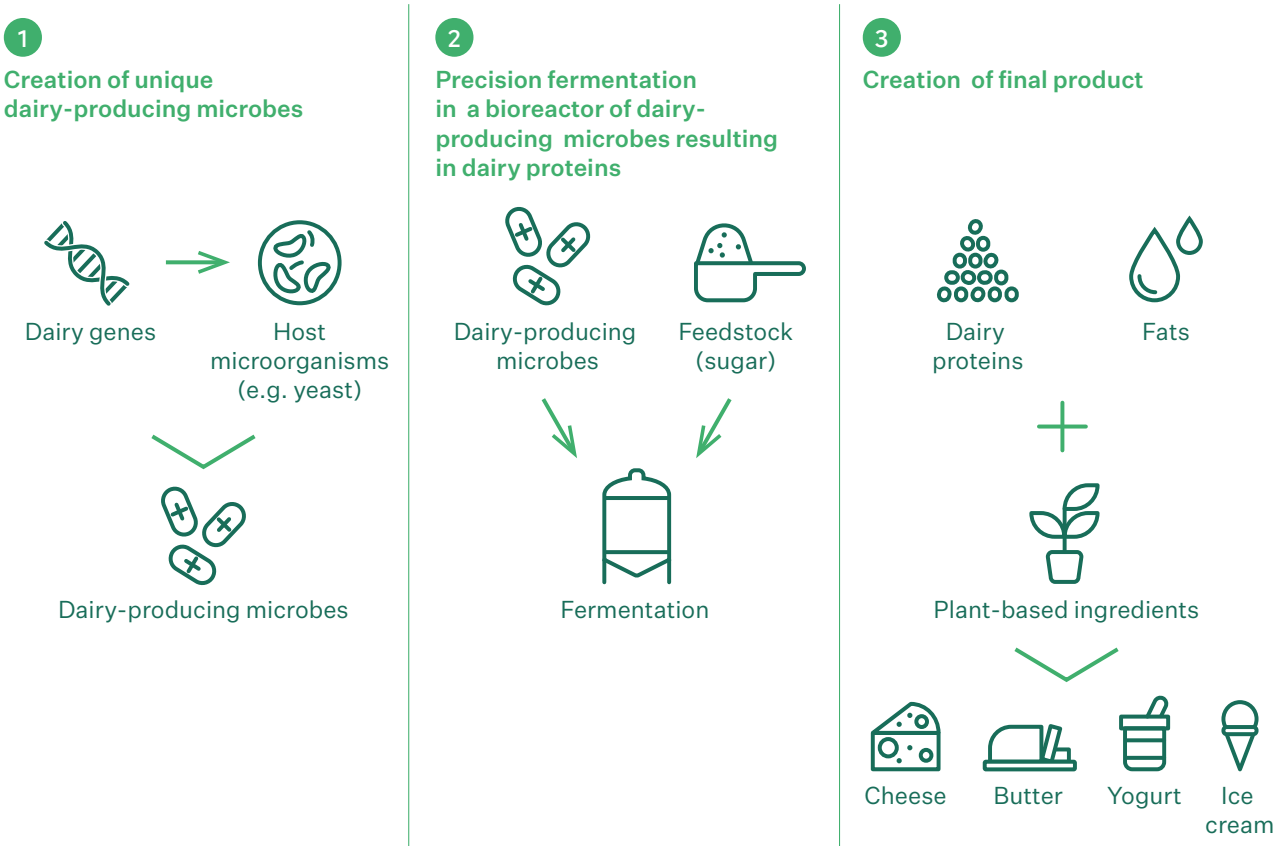
- Funding still low (both for research and infrastructure)
- Skills gap (need for qualified workforce and dedicated university curricula)
- Shortage of bioreactors
- Elevated costs for its production (mainly growth media and infrastructure)
- Consumer acceptance – cultural, religious, and health and safety
- Lack of regulatory approval
- Impact on traditional farming sector (social disruption)
- Environmental impact uncertainty (increased blue water use, freshwater eutrophication, and energy demands)

1.2.3 PRECISION FERMENTATION

Precision fermentation[92] involves the use of microorganisms to produce specific food components through genetic engineering and fermentation processes.

