FUTURE OF FOOD

Biotech-Driven Alternatives

AN INDUSTRY REPORT BY

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EXECUTIVE SUMMARY

Compelling industry reports from RethinkX and the Good Food Institute (GFI) indicate that the global food industry is primed for major disruption. As traditional food sources such agriculture and livestock become increasingly unsustainable and unstable, new techniques and biotechnologies such as cellular agriculture, precision biology, and others are emerging as solutions to the increasingly pressing issues surrounding our food sources.

Current practices within the food industry destabilize future outputs through environmental degradation and are predicted to lead to its eventual ruin. Furthermore, the industry is fraught with poor ethical and health implications. Fortunately, alternative food sources made available through biotechnologies offer solutions to each of these issues. The main alternatives of interest are plant-based, fermented, or cultivated proteins. Each of these alternatives are more environmentally sustainable and will soon be superior in key attributes such as nutrition, health, and taste. Coupled with sharply declining costs, they are primed to take on the growing global demand for protein.

The traditional meat industry is valued at US$1.7 tn, and while alternative protein is still small in comparison (est. US$10.38 bn in 2019), it is projected to grow rapidly to US$17.9 bn by 2025, registering a CAGR of up to 9.5%, while the traditional meat market will suffer due to its unsustainable design. Furthermore, the immense investment in alternatives will propel the industry forward rapidly. Impossible Foods, a major plant-based protein giant, has alone secured US$1.5 bn from many prominent VC investors, making it one of the most well-funded companies ever. Hundreds of other companies are emerging rapidly, buoyed by strong investment and consumer interest.

Despite early success, the alternatives industry is still rather nascent, which leaves plenty of room for further innovation and research. There are bountiful opportunities to enter into this industry, whether it be via a B2C food company, B2B tech/equipment-provider, or researching and developing new techniques and technologies.

While there are risks of low consumer adoption, unfavorable government regulation, or inability to quickly achieve price parity, it is becoming increasingly clear that there is an imminent disruption of the current food industry. With growing awareness of where our food comes from and the insidious issues with its production, more and more individuals are deviating from traditional animal-based food sources (especially protein) and are instead pursuing alternative diets. Veganism is at an all time high and only continues to grow, along with other alternative and flexitarian diets. Clearly our appetite for alternatives is growing –the future of food thus looks like biotech solutions.

INTRODUCTION

The future of food is in an increasingly perilous position. The global population is increasing rapidly, expected to exceed 10 billion people by 2050, but current agricultural practices and food technologies won't generate enough supply to feed the world. A deeper dive into our growing demand for food, especially meat, showcases how traditional food practices are directly at odds with our food security. Current food production practices are embroiled with a multitude of environmental, ethical, and health-related issues. The future of food must therefore look to new biotechnologies and alternative food sources to sustainably feed the world.

Our increasingly vulnerable food security is a multifactorial phenomenon. Current food practices, especially those of meat production and fishing, are incredibly unsustainable and are a huge contributing factor to climate change. Meat-production processes, especially for beef, rely heavily upon land-use, water-use, and additional ecological resources to raise animals for slaughter. These animals, furthermore, have a very inefficient feed to conversion ratio, which is the weight of feed divided by the edible weight produced (Figure 1).

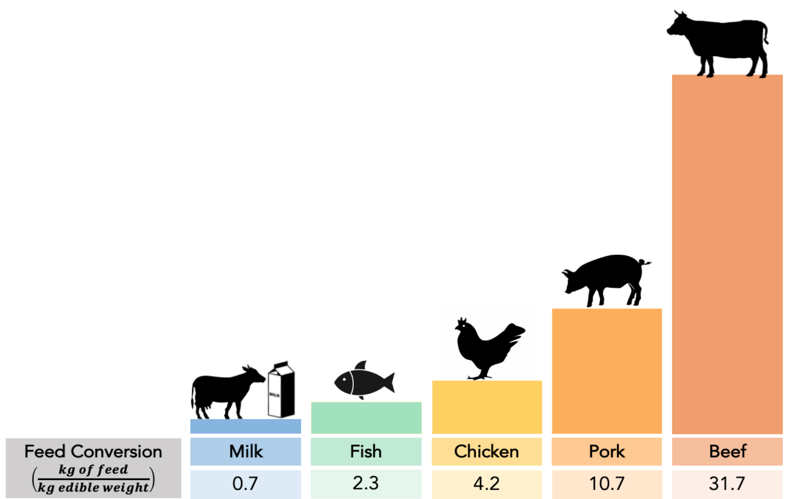

Figure 1. Feed conversion ratios for different livestock.

This has proven to be an incredibly unsustainable practice–in fact, livestock accounts for 14.5% of all anthropogenic greenhouse gas (GHG) emissions each year according to the UN Food and Agriculture Organization. Extreme climate events (e.g. floods, fires, droughts), water scarcity and pollution, and other accelerating factors of environmental degradation are leading to severely diminished food security via agricultural means.

Climate stability is also reliant upon stable oceans, and phenomena such as overfishing, pollution, and ocean warming have significantly depleted global fisheries and driven ocean ecosystems to the point of collapse. Similar to how the global demand for meat is increasing, global demand for seafood is expected to rise 30% within the next decade. Over 800 million people are at risk of malnutrition if fisheries continue to decline, and there are further risks to seafood consumers via contamination with heavy metals (e.g. mercury), persistent organic pollutants (POPs), and microplastics. Practices such as sustainable fisheries management and aquaculture are current methods used to mitigate rampant overfishing, but both have severe limitations.

Health concerns for current protein consumption are noteworthy. As mentioned, contaminated fish can have a whole host of negative effects on the human body depending upon the pollutant. Up to 90% of mercury – a known toxin to the human nervous system – found in the human body can be attributed to fish consumption. Many governments, however, still recommend fish as a source of fatty acids, despite the risks. There are also significant issues for land-based animals. Aside from concerns of meat contamination (e.g. *E. Coli*, Salmonella), usage of growth hormone and antibiotics in livestock animals may also have negative effects on the human body, most notably through increasing antibiotic resistance.

Heavy ethical considerations also mar traditional food consumption. Many industry practices are widely known to be ethically questionable, with multiple techniques shown to cause pain (physical or psychological) to the animals. For example, unhygienic and crowded living environments, immediate separation of calf and cow after birth, and forceful overproduction are prevalent in animal milk production businesses. Such practices have been widely exposed via documentaries and news stories and have become increasingly important to consumers. Barring all other factors, if food can be produced without causing harm to other living species, there is a basic moral duty to implement those methods or techniques. Luckily, ethical issues with current food production happen to align strongly with other environmental, economic, and health concerns, so there are no real roadblocks for trying to eliminate current animal agricultural practices.

Continuing with a business-as-usual approach to our food consumption would be cataclysmic for the environment and food security, but it may be difficult to convince consumers to significantly alter their dietary choices, even despite clear ethical and health concerns. Our taste for meat is growing rapidly, most notably in Asian countries (especially China), and meat production continues to skyrocket across the globe (Figure 2). Meat consumption furthermore tends to rise as countries accrue wealth, as there is a large correlation between per capita meat supply and GDP per capita. Alternative food sources and technologically-driven production methods will be the only way to provide adequate, sustainable, and nutritious food to the world.

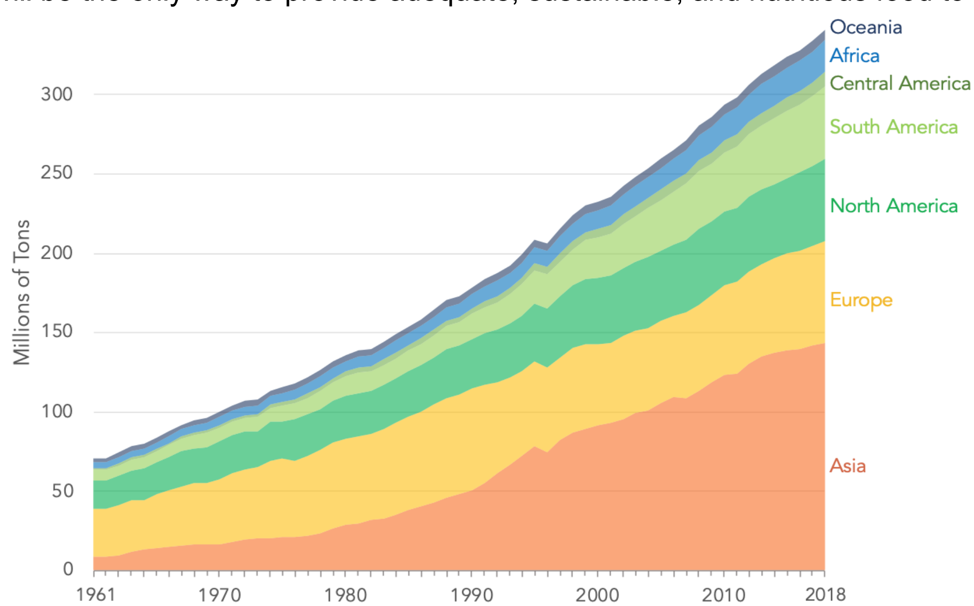

Figure 2. Global meat production from 1961 to 2018 (data from FAO).

Emerging and established biotechnologies to produce alternative foods will serve as the solution to this growing issue. Current technologies allow for the production of convincing meat-substitutes made from plants, insects, mycoproteins, and other naturally-occurring protein sources. Similarly, many companies are focused on producing cultivated meat, which is cellularly identical to animal meat, in laboratory environments. These techniques boast significantly improved environmental sustainability and satisfy consumers' desire to avoid animal slaughter. They are also significantly cheaper and less resource intensive than traditional protein production.

There is promise in alternatives when looking at more recent dietary trends. Business Insider called 2019 the "Year of the Vegan," signifying a monumental shift in consumer diets and behavior. Veganism is increasing rapidly, as more and more people try to avoid consuming all forms of animal products, including meat, dairy products, eggs, etc. Even more individuals subscribe to vegetarian, pescatarian, and "flexitarian" diets. In fact, around 8% of the world identifies as vegan, vegetarian, or something in between. The rise of flexitarian diets is particularly interesting, as it showcases a conscious effort of individuals to avoid meat and fish products, despite not cutting them out entirely. In all, 27% of the global population avoids consuming meat, either on a regular basis or entirely, which is promising (Figure 3).

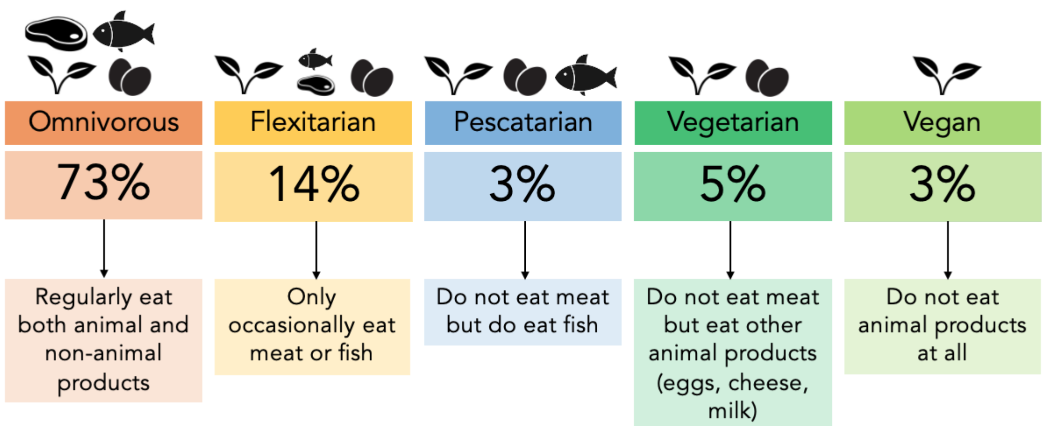

Figure 3. Prevalence of various global diets in 2019; n = 20313, 28 countries

With an increasingly educated customer base, consumers care more and more about the health, environmental, and ethical effects of what they eat. Alternatives will therefore be widely accepted if they can hit the necessary taste, texture, and nutritional values that consumers desire.

RethinkX posits in their breakout report [Rethinking Food and Agriculture 2020-2030] that we are primed now for the most significant disruption in food and agricultural production since the first domestication of plants and animals thousands of years ago. While 10,000 years ago humans learned to raise and breed macro-organisms for food sources, we now have the technologies necessary to domesticate microorganisms (Figures 4, 5). They predict that due to emerging alternatives' superiority in key attributes such as nutrition, health, and taste, and their sharply declining costs, the cattle farming industry will be all but bankrupt by 2030, with other livestock industries falling closely behind. Alternatives, whether plant-based, fermented, or cultivated, will offer a robust path forward into the future of food.

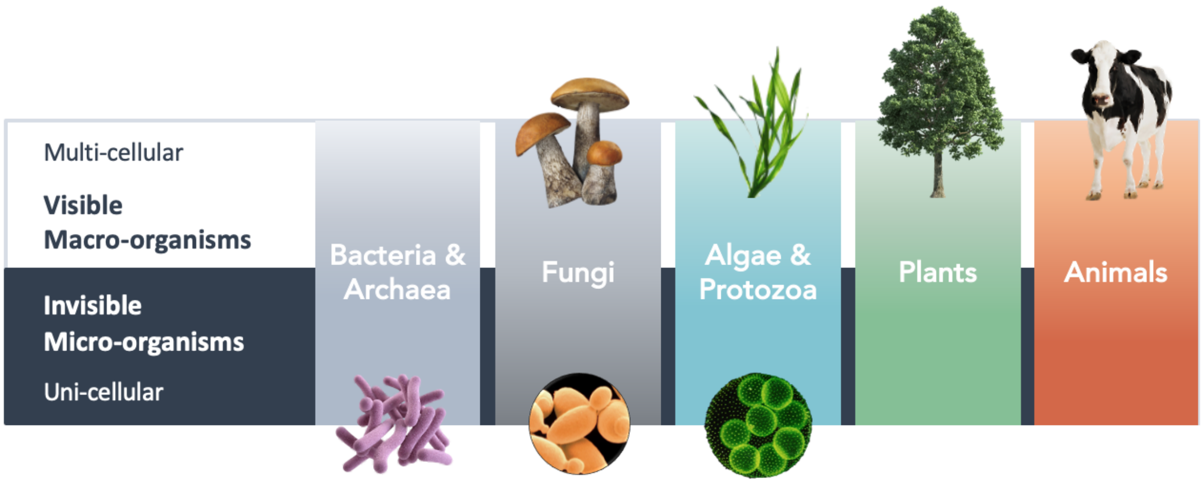

Figure 4. Domestication of macro vs. micro-organisms.

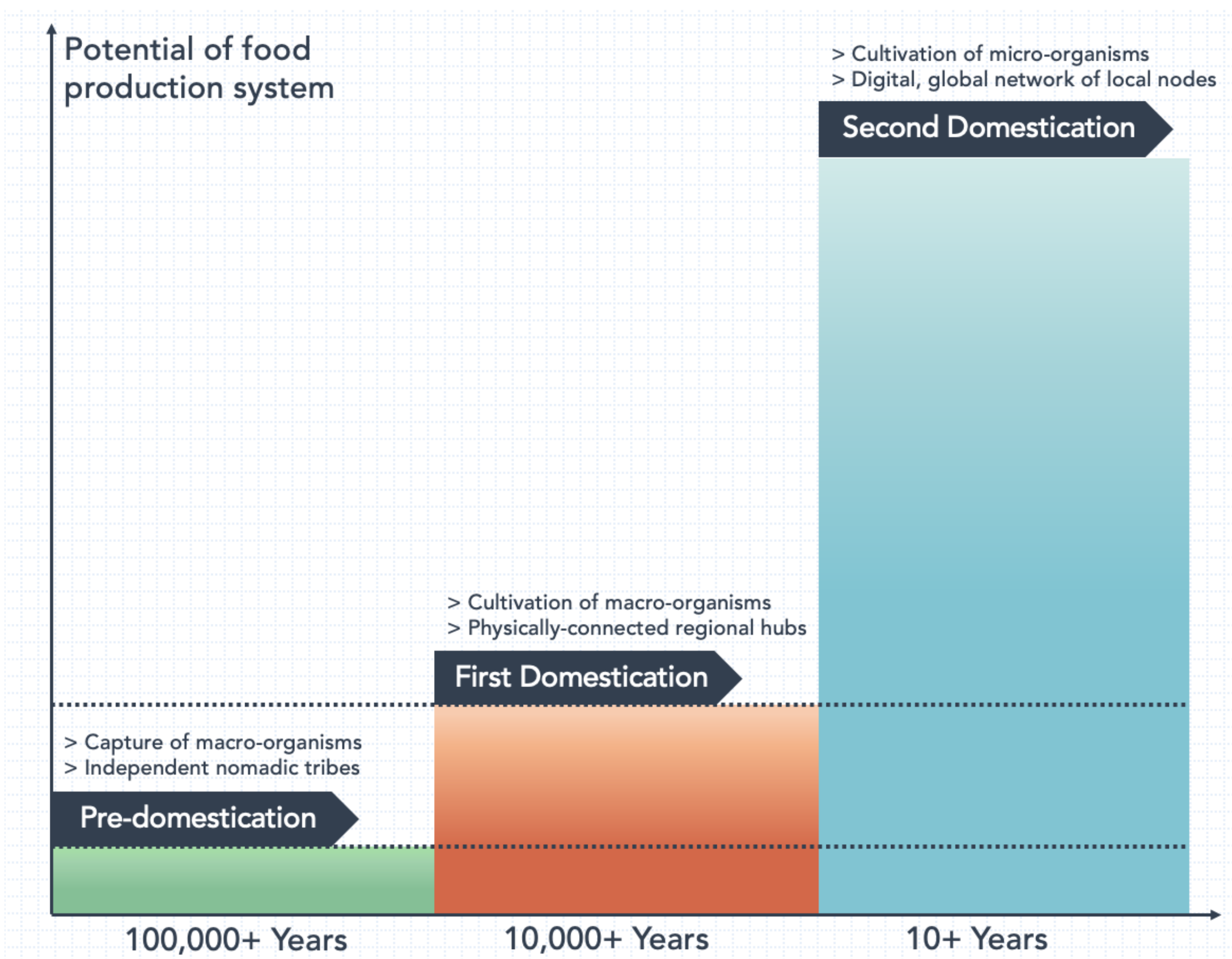

Figure 5. Timeline of the first and second domestication.

INDUSTRY OVERVIEW

There are a number of biotechnologies and techniques that can be used to create believable food alternatives for foods such as meats, dairy, and eggs. Biotechnologies such as cellular agriculture and precision biology represent classes of such exciting techniques to produce alternatives. The most common alternatives are currently plant-based, which mimic the taste and texture of traditional foods using plant sources and other engineered inputs. Techniques such as fermentation and cultivation, however, are becoming increasingly viable for producing foods that don't just mimic the taste and texture of regular food, but can actually create them without the need of an animal.

Plant-Based Alternatives

A wide variety of foods can be replicated using various plant sources and ingredients (Figure 6). While plant-based alternatives cannot obviously completely recreate the food at hand, they can still do a good job at mimicking the taste, texture, and other aspects of a traditionally-sourced food substance – enough to "trick" the consumer. Plant-based meats, seafood, and dairy substitutes (particularly milk) are well-established protein alternatives in the current marketplace.

Figure 6. Foods that can be mimicked with plant-based alternatives (GFI).

Alternatives are often built up using a similar molecular make-up to real beef, using proteins, lipids (fats), carbohydrates, minerals and vitamins. Most alternatives use a base plant protein source, and then add in other plant-based fats (e.g. coconut oil, sunflower oil), binders to keep the "meat" combined, and some main flavoring or coloring components. Soy and pea protein are currently the most popular protein alternatives for plant-based meats. Dominant industry player Impossible Foods uses soy as their main protein component in their alternative beef, and supplement it with binding agents, coconut oil, and genetically engineered *heme* which creates a "bleeding" effect and gives a more meat-like taste. Another competitor Beyond Meat, on the other hand, relies upon yellow pea-protein and potato protein, with beet for coloring. Both recipes produce a convincing beef substitute, visually and taste-wise (Figure 7).

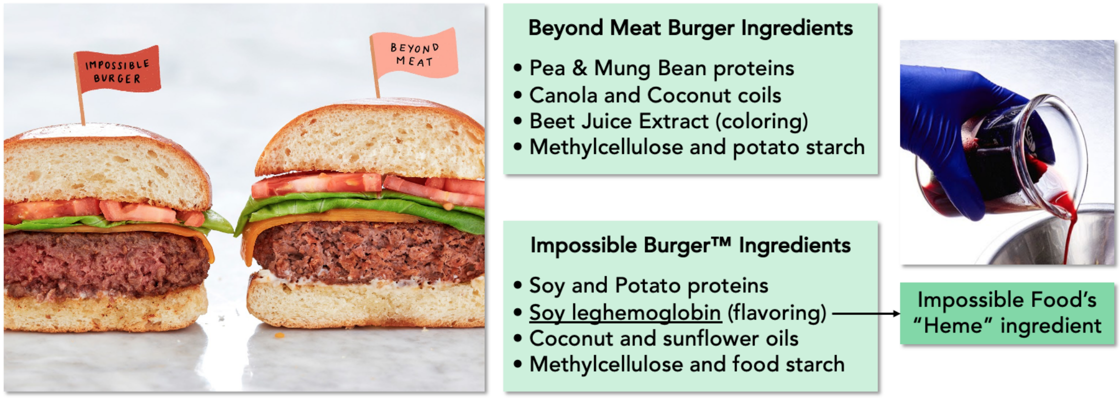

Figure 7. A comparison of popular plant-based burger meats and their key ingredients.

While ingredients come from agricultural sources, there is still a fair bit of food tech required to create convincing and delicious alternatives. Combining each ingredient with the right methods is just as important as finding the right ingredients. Extrusion, for example, is a common food processing technology that is most often used to mimic meat texture. Flavorings, colorants, and binding agents are also important for mimicking meat texture and taste and also keeping all ingredients combined. While some of these components can be sourced naturally (e.g. using seaweed or algae to flavor seafood alternatives), others are made in the lab, such as Impossible Food's signature "heme" ingredient.

While plant-based alternatives are a good starting point, they cannot fully replicate traditionally-sourced foods, and have some significant limitations. Within plant-based dairy, for example, it is very difficult to create cheeses, yoghurts, and ice creams, due to the chemical composition from bovine milk. Cheese in particular is made via a specific chemical reaction between rennet[1] and the protein casein found in milk, in which the rennet breaks down casein globules, causing them to coagulate and create a strong curd. Casein importantly is not a component of plant-substituted milk, so creating cheese and other dairy products proves to be more difficult (Figure 8).

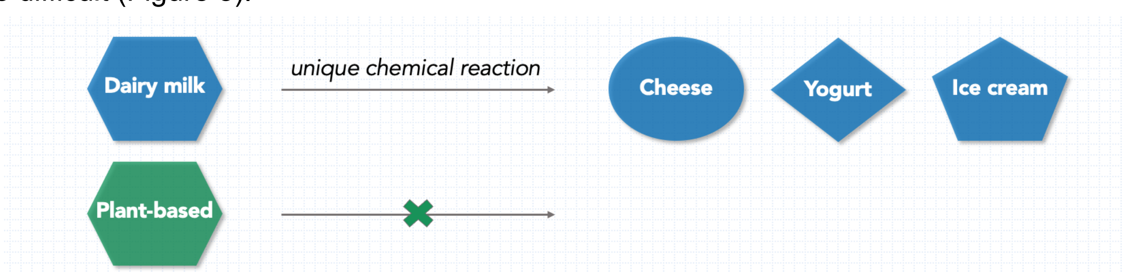

Figure 8. Schematic of the utility of dairy milk versus plant-based milk.