'Capable of producing proteins, vitamins, enzymes, natural pigments, and fats, precision fermentation is well-positioned to create high-value ingredients that improve the sensory characteristics and functional attributes of plant-based products or cultivated meat. Precision fermentation can be used to make products like egg proteins, dairy proteins, pepsin, animal-free meat proteins including heme [or "haem"], and fats.'[93]

Figure 3. Precision fermentation process



Source: Change Foods (2021)[94]

Precision fermentation techniques require:[95] host microorganisms such as bacteria or fungi; a culture medium, as in the case of cultivated meat, which will allow the microorganism to grow; a bioreactor controlling temperature and various conditions; and a downstream process that includes the extraction of the product and purification.

Precision fermentation can be classified as aerobic (requiring oxygen) or anaerobic (not requiring oxygen). 'Aerobic fermentation tends to have higher yields and lower toxic byproducts yet might require a constant supply of oxygen which can be expensive. Anaerobic fermentation's lack of oxygen supply can make it more cost-effective, yet it produces methane and other greenhouse gases as byproducts, making it less environmentally friendly.'[96]

Commercialisation and regulation

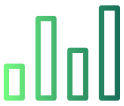
Precision fermentation has gained growing attention for its role in producing egg and dairy alternatives. Ongoing research and technological developments continue to push the boundaries of this innovative approach to food production. **At present, there are around 60 companies using precision fermentation to create alternative proteins.**[97] There are some companies present in the US market that have produced whey proteins, while production of casein with precision fermentation is still under development.[98] According to recent data published by Capacitor, the free worldwide database of manufacturing capacity, **Europe is leading in terms of the number of companies and the capacity of bioreactors:** 'with ~21.7 million litres uploaded (in the database) across 85 facilities. … In APAC [the Asia–Pacific region], only ~1.5 million litres have been uploaded across 27 facilities, but this is set to rise as biomanufacturing matures and CDMOs [contract development and manufacturing organisations] are established in the region.'[99]

In the UAE, the first precision fermentation manufacturing plant is being set up in Abu Dhabi by Change Foods – a US alternative dairy maker – which has signed an agreement with KEZAD Group (Khalifa Economic Zones Abu Dhabi). The plant is expected to have a capacity of 1.2 million litres to produce animal-free dairy that will replace the output of more than 10,000 cows (according to company estimates) by 2027.[100]

> **Europe is leading in terms of the number of companies and the capacity of bioreactors.**

Biomass fermentation

Next to precision fermentation, biomass fermentation is another technique that allows for production of proteins, even from thin air. In biomass fermentation 'the microorganisms that reproduce through this process are themselves ingredients for alternative proteins'.[101] The company Solar Foods uses various gases to ferment bacteria that can be dried into a powder-like substance (Solein) that is '65–70% protein, 5–8% fat (primarily unsaturated fats), 10–15% dietary fibres and 3–5% mineral nutrients. The macronutrient composition of the cells is very similar to that of dried soy or alga. While traditional fermentation has been used for thousands of years, precision fermentation to produce food is relatively new.'[102]



Market evolution

'Nearly 57% of the 136 companies focused on fermentation for alternative proteins were founded in the past three years, and the first animal-free dairy products only hit store shelves in 2020.'[103]

All-time investment in the sector is estimated at around $5 billion (2016–2022), with $842 million invested in 2022 alone. In addition, well-established food companies have started to pilot products with animal-free dairy in them.[104]

Allied Market Research recently published a report that provides an overview and forecast of the sector.[105] According to the report, **the global precision fermentation industry generated $1.3 billion in 2021 and is anticipated to generate $34.9 billion by 2031, witnessing a CAGR of 40.5% from 2022 to 2031**.[106]