Another issue with plant-based alt proteins are that of questionable health benefits. Many consumers believe that because these alternatives are constructed from plants, they are likely healthier than their real animal counterparts. There may be some evidence for this in the case of plant-based milks, however, the claim proves to not necessarily be true in the case of

[1] A complex mixture of enzymes produced in the stomachs of ruminant animals such as cows. It's main component is the active enzyme chymosin, which curdles the casein in milk.

meat substitutes – many companies have valued taste over health for their first products in order to attract a larger audience, and accordingly have packed their products with fats (e.g. coconut oil) and sodium, both of which are generally considered unhealthy in large quantities. This may prove to be a prevalent issue in the future, as many consumers are increasingly educated about their foods and place a strong emphasis on healthy lifestyles.

Alt products are furthermore more expensive than traditionally sourced foods so consumers are forced to pay a premium. Oat milk, for example, goes for US$5.29 per gallon whereas traditional dairy milk sells for US$2.17 per gallon. The supply chain and synthesis of certain ingredients can ratchet up the price quickly, so establishing and refining these inputs, as well as scaling-up production will be important for achieving price parity.

Despite these shortcomings, plant-based proteins offer undeniable environmental benefits as they do not rely upon animals for protein, which are resource-intensive – according to the United Nations Framework Convention on Climate Change (UNFCCC), the Impossible™ Burger created by Impossible Foods requires 96% less land, 87% less fresh water, and generates 89% fewer GHG emissions than a traditional beef burger. These numbers are similar across the industry, where alternatives show great reductions in land usage, water usage, and emissions.

Fermentation

Fermentation has been used for thousands of years in food production. The term "fermentation" takes on different meaning depending on the discipline it is applied to – in food tech, it has taken on a more generalized definition and refers to the cultivation of microbial organisms (e.g. bacteria, yeast, etc.) for various nutritional purposes, including: processing a foodstuff, growing more of said organism as a primary source of protein, or deriving specialized ingredients like flavorings, enzymes, and fats. There are three main types of fermentation used in the food and alternative protein industry, which are traditional fermentation, biomass fermentation, and precision fermentation (Figure 9).

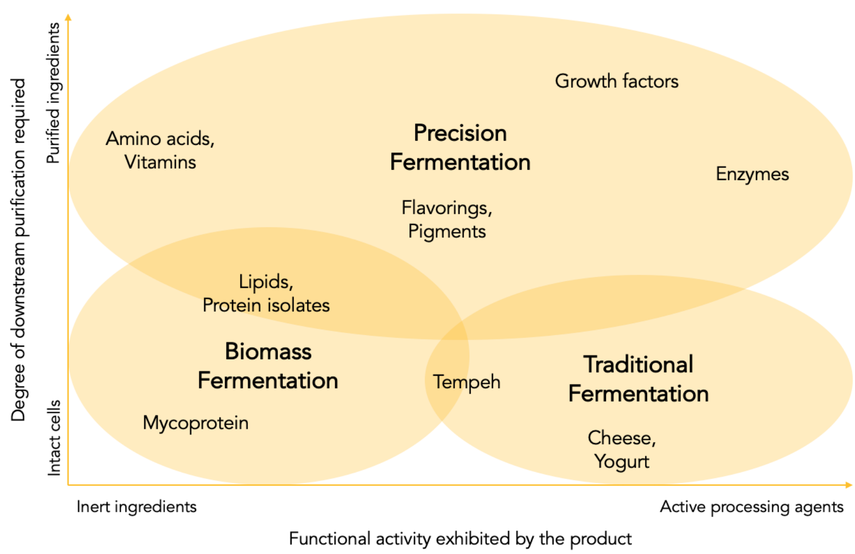

Figure 9. Conceptual landscape of fermentation-derived and enabled products (GFI).

Traditional fermentation uses intact living microorganisms to process plant-ingredients that results in products with unique flavors, nutritional profiles, and textures – historical examples of fermentation (alcohol, tempeh) are products of cells used as living biological processing units to convert raw materials into more desirable forms. The process of making beer, for example, utilizes yeast to ferment raw materials such as barley into grain alcohol. In the case of tempeh, fungal mycelium is grown on soybeans to break down antinutritional factors, improve nutritional content, and enhance the flavor profile. This technique has been widely used for thousands of years, however there is still plenty of room for innovation.

Biomass fermentation leverages the fast growth and high protein content of many microorganisms to efficiently produce large quantities of protein. The microbial biomass itself serves as an ingredient, with its cells intact or minimally processed, e.g. with the cells broken open to improve digestibility or to enrich for even higher protein content, akin to processing plant flours into protein concentrates and isolates. This biomass serves as the predominant ingredient of a food product or as one of several primary ingredients in a blend.

This type of fermentation is possible because many microorganisms offer innately high protein content (over 50% by dry weight for many fungal, bacterial, and algal species) coupled with extraordinarily fast and self-sufficient growth, requiring only simple and inexpensive nutrient feedstocks. While the generational cycle of animals raised for meat is on the order of months to years, and crop plants typically require growing seasons of weeks or months, the doubling time of most microorganisms is hours or even minutes. Cell culture processes, such as fermentation, capitalize on the fundamental biological property of exponential growth, meaning that every growth cycle can double the available biomass. When performed at the scale of hundreds of thousands of liters, these processes generate tens of metric tons of biomass every hour.

Precision fermentation (PF) is arguably the most interesting and versatile fermentation technique. It combines precision biology with traditional fermentation, using microbial hosts as "cell factories" for producing specific functional ingredients, such as proteins. These compounds typically require greater purity than the primary protein ingredients and are incorporated at lower levels. Such functional ingredients are powerful enablers of improved sensory characteristics and functional attributes of plant-based products or cultivated meat.

This fermentation category has been well established in the food industry for many years, but innovators are now investigating novel solutions tailored to the specific needs of the alternative protein industry. Biology provides food developers with an almost boundless palette of molecules from which to assemble flavors, textures, and aromas. However, not all these ingredients are easily sourced at large volumes and low prices. Theoretically, using microbial cells as the production host, PF allows for highly scalable manufacture of virtually any ingredient. Indeed, fermentation-derived ingredients are already widely used across the food industry. Highly purified fermentation-derived components are perhaps most visibly used in alternative protein products as functional ingredients (e.g. Impossible Food's heme).

While historically quite expensive, rapidly lowering costs for PF will make precision fermented products highly competitive with traditionally sourced ingredients and foods. One example is milk made via precision fermentation: traditional dairy milk from cows has two main proteins, casein and whey, which can be synthesized utilizing PF. Companies such as Perfect Day are therefore looking into creating "PF milk" – a product that closely bio-mimics real milk.

PF milk will be significantly cheaper over time, due to its lack of reliance upon raising cows and the rapidly decreasing cost of PF technologies (Figure 10) .

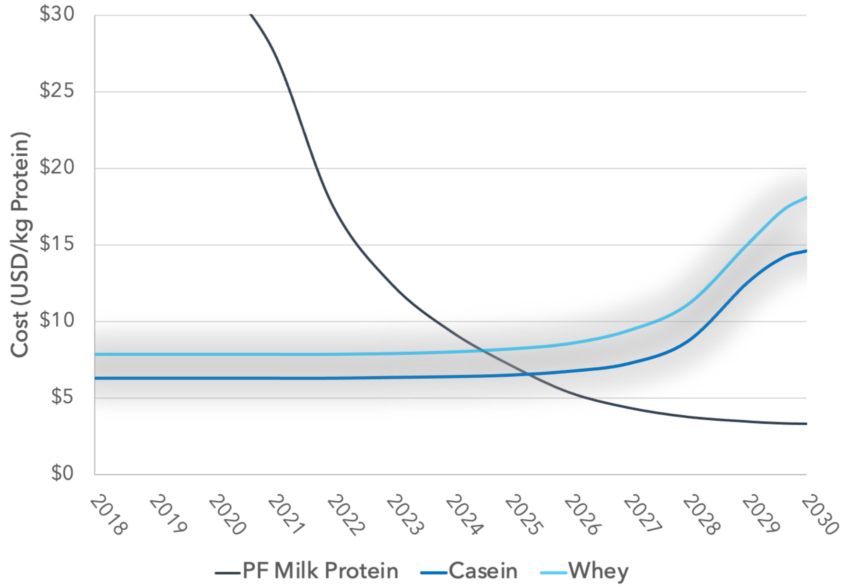

Figure 10. Cost estimates of PF dairy proteins compared to casein and whey over time.

We are still in the early days of the transition to a post-animal food production system. Fermentation, whether traditional, precision, or biomass, offers to support product development across the alternative protein landscape by scaling production of unique ingredients. Mycelium, microalgae, microbes, and fermented plant proteins can all provide the sensory experiences and full nutritional profiles of animal products, but without undesirable substances, such as cholesterol, antibiotics, and hormones. Fermentation will enable companies to meet the growing demand for protein at a cost that is competitive with or lower than that of animal products and potentially lift millions out of malnutrition in the future. This protein could ultimately be both less expensive to produce and higher quality than animal proteins.

Efficient protein production is good not just for human health but for planetary health. Microbes are much more efficient than livestock at converting calories into protein and high-value molecules (reducing pollutants and GHG emissions and saving water and land) and can consume a wider variety of feedstocks. These feedstocks are often low-cost industrial or agricultural side streams or waste streams. This lowers both variable and external costs associated with production, such as transportation of inputs.

Cultivated Alternatives

In conventional animal farming, cell growth occurs in an animal after resources such as land, food, and water are input. All told, it’s an incredibly inefficient process to convert external resources into animal meat. But the same cells can be grown in a much more efficient and sustainable way, using a piece of equipment called a cultivator. The cultivator facilitates the same biological process that happens inside an animal: it provides warmth and basic elements needed to build muscle, including water, proteins, carbohydrates, fats, vitamins, and minerals – it is not unlike how a greenhouse provides warmth, soil, water, and nutrients to allow plants to grow (Figure A1). These conditions and inputs allow cells from a given organism to proliferate and grow into what we know as animal meat (Figure 11).

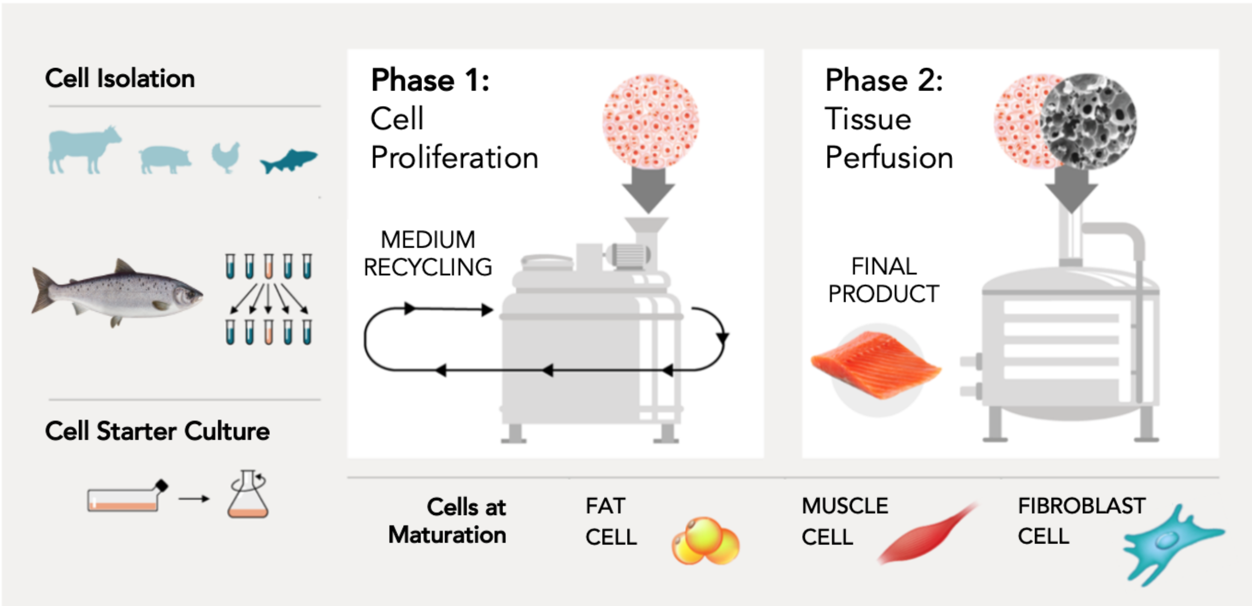

Figure 11. Cell-based meat production schematic for seafood (GFI).