Costs and price

The cost of the production process of precision fermentation remains high mainly due to the costs of fermenters. As stated in a recent article in *The Economist*, 'A fermenter that can hold up about 30 litres of milk can cost £150,000 ($190,000). Buying a cow, which can produce about as much in a day, will set you back £1,600.'[107] Approximate estimates indicate that the price for 1kg of one type of molecule produced with precision fermentation is $100, whereas it is roughly $10 per kg for casein or whey produced in the traditional way. However, by 2025 some companies believe that they will be cost-competitive with bulk animal protein and even become 10 times cheaper by 2035.[108]

Benefits

- Food security
- Sustainability (social, environmental)
- Averting animal slaughtering
- New technology applied to reduce environmental impact
- Consumer demand growing for healthy food (even if knowledge about precision fermentation is still lagging)
- Reduction in the cost of growth media in cultivated meat and seafood possible
- Less use of water in the production phase

Hindrances

- Public funding still low
- Skills gap (need for qualified workforce and dedicated university curricula)
- Shortage of bioreactors
- Price of products still not competitive
- Impact on traditional farming sector (social disruption)
- Regulatory uncertainties
- Consumer trust

Health considerations on alternative proteins

Non-communicable diseases (NCDs) are on the rise, costing around 41 million lives a year globally. Red meat (beef, pork, lamb, and veal) and processed meat (using high levels of salt and/or chemical preservatives, e.g. bacon, hot dogs, and sausages) are increasingly associated with NCDs. At the same time, meat is still recognised as having many good effects on health, including being a valuable source of protein.

When it comes to the alternative protein sector, there is still no common view on whether it offers a healthier option, mainly because of a lack of data.[109] The elements under scrutiny concern the amount of calories, protein, iron and sodium – the latter linked to processed food – and additives (such as colouring, flavouring, and binding agents, most commonly known as the E numbers on an ingredients list).

Considerations regarding individual products, though, would not be accurate without assessing overall dietary patterns.[110] **The benefits of alternative proteins in comparison with traditional meat can be linked to antibiotic resistance** and the spread of zoonotic diseases. Alternative proteins, differently from traditional farmed meat, 'do not require antibiotics for their production and therefore will not contribute to the proliferation of antibiotic-resistant microorganisms',[111] and, in the production of cultivated meat, there would be the possibility of adjusting the levels of cholesterol and fat, but this would then lead to a reassessment of its nutritional values. In addition, the scientific community has pointed out on various occasions that zoonotic diseases and pandemics are more likely to happen if demand for animal production increases. According to the United Nations Environment Programme, among the main drivers linked to insurgence of zoonotic diseases are the increasing demand for animal protein and unsustainable agriculture intensification.[112] 'Since 1940, agricultural intensification measures such as dams, irrigation projects and factory farms have been associated with more than 25 per cent of all – and more than 50 per cent of zoonotic – infectious diseases that have emerged in humans.' [113]

The move towards promoting healthy diets and supporting communities in need of access to healthier products is expanding. In June 2023, the UAE launched the UAE National Nutrition Strategy 2022–2030[114] to deliver healthy food from a sustainable system and improve the nutritional status of the UAE population.[115]

> The global precision fermentation industry generated $1.3 billion in 2021 and is anticipated to generate $34.9 billion by 2031, witnessing a CAGR of 40.5% from 2022 to 2031.

2. WHAT IS NEXT? FUTURE FOOD OPPORTUNITIES[116]

The **alternative proteins** we have assessed throughout this report – plant-based meat, cultivated meat and seafood, and precision fermentation – **all hold the potential to contribute to a more sustainable food system.** In the paragraphs that follow, we describe opportunities that could arise by investing in the alternative protein sector.

In all cases, a collective effort is needed, pulling together public policy, research funds, investment in infrastructure, and the creation of dedicated university careers. But, first and foremost, it will require swift adaptation of the current regulatory system to allow the alternative protein ecosystem to flourish.