These meats are part of the nascent field of *cellular agriculture*, which is the production of agricultural products from cell cultures. Cultivated meats would fall under the category of *cellular* products as they have been made from once-living cells, which can be isolated from any animal (e.g. cow, pig, chicken, fish).

The cell growth of cultivated meats is not unlike that of microbes grown via fermentation methods (any of which can also be grown in a cultivator or bioreactor). The key difference, however, is that of cell type. Cultivated meats refer to the proliferation of real animal cells (e.g. muscle, fat, tendon) that have been harvested from a target animal's tissues. Biomass fermentation, in contrast, represents the rapid growth of microorganisms, such as fungi. While fermentation options can certainly offer high protein alternatives, cultivated meats are desirable based on their ability to fully replicate animal meat without having to raise and harm any animals.

This promise is, however, more theoretical compared to other alternative methods. While there are many companies working in the cultivated meat space, there have not yet been any products taken to market. Though this technique has been shown to work in lab settings, there are many challenges in creating a substance that fully mimics meat, especially whole-cut. While muscle cells may be able to grow in a cultivator, creating the right texture, combined with fats, tendons, and sinews in a whole cut of meat is a different task entirely. One technique being utilized is combining 3D printing[2] with cultivated meat production, in order to recreate true

[2] 3D printing, also referred to as additive manufacturing, is a fast developing digital technology where a three-dimensional solid object is created from a digital file. The creation of a 3D printed object is achieved using additive processes, in which an object is created by laying down successive layers of material (e.g. plastic, cells) until the object is created.

muscle structure. There is still, however, plenty of research necessary to optimize cell culture technology.

Cultivated meats can be referred to by many different terms: cultured, cell-based, cell-cultured, clean, slaughter-free, lab-grown, *in vitro,* etc. While each name represents the same process, there has been much debate about which moniker is best. For example, “clean” and “lab-made” have been pushed heavily by media outlets for increased article clicks, however most scientists and alternative meat companies do not believe it is an accurate or appealing representation of what is being produced. The Good Food Institute and many others have now settled on “cultivated” meats as being the most accurate and accepted definition, though “cell-based” and “cultured” are also quite common.

GLOBAL FOOD MARKETS

Global Traditional Proteins Market

The traditional proteins market is very well-established across all segments, and represents the vast majority of market share compared to alternatives. The global traditional meat market was valued at approximately US$1.7 tn in 2019, according to the UN's Food and Agriculture Organization (FAO). Even global dairy products, which have a more established alternatives market, are still dominated by animal-produced dairy. The current landscape of the global milk industry, for example, is predominantly occupied by animal milk, which has globally US$538.8 bn in revenue.

Protein consumption varies significantly globally. Different populations and ethnic communities globally consume different amounts and types of meat. In the Middle East and much of Asia-Pacific, for example, most protein comes from legumes and seafood, while Chinese consumers mainly rely on beef, pork, and poultry. In China, approximately 50% of animal protein calories come from pork, compared with the Middle East, which reports nearly 50% of protein calories from dairy and eggs. Comparatively, U.S. residents consume almost twice the amount of beef protein compared with the global average.

Global demand for premium proteins is booming with socio-economic changes like rising incomes, increased urbanization, and aging population. Increased demand for protein, however, will place increased pressure on planetary resources to supply not only more, but also differing types of food. Though it appears that traditional proteins have a very secure position in terms of market share, it is likely that within the next decade the market will experience a sharp decline in desirability and may crash completely, as ReThinkX posits. The supply chain of traditional markets is not secure and subject to high volatility, as the COVID-19 pandemic showcased – large dairy farmers, for example, were forced to dump enormous quantities of perfectly good milk due to fraught supply chain issues in early 2020.

Global Alternative Markets

Alternative Protein

The alternative protein industry has grown significantly in recent years, developing slowly since the mid-2000's and exploding in the late 2010's. Meticulous Research estimates the overall market size for alternative proteins will reach US$17.9 bn by 2025, registering a CAGR of up to 9.5%. The largest segment of the overall market is undeniably plant-based alternatives, which make up well over half the market share, with some estimates exceeding 80%. The size of the plant-based alternatives market was estimated to be approximately US$10 bn in 2019, and is expected to reach US$14 bn by 2025 growing at a CAGR between 7 and 9%. Other alternatives include substances such as fermented protein, insect protein, and others – this segment is much smaller, around US$2 bn in 2019, but still growing steadily at a similar rate of around 8% (Figure 12). Importantly, cultivated meats are not yet considered within this market sizing as they are not yet available for purchase – many companies hope to bring their products to market in the early-to-mid 2020's.

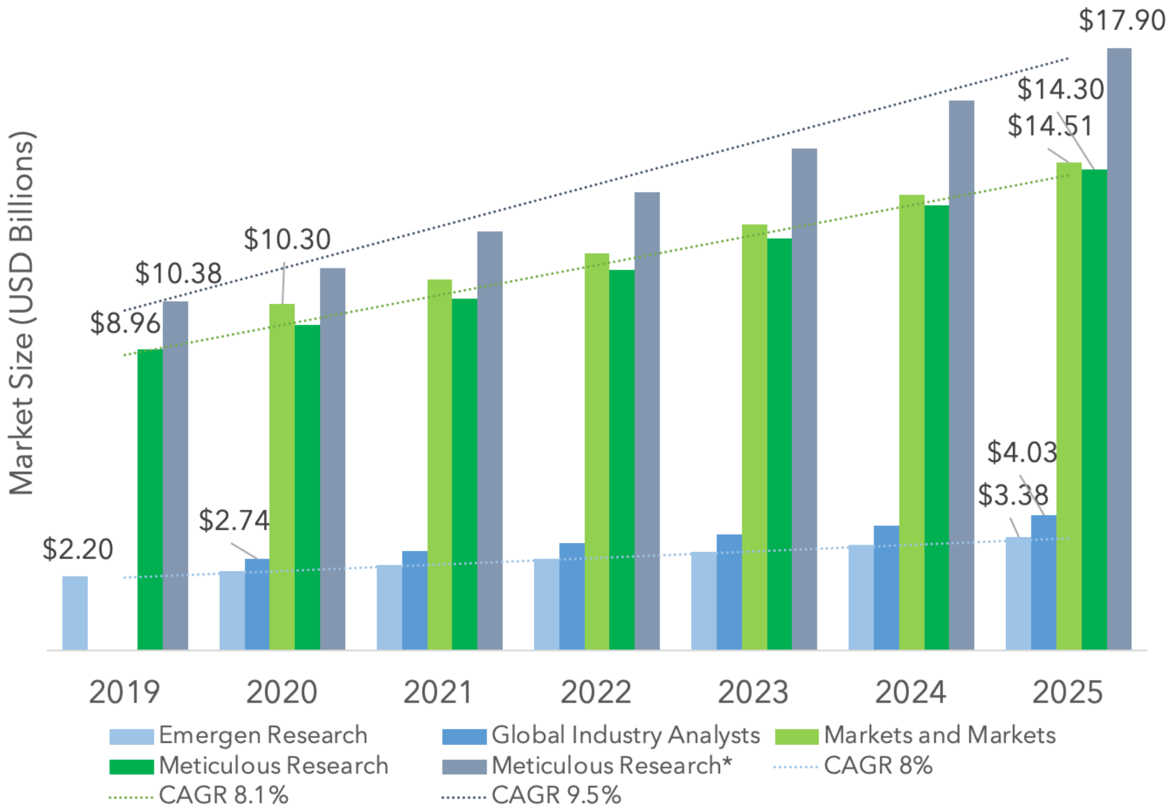

Figure 12. Global Alternative Protein Market Size and Growth Estimates, from 2019 to 2025.
(blue = other alt proteins; green = plant-based; gray = alt proteins as a whole)

Several factors have contributed to this evolution, specifically an increased consumer interest in the health, pricing, and ethical considerations (e.g. where meat is sourced from, animal welfare) of different types of protein. A main driver for the adoption of alternative proteins, especially plant-based, is a shift of consumer demand to wellness-focused organic foods and beverages. This is especially true in Western countries such as the U.S. In a 2018 study, 82% of U.S. consumers perceived plant-based proteins to be healthy, while only 74% rated animal proteins in the same way. A potential drawback to market growth is a consumer aversion to or concern about GMO-use in food products. Examples of such crops include soy, wheat, and pea, which are among the prominent sources used in the processing and production of plant-based proteins. They are produced primarily in countries such as Brazil, the U.S., Canada, China, and India, which also represent a key portion of the demand for plant-based food & beverages among consumers.

The COVID-19 pandemic has also had a profound impact on the alternative proteins market. Given the growing consumer awareness of the impact of the pandemic on meat production, consumers have begun adopting plant-based alternatives instead, resulting in a sales surge of over 500% for meat alternative brands. The pandemic has also influenced the sales of plant-based snacks, dairy alternatives, and supplements, as consumers move towards a healthier lifestyle. Overall, the pandemic has accelerated the acceptance of vegetarianism and has furthermore showcased a greater emphasis on environmental factors.

Alternative Dairy

The global alternative dairy industry is very well-established, registering as the largest global alternatives market. The fast-growing plant-based milk industry has gained 13% of the U.S. milk market share in 2019. In fact, McKinsey's 2018 Dairy Survey reported that 73% of millennials and some Gen Z had purchased a dairy-free alternative product at some point within the year of 2018. The overall global market size of plant-based dairy alternatives was estimated to be between US$12 mn and US$19 mn in 2019, and is expected to grow at a rapid CAGR between 11 and 17%, to reach up to US$40 mn by 2025 (Figure 13). Lab-made is not currently included in the market, however, it will be a competitive industry in the near future and a predominant one in the long-run as precision fermentation costs decrease.

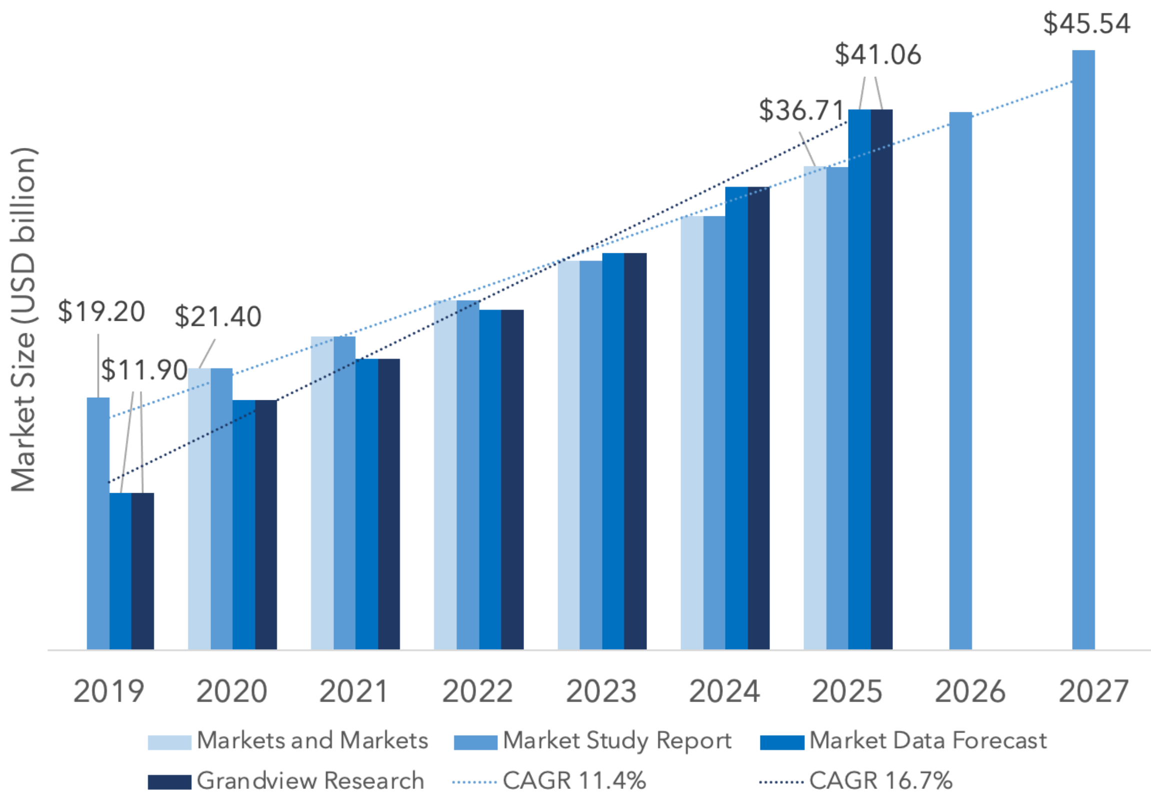

Figure 13. Global Alternative Dairy Market Size and Growth Estimates, from 2019 to 2027.