2.1 WHAT IF OUR HOUSEHOLDS MANUFACTURED OUR OWN FOOD?

DELOCALISING FOOD PRODUCTION (VISIONARY)[117]

People will have access to personal portable bioreactors so that they can produce food at home. To avoid pressure on energy consumption, houses are dependent on renewable energy. **The house of the future is also a place where the family manufactures their own food.**

BENEFITS

- Ability to tailor food production to personal health requirements
- More awareness of how to use energy and resources at home in a circular way, which will make households more sustainable
- Less food waste

RISKS

- For consumers and manufacturers: liability if food gets contaminated
- Health and safety standards would need to be globally mainstreamed to sell growth media, cells, and bacteria online to the general public
- Energy consumption per household would grow

TRENDS

- Longevity and well-being
- Health tech
- Transforming energy
- Urbanisation

MEGATRENDS

- Saving ecosystems

SECTORS AFFECTED

- Consumer goods, services and retail
- Health and health care
- Advanced materials and biotechnology
- Immersive technology

> **The house of the future could become a place where people can create their own food, water, and medicines all powered by home-made energy.**

WHY IT MATTERS TODAY

Large-scale production of cellular agriculture products requires substantial investments.[118] It might take a long time before these foods become commercially viable. In the meantime, several companies are trying to provide different solutions by creating small portable bioreactors that everyone could use for production of smaller quantities, for example at home or in restaurants.[119] For this to happen, standards and regulations will need to be in place to allow safe use of the bioreactors, the price of cell growth media will need to reduce in order to be accessible to people (between $0.6 and $10 per litre of meat produced may be possible),[120] and technicians able to correctly install and repair these machines need to become available.

A portable 1 litre bioreactor can produce 10g of meat in two weeks. The bioreactors need to maintain a temperature of 37°C and they need fresh water. The current cost of one bioreactor, composed of two modules, is around $5,000.[121]

In the MENA region, renewable energy could help to cut costs for the powering of bioreactors. Energy consumption in households and commercial buildings is elevated;[122] however, work is ongoing to see how homes could be powered by renewable energy in a systematic way (e.g. solar power, heat pumps).

THE OPPORTUNITY IN THE NEXT 20 YEARS

The house of the future[123] could become a place where people can create their own food, water, and medicines all powered by home-made energy.

Every household will have the chance to search on the market for the bacteria, cells, and growth media of choice with which to feed its portable bioreactor. This innovation will also require much more awareness of the value of nutrition and more health and safety information about food. We will be moving from a feeding attitude to a nourishing attitude.

Using portable bioreactors, people will be able to produce the amount of food needed by planning for it and in this way reduce the amount of food wasted. This will reduce some environmental impact of the global supply chains linked to shipping and trucking (including emissions from refrigeration). This would have benefits such as reducing methane emissions from landfills and lowering the carbon footprint.[124] Alternatively, mid-sized bioreactors could be built at community level, providing a source of income and jobs for the community in a similar fashion to commercial farms.

This delocalisation of the food production chain will support the reduction of food price volatility and have positive effects on the affordability and security of food.

2.2 WHAT IF THE FOOD CAME FROM THINGS WE CANNOT SEE?

EATING THE INVISIBLE (TRANSITIONAL)

BENEFITS

- Less pressure on the planet's resources and a more diversified use of natural resources
- Possibility for disadvantaged regions to create their own food

RISKS

- Potential disruption of rural areas
- Increased dependence on technology
- Increased pressure on energy systems

TRENDS

- Longevity and well-being
- Health tech
- Food–water–energy nexus

MEGATRENDS

- Saving ecosystems

SECTORS AFFECTED

- Agriculture and food
- Consumer goods, services, and retail
- Advanced materials and biotechnology
- Health and health care
- Information and communication technology

> **The production of food proteins from thin air could be decentralised and happen irrespective of the climatic conditions of a region and could involve habitats ranging from desert to forests.**