Plant-based alternatives' prevalence is due to a number of factors, namely that many individuals across the globe cannot or choose not to consume traditional dairy products. This may be either due to lactose intolerance, ethical or dietary reasons such as veganism, or the perceived health benefits of plant-based dairy. Dairy alternatives such as soy, rice, oat, and almond milk are considered healthy by many, owing to the presence of several essential vitamins and minerals. Most dairy alternatives also have a lower fat content, as well as lower levels of cholesterol, and most importantly, no lactose.

Alternative dairy is dominated by plant-based milk products, likely due to milk's dietary prevalence and difficulty producing other convincing dairy substitutes with plants. Asia-Pacific is predicted to account for the majority of market share between now and 2027. The large market share in this region is attributed to rapid urbanization, diet diversification, and liberalization of foreign direct investment in the food sector. Apart from this, rise in income, purchasing power, rapid growth of the middle-class population, increase in consumer awareness about health and fitness, and consumer demand for nutritional and healthy products provide promising prospects to the market players for growth and diversification in the region’s food sector.

INDUSTRY PLAYERS

Established Alternatives

Of all potential alternatives, plant-based foods reign supreme in the marketplace. Plant-based meat, dairy, and eggs are all available to purchase in your standard grocery store, which is not yet true for most fermented and all cultivated products. There are a number of major companies that create solely plant-based alternatives, and the number of companies continues to grow as funding is so abundant (Figure 14).

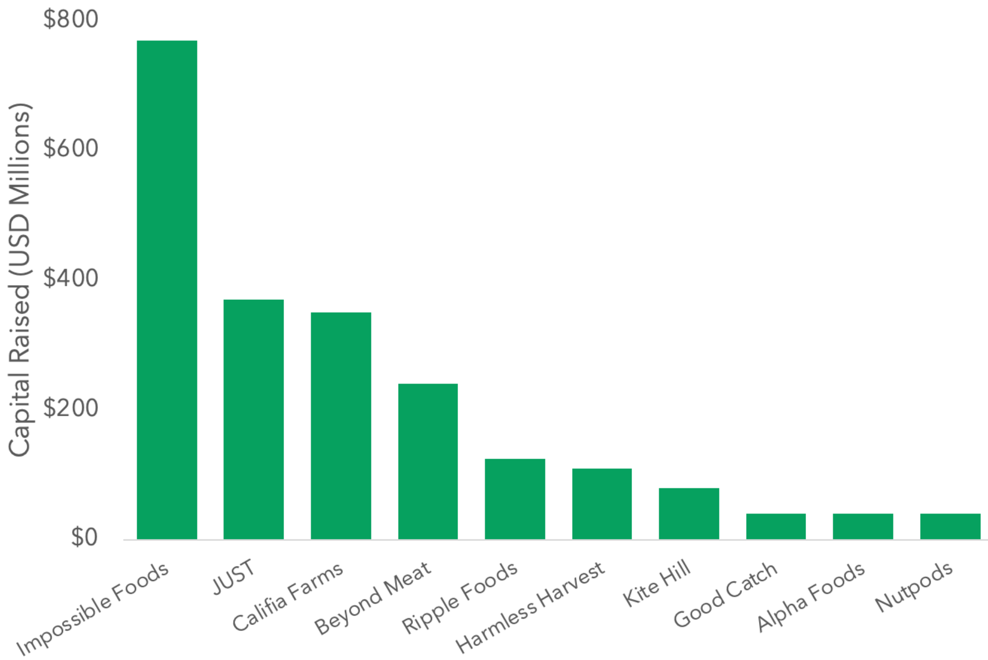

Figure 14. Most Funded Plant-Based Food Companies by VC Raised (1980- 2019).

Plant-based meats, particularly the plant-based burger, has continued to generate considerable interest with consumers, investors, and the press. The two titans are well-known and recognized in the public eye: Impossible Foods and Beyond Meat. Both companies offer plant-based burger and pork products and have seemingly proved to the average consumer that plant-based meat can be tasty and popular. When going public in early 2019, Beyond Meat had a record-setting IPO and both companies have had numerous retail and food service launches. Impossible Foods, for example, offers its Impossible Burger at Burger King, Red Robin, White Castle, HardRock Cafe, the Cheesecake Factory, and others.

Plant-based meat product launches, however, are not limited to the popular Beyond Meat and Impossible Foods. Established plant-based meat brands, such as Lightlife, MorningStar Farms, and Sweet Earth, announced their next generation of plant-based meat products in 2019. Plant-based seafood, as well, is a small but quickly expanding sector and experienced numerous product launches in 2019. Good Catch's plant-based tuna made its national retail debut in Whole Foods and Thrive Market in February, along with New York regional grocer Fairway Market. The top 10 plant-based sellers of 2019 can be seen in Table A1.

Plant-based dairy products, specifically milks, also dominate the market, and thus are saturated with many companies. While almond-based dairy products have dominated in the past, oat-based products have risen in recent years, which is reflected in Table A2. A few stand-out competitors include Califia Farms, which was one of the most well-funded and well-selling plant-based dairy companies. Some of their most popular products include their oat- and almond-based milks, creamers, and yoghurts. Other dairy companies that received large amounts of funding in 2019 include Ripple Foods (pea-protein based dairy products), Harmless Harvest (coconut water, smoothies, and dairy-free yogurt), Kite Hill (almond milk yoghurts, cream cheese, pastas, and ricotta), and Nutpods (dairy-free coffee creamers).

The sea of change started by plant-based milk and propelled upward by plant-based meat has lifted the plant-based food industry as a whole, with nascent categories (such as plant-based eggs) also experiencing increased innovation and growth. The company JUST, in particular, creates plant-based egg products and received the second most capital funding of any plant-based company in 2019. In fact, Whole Foods leveraged branded partnerships to launch JUST egg breakfast sandwiches with Lightlife bacon, Gardein sausage, and Good Planet cheese on its breakfast menu. Such promotions build consumer awareness, further accelerating sales across plant-based categories.

Overall, plant-based alternatives represent an increasingly saturated marketplace, with an abundance of funding and companies entering at a rapid rate. The interest in such products have poised the market for accelerated growth in the 2020's, and there will likely be a renewed focus on less available products such as seafood or chicken alternatives in the coming future. There is still much room for entry into the market.

Emerging Players

The two alternative techniques that have not yet entered the marketplace or are just beginning to be sold are fermentation- and cultivation-made foods. These technologies, while scientifically sound, have not yet been commercialized to the same degree as plant-based foods. This is likely, however, to change rapidly in the coming years.

Some fermented products exist in the marketplace currently, but are in far less demand than plant-based alternatives. The most established company is Quorn, which has actually been sold in grocery stores for the better part of three decades. Quorn uses a fermentation-derived biomass technique to produce its extensive product line, which includes everything from meatless patties to “Chik’n” cutlets. Newer fermentation-based companies, however, have been rising in significance – while plant-based companies continue to receive the most funding, fermentation companies are increasing their monetary outlook quickly and actually out-funded cultivation-based companies in 2020.

Creation of proteins, lipids, and functional ingredients for meat, egg, and dairy alternatives is one of the newest and most promising applications for fermentation. The Good Food Institute identified 68 companies using fermentation to produce or support animal-free formulations of meat, eggs, and dairy or their functional equivalents (e.g., a fermentation-derived ingredient to replace eggs in baking), however these represent only publicly disclosed projects, so the actual number could be much higher. 44 of those companies are dedicated to alternative protein applications, with 18 biomass, 21 precision fermentation, and 5 traditional fermentation companies (Table A3).

Within these competitors are a vast array of end-products. Fermentation allows for a wide diversity of alternatives, including meat (ground and whole-cut), egg and egg replacements, dairy (milk, ice cream, butter, cheese), gelatin, seafood, and fats and oils. Companies such as Meati, Atlast Food Co., and Prime Roots utilize various fermentation methods to mimic whole-cut meats such as steak, chicken, and bacon[3]. Clara Foods is the first fermentation-based egg protein company, using yeast to produce egg albumen proteins as a cooking and baking ingredient. Perfect Day is the first company to make the main milk proteins casein and whey for food applications using microbes – this production technology will enable a new generation of biomimicking flora-based cheeses, ice creams, yogurts, and butters, superior to plant-based alternatives. These aforementioned companies represent just the tip of the iceberg when it comes to the potential for fermentation-made foods and ingredients. The vast majority of fermentation-enabled alternative protein products either have come to market in the past few years or are likely to launch within the next few years. Many will not rely purely on fermentation but will include plant and animal cell components, just as Impossible Foods' beef derives from a mixture of plant and microbial sources.

While fermentation companies continue to sharply increase, cultivated meat has also seen an explosion of new companies and interest. Entrepreneurial investment in cultivated meat accelerated in 2019, culminating in the public announcement of 55 total cultivated meat and seafood industry startups by the end of the year (Table A4). Such companies are incredibly international, headquartered in at least 19 countries, with the vast majority located in the U.S., followed by Israel and Germany (Figure 15).

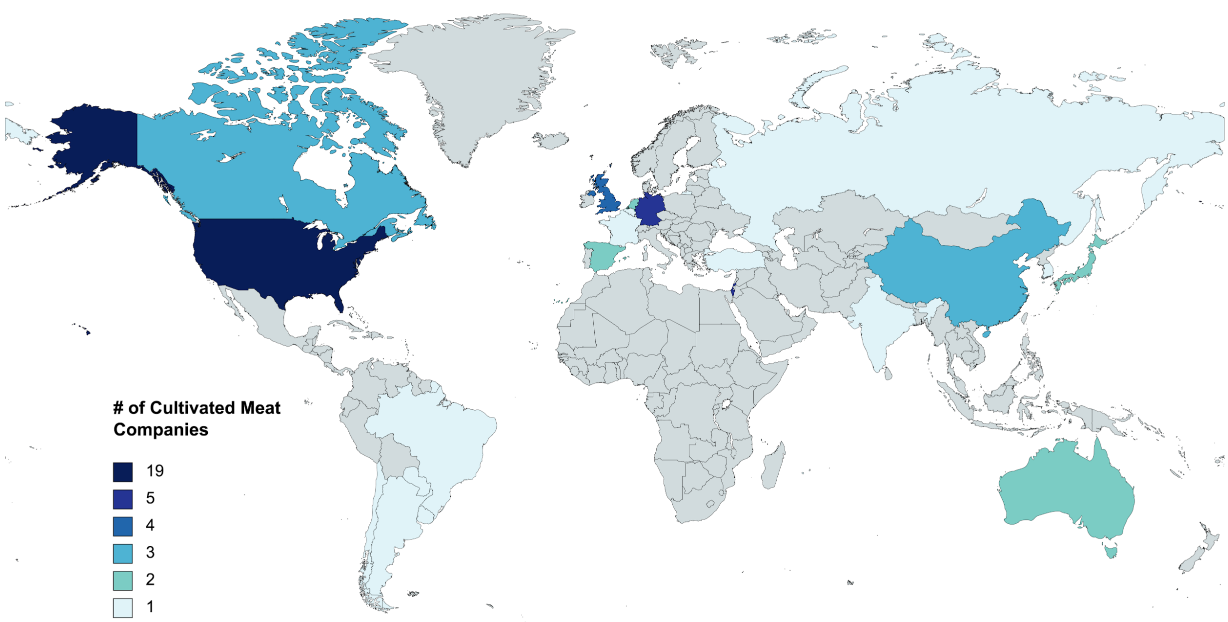

Figure 15. Geographic distribution of cultivated meat companies.