WHY IT MATTERS TODAY

Our diets are based predominantly on 12 crops and 5 animals.[125] Our planet's limited resources are under pressure and there is a growing push to transform our food systems. A great deal of attention is given to the adaptability of crops to different climate-disadvantaged areas as well as establishing salt-tolerant crops.[126]

The world is looking for new sources of food. We have started to produce food with methods that are not dependent on agriculture, the weather, or the climate. Proteins made out of thin air and renewable electricity are entering the market.[127] For example, based on a concept developed by NASA in the 1960s, a Finnish company has invented Solein. 'Solein is made from natural single-cell organisms, which are grown in a biomass fermentation process. Water is split with renewable electricity into hydrogen and oxygen. The cells are fed CO_2, hydrogen, and mineral nutrients.' [128]

The production of food proteins from thin air could be decentralised and happen irrespective of the climatic conditions of a region and could involve habitats ranging from desert to forests.

In the field of cultivated meat and seafood, companies are also exploring the potential to eat food from extinct species (e.g. dodo poultry). An Australian company produced a meatball from a mammoth.[129] However, the allergens in these new meats and the possible effects on humans still need further analysis.

THE OPPORTUNITY IN THE NEXT 10 YEARS

Food out of thin air might offer a solution to the growing number of people facing hunger and malnutrition around the world. The creation of food irrespective of climatic conditions can support the food security of most disadvantaged communities. As is the case for on-demand food, portable bioreactors could be sent to areas experiencing famine. More bacteria could be found that can produce proteins from gases around us. New techniques could also support economic growth by reducing reliance on food imports.

Creating cultivated meat from cells of extinct animals, if culturally and socially acceptable, can also represent an opportunity in certain geographical areas. Research on allergens in this meat can also have additional spillover effects on research linked to the spread of diseases between animals and humans.

2.3 WHAT IF ALL THIS COULD BE MORE THAN JUST FOOD?

CULTIVATED FASHION AND MORE (TRANSITIONAL)

Cultivation techniques could produce a replacement for animal leather. Cultivated leather, comfortable and stretchable, will be used in many different applications from fashion and accessories to automotive upholstery. **The house of the future is also a place where the family manufactures their own food.**

BENEFITS

- Reduced animal slaughtering for the production of leather goods
- Positive impact on the environment

RISKS

- Increased energy consumption
- Possible disruption to the traditional leather industry

TRENDS

- New materials
- Restoration

MEGATRENDS

- Saving ecosystems

SECTORS AFFECTED

- Consumer goods, services and retail
- Advanced materials and biotechnology

> **It is possible to make 'billions of square feet of leather with a single, harmless biopsy from one cow'.**

WHY IT MATTERS TODAY

'The global leather goods market size was evaluated at $420 billion in 2022 and it is expected to hit around $735 billion by 2032 with a noteworthy CAGR of 5.76% from 2023 to 2032.'[130] **Estimates suggest that every year around 1 billion animals**[131] **around the world are slaughtered to produce leather goods.** With a growing population and a growing demand for premium leather products, not only for fashion but also in other sectors such as the automotive industry, cell cultivation might provide an alternative.

Thanks to cell cultivation, it will be possible to create a leather surface without blemishes and without the need for stitching as one could, in theory, produce any size and shape (and depth) of leather.[132]

THE OPPORTUNITY IN THE NEXT 10 YEARS

It is possible to make 'billions of square feet of leather with a single, harmless biopsy from one cow'. The leather is grown in bioreactors and the amount of product produced is exactly what is needed, simplifying the tanning process and thus having a much less significant impact on the environment.[133] With the use of renewable energy for powering bioreactors, laboratory-grown leather offers a more sustainable solution by streamlining the tanning process and reducing material consumption during the manufacturing process.[134]

> Estimates suggest that every year around 1 billion animals around the world are slaughtered to produce leather goods.