[3] Meati employs submerged fermentation to create substitutes for steak and chicken, while Atlast Food Co. and Prime Roots create "bacon" using solid-state fermentation and mycoprotein respectively.

By the end of 2019, startups were pursuing more than 15 types of cultivated meat, the most common being beef, chicken, pork, and various types of fish (e.g. salmon, tuna, shrimp). There were also, however, many companies pursuing more niche protein types, with some examples including duck (foie gras), lamb, kangaroo, horse, sturgeon, fish maw, and mouse. These various meat types are desirable for both their technical characteristics (i.e., factors in difficulty or ease of cultivation) and their appeal to the companies' first target markets. Wild Earth, for example, has focused on recreating mouse meat as a key component in their cultivated cat food.

Cultivated meat companies can differentiate themselves in other ways than meat-type: go-to-market strategies (launch country and plan), marquee partnerships (e.g., Memphis Meats with Tyson and Cargill, BlueNalu and Mosa Meat with Nutreco, and Mosa Meat with Merck), and ethics and sustainability claims. There is furthermore an emerging ecosystem of B2B startups providing technical equipment to cultivated meat producers – such companies supply specialty specific technologies such as bioreactors, scaffolding, cell culture media, cell lines, software, and even complete cultivation platforms.

The main issue at hand is whether cultivated meat companies can ultimately bring quality, affordable cultivated meat to market at scale. Once a company does this with one cultivated meat product, creating additional product lines and types of cultivated meat will be virtually unimpeded and more responsive to consumer demand. While still a nascent industry, it is showing signs of increasing maturity, with multiple lab-scale proofs of concept and a focus on scaling up production after several Series A fundraising rounds. The Good Food Institute predicts that cultivated meat will become a mainstream area for investment, study, and business. Looking even further ahead, intersections of the three alternative protein categories will enable a new wave of paradigm-shifting meat, egg, and dairy products and ingredients that meet consumer expectations for taste, price, and accessibility.

Established Food Companies

While there many all plant-based companies have come onto the scene, it is important to note that major established food competitors have also sprung into action, owing in major part to the high demand for plant-based alternatives. From 2017 through 2019, retail sales of plant-based meats grew 31%, while total U.S. retail meat sales grew only 5%. Because there is a clear demand for such products, major food companies have been investing heavily in outside companies such as Impossible Foods while simultaneously pushing out their own product plant-based lines. The world's 5 largest food companies (PepsiCo, Tyson Foods, Nestlé, JBS USA, and KraftHeinz) all became involved in plant-based proteins in 2019 and 9 out of the 10 largest U.S. meat companies became involved with plant-based meats by either launching, buying, or collaborating on a brand.

Many animal-based meat companies also launched their own *blended* meat product lines in 2019. Hormel introduced both a plant-based meat brand, Happy Little Plants, and a blended product, The Great Organic Blend Burger, under their Applegate Farms brand. Tyson and Perdue also debuted blended products, Tyson with their Raised & Rooted brand of blended burgers and meatless nuggets and Perdue with their Chicken Plus line of blended chicken, chickpea, and cauliflower nuggets. While these blended products are not plant-based, their launches still highlight animal-based meat companies' efforts to respond to growing consumer interest in reducing meat consumption.

These companies have also shown interest in the burgeoning fermentation and cultivation markets. Tyson Ventures, for example, has invested capital in both Future Meat Technologies and Memphis Meats which are cultivated beef startups. Memphis Meats also has a partnership with Cargill. It is apparent that these established food companies have seen the change in sentiments and demand surrounding food, and are acting accordingly to align their companies with the ever-clearer future trajectory of the food industry.

OPPORTUNITIES

Food Companies

Due to the rapid pace of alternative food companies popping up and the abundance of funding, there are many opportunities to enter the space with a good product. Alternative food companies have received lots of funding and attention, starting with a breakout year for alternative protein startups in 2019, with a record US$825 mn invested. Already, US$1.5 bn has been invested through July of 2020, showcasing rapid growth in the sector. Big investors, such as Bill-Gates backed Breakthrough Energy Ventures, Temasek, Horizons Ventures, CPP Investment Board, Louis Dreyfus Co., Bunge Ventures, and ADM Capital have all backed companies in the space. Established food companies such as Kellogg, Danone, Kraft Heinz, Mars, and Tyson Foods' investment arm have also backed alternative food companies and many have rapidly been attempting to replicate or produce their own alternatives.

Earlier in the decade, plant-based alternative companies dominated, receiving the vast majority of VC funds. The two largest financing events of 2019, for example, were Impossible Foods' $300 million Series E funding round and Beyond Meat's record-setting IPO—the first from a plant-based meat company—which raised more than $250 million in capital for the company. Impossible Foods is currently the most well-funded alternative protein company, having received upwards of US$1.4 bn to date in total funding with 45 investors. It's direct competitor Beyond Meat started with Bill Gates as an angel investor and has also raised up to US$122 mn, going public (BYND) in 2019.

Other cultivated and fermentation-based companies have started to take off with VC funding. Fermentation-focused startups alone have raised $435 m by the end of July 2020, which is overall 3.5 times more capital than cultivated meat companies, and almost 60% of U.S. plant-based meat, egg, and dairy companies (Figure 16).

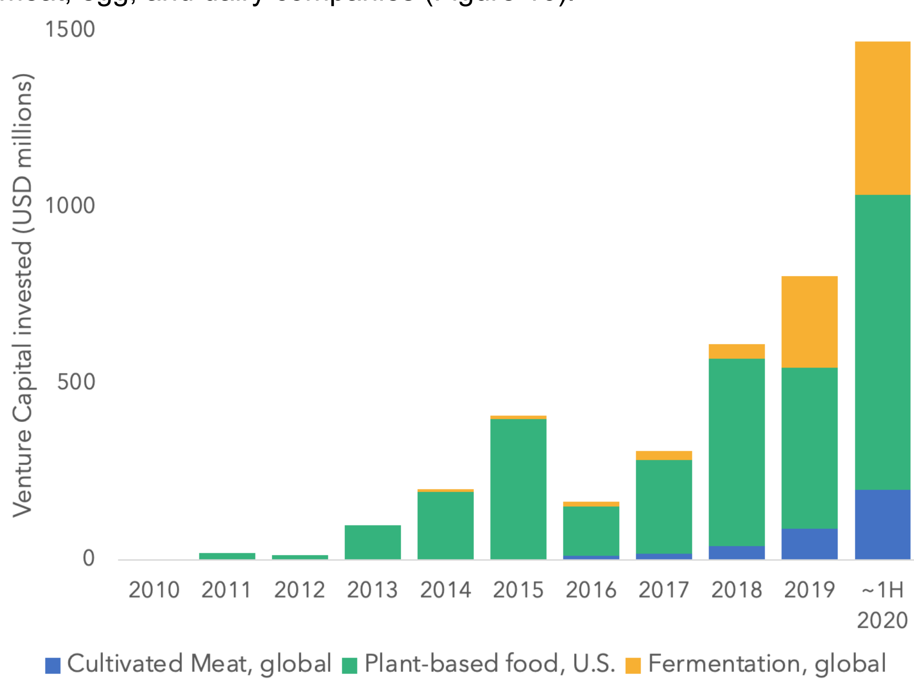

Figure 16. Venture capital investment trends in alternative proteins from 2010 to July 2020.

Exciting fermentation techniques, especially precision fermentation, will offer many future avenues for creating believable and desirable alternative foods. Useful alternative dairy products can be produced, for example, using PF technologies which companies such as Perfect Day have capitalized on. There is still plenty of room for entry, however, as not one company currently dominates the sector.

Coming up with an innovative food product is quite feasible, given the large variety of food options and techniques available. Importantly, the quality of the product is paramount for success. Customers need to not only be satisfied with a meat-replacement, but they need to crave it. Mouthfeel and texture play a large role in achieving this, so optimizing these parameters to better mimic meat will increase customer satisfaction and product success. Taste is also an interesting place for innovation, especially through techniques such as PF.

Technological Advancements

Though many of these technologies are well-developed, there is still plenty of room for improvement in many areas. Various opportunities in plant-based, fermented, and cultivated alternatives are listed below. Importantly, these opportunities are non-exhaustive, as there is much room for innovation in these relatively nascent fields.

Opportunities in plant-based alternatives:

1. Genetic engineering to improve the growth of raw-materials (plants) as protein sources. There is an extensive precedent for genetic engineering within the world of food. The potential to optimize the plants used in plant-based protein alternatives (e.g. increase amount of protein, increase yield, etc.) will help further alleviate resource strain and potentially lower prices for existing products.

2. Identifying and predicting the best possible plant-species for use (modeling project). The Earth's flora and fauna are vastly under-explored, which means there may be millions of possible plant species that could be utilized for protein alternatives. The current process to test if a plant is suitable for alternative protein production is lab-intensive, expensive, and time consuming. A model may offer quick and cheap insights into further plant alternatives to explore.

3. Utilizing all functional components of plants for production. Currently plants are used solely as a protein component for production of plant-based meats, while other critical ingredients (e.g. fats) are added from other sources. There may be ways to derive more ingredients from the plants themselves by exploring fractionation (breaking down a plant into its component parts).

4. Achieving optimal mouthfeel and texture to better mimic meat and increase customer satisfaction. Currently *extrusion* is the most widely used method to mimic texture, however it is underexplored for plant-use and warrants further investigation, as do any number of other novel techniques that may ultimately provide a texture closer to that of real meat.

Opportunities in fermentation (See Figure A2 for a graphical representation):

1. Target selection and design – applies only to PF. Molecule(s) of interest (e.g. a protein, flavor compound, etc.) are referred to as the target[4]. Ideal targets may originate in species that are extraordinarily rare, difficult to harvest, expensive, or otherwise inaccessible or impractical; targets are furthermore not limited to those found in nature: Novel variants can be engineered. There are many opportunities to select new targets or come up with novel compounds using genetic engineering and PF.

2. Strain development. While it accounts for a significant fraction of research in the fermentation sector, immense development is still possible. High-throughput methods of strain selection, adaptation, screening, and engineering enable innovators to iterate new strains with greater speed and precision. While some of the work in this sector will involve biotechnological tools (e.g. genetic engineering), vast progress remains to be made through simple adaptation and breeding strategies powered by advanced genomic insights. For decades, the fermentation sector has relied on a small number of well-established staple species – novel hosts may outperform incumbents, and will be paramount to research further.

3. Feedstock optimization. Feedstocks are the major cost driver for most fermentation processes. Thus, a great deal of optimization is possible in engineering industrial-scale production schemes to use side streams from other industries. There is enormous potential to convert waste products or agro-industrial byproducts into high-quality protein biomass, which presents gains for both economic viability and sustainability.

4. Bioprocess Design. For decades, microbial fermentation has operated at massive scales, with individual cultivation tanks as large as hundreds of thousands of liters. However, the scale, cost sensitivity, and sustainability considerations associated with alternative protein applications may warrant approaches distinct from classical stirred-tank bioreactors, inviting innovation for novel bioprocess and bioreactor designs. Research into retrofitting existing manufacturing facilities and equipment to suit the needs of alternative protein applications is also a key area of opportunity.

Opportunities in cultivated meats (See Figure A3 for a further list):

1. Finding and supplying a suitable substitute for Fetal Bovine Serum (FBS) as a growth-factor necessary for cell replication. FBS is a blood-based serum taken from the hearts of fetal cows that is currently used as a growth-factor for cell replication to create cultivated meats. It is currently sourced as a byproduct from the cattle industry, when pregnant cows are slaughtered, which brings into question the ethical nature of this

[4] A target represents a specific molecule or mixture of molecules being produced via precision fermentation. This can be any molecule or compound that is producible through a biological pathway. Examples include: proteins, lipids, flavor compounds, fragrances, enzymes, growth factors, pigments, vitamins, or other classes of molecules.

input. The price of the serum is extremely high and variable, so finding a sustainable and ethical replacement is paramount for providing low-priced meat, scaling-up capabilities, and positive customer reception.

2. Establishing a supply of “immortal” cell lines to reduce reliance upon cell extraction from living organisms. Currently stem cells are painlessly harvested via biopsy from animals put under general anesthesia. When isolated and put into an appropriate environment the cells will proliferate and start to form target cell mass (blood, muscle, fat). However, there is a limit to cell replication--overcoming this limit and creating a “cell bank” will be important for lowering the cost of cultivated meat and increasing accessibility.

3. Ensuring cell differentiation into preferred tissue types at scale. Differentiation into preferred tissue types (blood, muscle, fat) at scale has proven to be a challenge as compared to the much smaller lab-setting. Optimizing cell media and growth factors will be an important consideration to overcome this barrier to scaling-up.

4. Optimization of the design of sensors and equipment for facilities to ensure quality and efficiency for large-scale meat production. Because cultivated meat is still in its infancy and not yet available on the market, there is ample opportunity for innovation and improvement when it comes to scaling up production. There are many technological devices necessary for the safe production of cultivated meat, which can be improved, invented, and ultimately marketed to existing distribution companies.

RISKS & CONSIDERATIONS

As RethinkX writes: “The disruption of food and agriculture is inevitable – modern products will be cheaper and superior in every conceivable way – but policymakers, investors, businesses, and civil society as a whole have the power to slow down or speed up their adoption.” While the future of the food landscape is indeed promising, there are still a number of potential drawbacks to consider within the space, aligned with what RethinkX denotes.

Price Parity

An immediate concern is that of price parity. Current alternatives are more costly than their traditional counterparts. Products currently available on the market, specifically plant-based alternatives, require consumers to pay a premium. The Impossible Whopper™ sold at Burger King, for example, is priced on average at US$5.19 as compared to US$4.19 for a normal Whopper. While this is a barrier for some, many consumers still seem willing to pay a premium price due to positive environmental, ethical, and health implications.

Product prices will furthermore continue to decrease as inputs and supply chains are refined, and technological innovations streamline the production process and allow for scale-up. Certain technologies continue to become increasingly cost-effective, e.g. precision fermentation, which has substantially reduced costs over time. The same is true for cell-based technologies. The first cultivated burger created in 2013, for example, cost around US$2.65 mn/kg. It is estimated that the cost will decrease, however, to US$10/kg between 2023-2025, with some companies such as Future Meat hoping to price their cultivated beef below that milestone as early as 2022. Eventually, such technologies will be substantially less expensive than traditional methods, which will push forward food industry disruption (Figure 17).

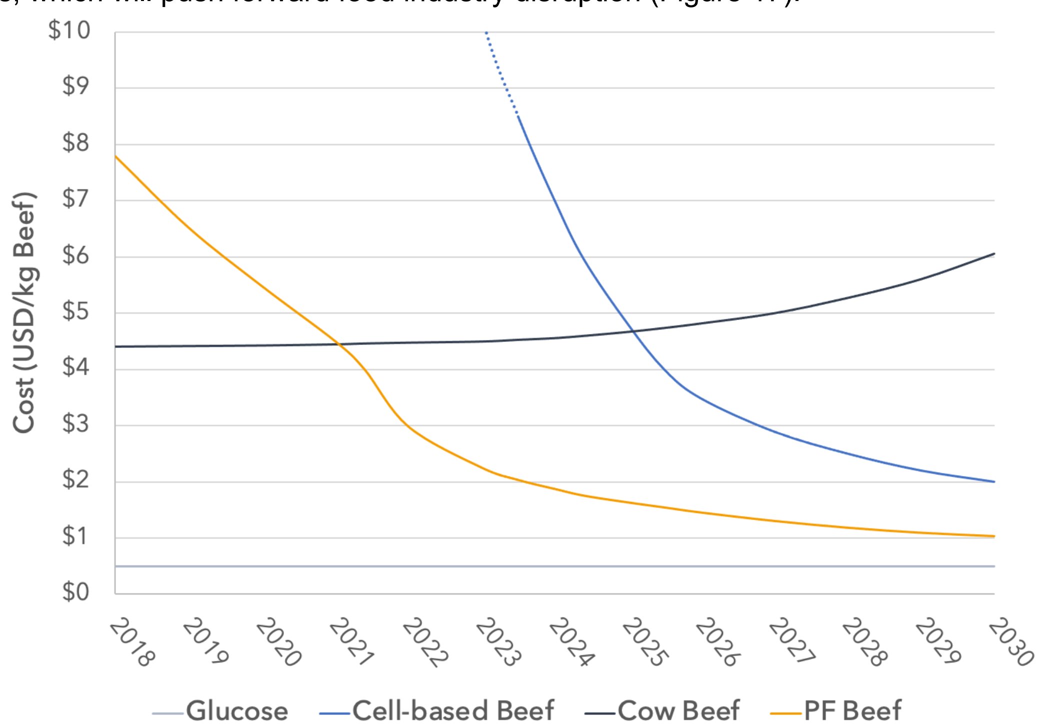

Figure 17. Cost of PF-enabled beef and Cell-based beef over time in USD/kg.

Government Regulation

Government acceptance of alternative foods is paramount for the industry to succeed. Regulation will play an important role in pricing, access and consumer acceptance of such alternatives. Consumers are ever more conscious about what is in their food, so if an alternative or ingredient is not shown to be safe by national standards, they will be less likely to adopt it. Impossible Foods, for example, has an important component of their alt protein products called "heme" which they derive from soy leghemoglobin. The FDA classifies the ingredient as "generally recognized as safe" (GRAS), rather than blanketly approving the substance, which has had a palpable impact on consumer perception of the ingredient. No one wants to consume something that may have unknown adverse health effects.

Cultivated meats in particular will require a new framework. Due to the new technologies, governments need to assess safety of consumption and create a regulatory framework for creating, distributing, and labeling products. In the U.S., for example, some states have passed laws banning the use of the term "meat" in labeling such products, which would have negative consequences on its adoption. The U.S. Department of Agriculture (USDA) and FDA have now come up with a framework that provides a transparent path to market – while the issue of labeling is still outstanding, an approval by the USDA to use terms like "cell-based meat," "slaughter-free meat" or any other labeling will override those states' rulings. These regulatory kinks are not just contained to the U.S. – there have been regulatory questions in E.U. and other global entities. Singapore recently (Dec 2020) approved the sale of Eat Just's cell-cultured chicken, becoming the first country in the world to approve a cultivated meat.

Governments ultimately have the power to either promote or discourage growth in this sector. How governments classify specific ingredients and define alternatives such as cultivated meats in general will have a significant effect on consumer adoption. Important to note is there are no geographical barriers to the food alternatives industry, so if any governments fail to support the emerging food disruption it will be to their detriment, as other major powers will "capture the health, wealth, and jobs that accrue," as RethinkX posits. Policymakers must therefore start planning for modern food disruption in order to capture all of its many benefits.

Consumer Adoption

There is some cause for concern for how consumers will perceive food alternatives and whether or not they will actually buy and consume such products. To some, emerging technologies around food is exciting and shows a world of promise, especially for those ascribing to alternative diets (e.g. vegan, flexitarian). Consumers have become increasingly educated about what they put into their bodies, and many have a desire to consume what they perceive to be "natural." Strong pushes for "organic" and "GMO-free" foods signify this nature-based mindset. While the technology and science behind the alternatives is sound and safe, many consumers feel uneasy about consuming food that isn't sourced in a natural way.

Furthermore, "disgust" has been shown to be the largest predictor of acceptance by U.S. consumers. Humans have evolved to be able to perceive minute differences in the taste of our food in order to know that what we are consuming is safe (i.e. that our food is not spoiled and will not harm or poison us). Because of this, our palettes are quite sophisticated and any taste, texture, or sensory deviation from what we consider to be normal will stick out to us. Our food substitutes must therefore be nearly indistinguishable from the original, especially in the case of cultivated meats, or consumer adoption will be scant.

Despite these concerns, consumer education may actually work in alternative's favor. Many individuals are increasingly aware of the adverse environmental effects of traditional food practices, and sensitivity to animal cruelty and health implications continues to grow. Business Insider dubbed 2019 the "Year of the Vegan," and for good reason. As consumers become more educated, many become increasingly focused on substantially decreasing or striking meat entirely from their diets. The number of individuals who subscribe to vegan, vegetarian, and flexitarian diets continues to increase.

Furthermore, studies have shown a widespread willingness to try and regularly adopt alternatives, especially in non-Western countries. A recent study in Frontiers in Sustainable Food Systems explored consumer acceptance of plant-based and cultivated meats across three major countries: the U.S., China, and India. The study highlights that there is a "significantly higher likelihood of urban, well-educated and high income consumers in India and China purchasing clean meat and plant-based meat compared to consumers in the USA" (Byrant et al., 2019).

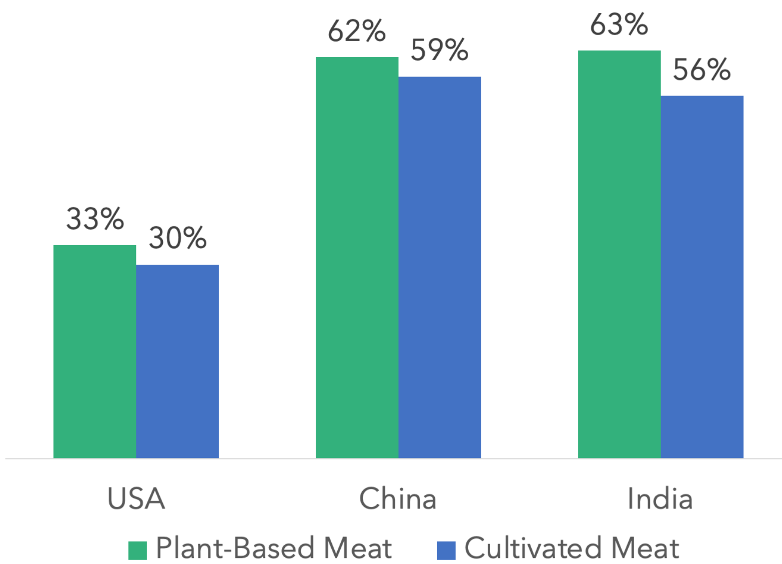

Figure 18. Percentage of consumers that are "very or extremely likely to purchase plant-based or cultivated meat on a regular basis"; n = 3,030 (Bryant, et al., 2019).

It was shown that "disgust" was the highest predictor of acceptance, but that was a quality unique to the U.S. The study further elucidates how most consumer research has been conducted disproportionately in Western countries, which ignores a significant consumer base and leaving emerging markets unexplored. Ultimately it is clear that strong marketing and consumer educational efforts will be necessary across the globe, in order to prove to consumers the safety and importance of the new food revolution.

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APPENDIX A. Supplementary Figures.

Figure A1. Plant cultivation versus meat cultivation schematic (taken from GFI).