2.4 WHAT IF FUTURE FOOD CAME FROM SPACE?

FOOD FROM SPACE (VISIONARY)

Astronauts can create their own food in portable and fully circular bioreactors on their trip to Mars. Powered by solar energy, spaceships dedicated to the production of food are set in orbit.

BENEFITS

- Expanded access to food for those living on earth
- Development of sustainable food production techniques
- Supporting further space activity and contributing to growth

TRENDS

- Future of space
- Transforming energy
- Food–water–energy nexus

SECTORS AFFECTED

- Agriculture and food
- Advanced materials and biotechnology
- Automotive, aerospace, and aviation

RISKS

- Human-caused or accidental damage (e.g. from space debris) to space food production facilities
- Disruption of AFS on earth, especially for people employed in the sector
- Difficulties monitoring the production process and attributing liability in case of health or safety issues of the food products

MEGATRENDS

- Energy boundaries

> **International and national space agencies from around the world are assessing new ways of producing food.**

WHY IT MATTERS TODAY

International and national space agencies from around the world are assessing new ways of producing food in space that is resistant to microgravity and that meets the nutritional demands of astronauts.[135]

The Mohammed Bin Rashid Space Centre, through the Mars 2117 project, is aiming to develop scientific capability that will allow human beings to create colonies on Mars within the next 100 years, including food production.[136] Precision fermentation and cultivated meat and seafood are being studied to assess their feasibility in space conditions especially for prolonged missions into space.[137]

THE OPPORTUNITY IN THE NEXT 50 YEARS

A fully regenerative food system in orbit would relieve some of the pressure on our planet. Space manufacturing plants powered by renewable energy could replace production of energy-to-food on land. As is the case for 'Opportunity #48 (2023) – Space as storage',[138] the space manufacturing plants could be designed thanks to breakthrough innovations in materials science, advanced manufacturing, nanotechnology, and robots.

These projects would benefit everyone and ideally they would be run as international cooperation projects controlled by dedicated international committees. The management of resources on earth would then be based on the needs of the various populations, especially those affected by adverse climatic conditions. The creation of a value chain for transport of food on earth would benefit the growing space economy. The space economy grew to roughly $447 billion in 2022 – up from $280 billion in 2010 – and it is projected to become a $1 trillion industry by 2030 thanks to continuous technological developments and new applications.[139]

3. CONCLUDING REMARKS

The alternative proteins ecosystem is moving fast and many countries are looking into developing the building blocks to allow for their research, manufacturing, and distribution.

For this sector to take off globally, different aspects must be taken into consideration. First, health and safety aspects of these products will need to be carefully studied to be sure they can be part of the menu of the future. Second, the right **regulations** will need to be in place to develop clear guidelines for commercialisation adoption. Third, the level of **investments and funding** would need to increase to support the production at scale of alternative proteins by using sustainable technologies (such as renewable energy). Fourth, appropriate curricula should be available to students for them to acquire the **right sets of skills**. Finally, **consumers** will need to be consulted closely to produce culturally consistent products and to ensure that the new technologies are meeting requirements of people worldwide.

> **For this sector to take off globally, different aspects must be taken into consideration.**

'Future Food' tasting at the Dubai Future Forum, 28 November 2023.

In line with the UAE National Food Security Strategy 2051,[140] Dubai has already launched several initiatives to support innovative food technologies, such as facilitating the set-up of a 'Food Tech Valley',[141] allowing the first plant-based meat manufacturing facilities to be established in the UAE,[142] and organising the biggest tasting of 'food of the future' on the occasion of the Dubai Future Forum.[143] Dubai, with a population projected to grow from 3.3 to 7.8 million inhabitants by 2040,[144] is looking to create a resilient food system in line with the UAE National Food Security Strategy 2051 to meet demand for sustainable and healthy food.

Alternatives to animal proteins are an important element in the global discussion on food security and sustainability. Dubai, thanks to its resources – people, energy, space, geographical position – might have an interest in investigating these development further.

> In line with the UAE National Food Security Strategy 2051, Dubai has already launched several initiatives to support innovative food technologies

GLOSSARY

Agri-food systems

Agri-food systems encompass all activities in the agricultural sector, specifically all processes involved in the production, storage, transportation, distribution, and disposal of agricultural products, as well as inputs and outputs, consumers and suppliers, and associated management and underlying policies.

Biotechnology

Biotechnology uses and engineers living organisms and biological matter (genetically or at the molecular level) to develop processes and products for health care, pharmaceuticals, materials, fuels, and agriculture and food systems.

Cellular agriculture

Cellular agriculture is a term that has been commonly used to indicate the production of animal-based products from cell cultures rather than directly from animals. Although the FAO does not recognise it as a separate branch of science, cellular agriculture can be considered to comprise two different approaches: cell cultivation (cellular) and precision fermentation (acellular).[145]

Cellular (cell) cultivation

Cellular (cell) cultivation is a method of growing fish or meat directly from cells extracted with a biopsy from an animal, alive or slaughtered. Once extracted, the cells are initially grown in a suitable growth medium in small batches before transfer to a dedicated bioreactor.[146] 'Similar to what happens inside an animal's body, the cells are fed an oxygen-rich cell culture medium made up of basic nutrients such as amino acids, glucose, vitamins, and inorganic salts, and supplemented with growth factors and other proteins.'[147]

Cultivated meat

Cultivated meat, also known as cultured meat, is genuine animal meat (including seafood and organ meats) produced by cultivating animal cells directly. This production method eliminates the need to raise and slaughter farm animals for food. Cultivated meat is made of cell types that can be arranged in the same way as or a similar structure to animal tissues, thus replicating the sensory and nutritional profiles of conventional meat.[148]

Eutrophication

The enrichment of water by nutrients, especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned.[149]

Haem/Heme

The part of certain molecules that contains iron. The haem part of haemoglobin is the substance inside red blood cells that binds to oxygen in the lungs and carries it to the tissues.[150]

Plant-based meat

Food that mimics meat products but is made from plants.[151]

Precision fermentation

Precision fermentation[152] involves the use of microorganisms to produce specific food components through genetic engineering and fermentation processes.

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ABOUT THE DUBAI FUTURE FOUNDATION

Dubai Future Foundation aims to realise the vision of His Highness Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of the UAE and Ruler of Dubai, for the future of Dubai and consolidate its global status as a leading city of the future. In partnership with government entities, international companies, startups, and entrepreneurs in the UAE and around the world, Dubai Future Foundation drives joint efforts to collectively imagine, design, and execute the future of Dubai.

Under the supervision and with the support of His Highness Sheikh Hamdan bin Mohammed bin Rashid Al Maktoum, Crown Prince of Dubai, Chairman of the Executive Council of Dubai, and Chairman of the Board of Trustees of Dubai Future Foundation, DFF works on a three-pronged strategy: imagine, design, and execute the future. It does this through developing and launching national and global programmes and initiatives, preparing plans and strategies for the future, issuing foresight reports, and supporting innovative and qualitative projects.

These contribute to positioning Dubai as a global capital for the development and adoption of the latest innovative solutions and practices to serve humanity. Dubai Future Foundation focuses on identifying the most prominent challenges facing cities, communities, and sectors in the future and transforming them into promising growth opportunities by collecting and analysing data, studying global trends, and keeping pace with and preparing for rapid changes. It is also looking at future sectors, their integration, and the reshaping of current industries.

Dubai Future Foundation oversees many pioneering projects and initiatives, such as the Museum of the Future, Area 2071, The Centre for the Fourth Industrial Revolution UAE, Dubai Future Accelerators, One Million Arab Coders, Dubai Future District, Dubai Future Solutions, Dubai Future Forum, and Dubai Metaverse Assembly. Its many knowledge initiatives and future design centres contribute to building specialised local talents for future requirements and empowering them with the necessary skills to contribute to the sustainable development of Dubai.

dubaifuture.ae

research@dubaifuture.gov.ae

@dubaifuture

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