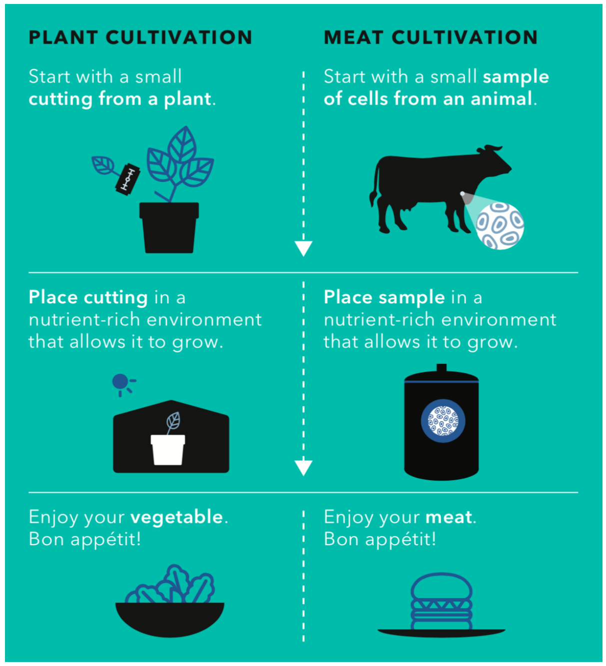

Figure A2. Opportunities for technology development across all aspects of the fermentation value chain (taken from GFI).

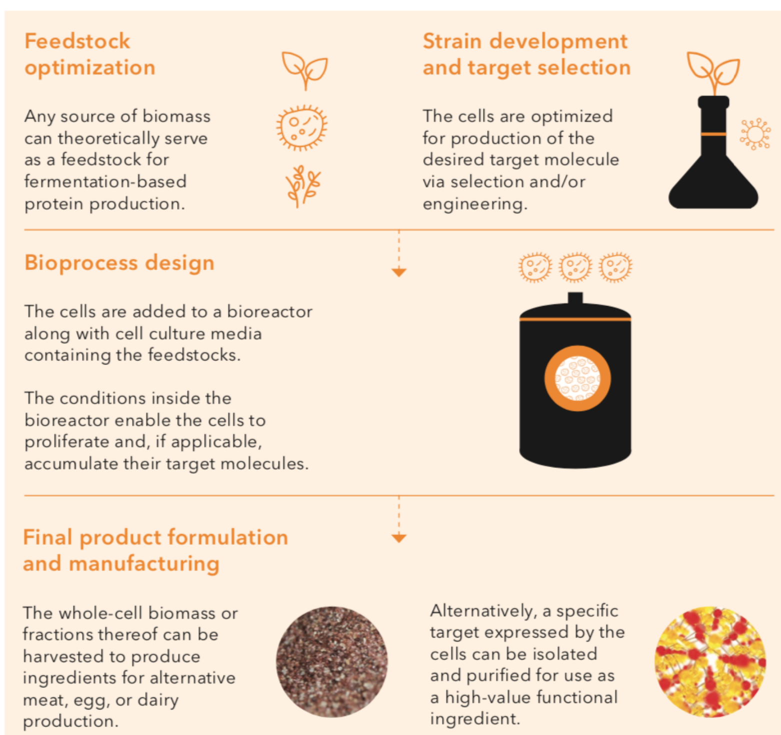

Figure A3. Example Value-Chain Points of Entry for Cultivated Meats (taken from GFI).

Upstream/Production

Cell Line Development
- Novel/exotic cell line isolation and biobanking
- Automated image analysis for cell screening
- Footprint-free immortalization
- Genetic engineering

Cell Culture Media
- Microfluidics
- Growth factor engineering
- Small molecule screening
- Ingredient discovery software
- Fermentation

Scaffolding
- Biopolymer hydrogels and nanotubes
- 3-D printing
- Photopolymerization
- Self-directed architecture

Bioreactors/Cultivators
- IoT sensors for adaptive control
- Media recycling and filtration
- Continuous bioprocessing
- Workflow automation

Downstream/Collateral

Production
- Cultivated-plant-based hybrids
- Co-manufacturing
- White label
- Facility design and construction
- Food product development

Sales and Distribution
- Brokerage
- International expansion
- Branding and marketing
- Local cultural expertise

Supply Chain
- Efficient global sourcing
- Quality assurance
- Packaging

Other
- Safety certifications
- GRAS ingredient approval
- Production side stream utilization
- Business and legal services
- Technology transfer

Table A1. Top 10 Plant-Based Meat Brands by U.S. Retail* Sales, 2019 (GFI).

Company	Parent Company	Location	Founded
Beyond Meat	N/A	El Segundo, CA	2009
Boca	The Kraft Heinz Company	Madison, WI	1993
Dr. Praeger's	N/A	Elmwood Park, NJ	1992
Field Roast	Maple Leaf Foods	Seattle, WA	1997
Gardein	Conagra	Richmond, BC	2003
Lightlife	Maple Leaf Foods	Turners Falls, MA	1979
MorningStar Farms	Kellogg's	Battle Creek, MI	1975
Quorn	Monde Nissan	Stokesley, UK	1985
Sweet Earth	Nestlé	Moss Landing, CA	2011
Tofurkey	N/A	Hood River, OR	1980

*Does not include foodservice, so Impossible Foods is excluded as of 2019, though they were a leading plant-based meat brand in foodservice. Impossible Foods is now retail-available.

Table A2. Top 10 Plant-Based Milk Brands by U.S. Retail Dollar Sales, 2019 (GFI)

Company	**Parent Company**	**Location**	**Founded**	**Product Base**
Blue Diamond	N/A	Sacramento, CA	1910	Almond
Califia Farms	N/A	Los Angeles, CA	2010	Almond, oat
Dream	Hain Celestial	St Louis, MO	1971	Almond, coconut
Good Karma	Dean Foods	Boulder, CO	1996	Flaxseed
Oatly	Privately Owned	Malmö, Sweden	1994	Oat
Planet Oat	HP Hood LLC	Lynnfield, MA	2018	Oat
Pacific Foods	Campbell Soup Co.	Tualatin, OR	1987	Hazelnut, Cashew
Ripple	N/A	Emeryville, CA	2015	Pea
Silk	Danone	Broomfield, CO	1978	Almond, oat
So Delicious	Danone	Broomfield, CO	1987	Almond, cashew

Table A3. Companies focused on fermentation for animal-free meat, eggs, and dairy, mid-2020 (GFI).

Company	Description	Location	Founded	Investment	Tech
3F Bio	Mycoprotein production process for meat alts and protein ingredients	Glasgow, Scotland, UK	2015	$9.22 Mn (Series A)	Biomass
Afineur	Fermentation-derived protein for plant-based foods	New York, NY, USA	2014	$0.22 Mn (accelerator/ incubator)	Traditional, biomass
Air Protein	Alternative meat (chicken, beef, pork) and seafood transformed from CO_2	Berkeley, CA, USA	2019	N/A	Biomass
Algama	Platform for microalgae-based foods and ingredients (including egg, seafood, meat, and dairy replacements)	Paris, France	2016	$9.56 Mn (Series A)	Biomass
Atlast Food Co	Whole-cut mycelium-based meats (starting with bacon)	Green Island, NY, USA	2019	$7 Mn (Seed)	Biomass
Bond Pet Foods	Microbially produced animal proteins for pet food	Boulder, CO, USA	2015	$1.2 Mn (Seed)	PF

BTFRY	Prototyping for mycelium use in plant-based snacks, supplements, and meat alternatives	Chicago, IL, USA	2018	N/A	Biomass
Change Foods	Proteins and fats for dairy (starting with cheese)	San Francisco, CA, USA	2019	N/A	PF
Circe	Fermentation of dairy triglycerides and synthetic polymers (spinout of Wyss translation program)	Boston, MA, USA	2020	N/A	PF
Clara Foods	Egg proteins through fermentation	San Francisco, CA, USA	2014	$56.80 Mn (Series B)	PF
Cultivated	Alternatives to dairy products through microbial fermentation	Lausanne, Switzerland	2020	N/A	PF
Final Foods	Whey proteins for cheese produced by yeast in open source bioreactor	Santa Clara, CA, USA	2020	N/A	PF
Foods Myco Mizoram	Mycelium-derived meat	Aizawl, India	2019	N/A	Biomass
Fumi Ingredients	Egg replacement ingredient through microbial fermentation	Wageningen , Netherlands	2019	$0.60 Mn (Seed)	PF
Fybraworks Foods	Mycelium as an expression platform for animal muscle proteins for meat alternatives	Minneapolis, MN, USA	2020	N/A	PF
Harmony	Infant formula using human milk proteins procured via fermentation	Boston, MA, USA	2020	N/A	PF
Helaina	Infant formula using human milk proteins produced via fermentation	New York, NY, USA	2020	N/A	PF
Imagindairy Ltd.	Development of milk proteins with AI platform and fermentation	Israel	2020	$850,000	PF
Kernel Mycofood	Decentralized production of mycoprotein	Buenos Aires, Argentina	2019	N/A	Biomass
Kinoko-Tech	Mycelium-derived meat	Rehovot,	2019	N/A	Biomass

	producer	Israel			
LegenDairy Foods	Milk proteins for dairy products using microbes	Berlin, Germany	2019	$4.43 Mn (Seed)	PF
Meati (formerly Emergy Foods)	Whole-muscle meats made from mycelium, including steak, chicken, and fish	Boulder, CO, USA	2016	$7.17 Mn (Seed)	Biomass
Mediterranean Food Lab	Novel methods inspired by traditional fermentation technologies to produce plant-based products and improve the sensory qualities of a wide range of plant-based meats and other foods	Tel Aviv, Israel	2019	<$500,000 (Seed)	Traditional
More Foods	Yeast-based meats	Tel Aviv, Israel	2019	N/A	Biomass
Motif FoodWorks	Functional Ingredients, ingredient systems, and whole formulations for plant-based foods	Boston, MA, USA	2018	$117.50 Mn (Series A)	PF
Mushlabs	Mycelium-based ingredients for meat alternatives	Berlin, Germany	2018	Undisclosed (Seed)	Biomass
Mycorena	Industrial side streams into fungi-based protein for food applications (e.g. Swedish meatballs)	Gothenburg, Sweden	2017	$1.78 Mn (Seed)	Biomass
MycoTechnology	Fungi-based bitter blocker ingredient and protein	Aurora, CO, USA	2013	$120.67 Mn (Series D)	Traditional
Nature's Fynd	Edible protein through cultivation of extremophile organisms through liquid air interface fermentation	Chicago, IL, USA	2014	$113 Mn (Series B)	Biomass
New Culture	Casin for cheese production (starting with mozzarella)	San Francisco, CA, USA	2018	$3.70 Mn (Seed)	PF
Nourish Ingredients	Fermentation-derived fats for meat, dairy, and fish alternatives	Brisbane, Australia	2019	N/A	PF
novacca	Milk proteins using fermentation platform	Nivå, Denmark	2018	N/A	PF
Perfect DAY	Milk proteins using	Berkeley,	2014	$360 Mn	PF

	fermentation platform	CA, USA		(Series C)	
PLANETARIAN S	Fermentation of plant-based meats from sunflower cakes to improve functionality	Palo Alto, CA, USA	2017	$0.85 Mn (Seed)	Traditional
Prime Roots	Meat analogs made from mycoprotein	San Francisco, CA, USA	2017	$4.50 Mn (Seed)	Traditional
Provenance Bio	Synbio tools to create animal proteins (e.g. collagen for cultivated meat)	San Francisco, CA, USA	2016	Undisclosed (Seed)	PF
Pura	Mycoprotein production and fermentation to enhance plant-based foods	Inarzo, Italy	2019	N/A	Biomass
Quorn	Pioneering mycoprotein meat alternatives	Stokesley, English, UK	1985	Undisclosed (acquisition by Monde Nissin)	Biomass
Remilk	Fermentation-derived dairy molecules	Tel Aviv, Israel	2019	Undisclosed (Seed)	PF
Solar Foods	Electrolysis-enabled novel protein under Solein brand for food ingredients, plant-based meat alternatives, and cultivated meat	Helsinki, Finland	2017	$2.46 Mn (Seed)	Biomass
Sophie's BioNutrients	Micro to create proteins for plant-based meat and dairy	Singapore	2013	N/A	Biomass
The Protein Brewery	Fungi-based protein to replace meat under the Fermotein brand and fungi-produced egg proteins	Breda, Netherlands	2019	Undisclosed (Seed)	Biomass
Triton Algae Innovations	Heme and other meat-like compounds from microalgae for plant-based meat applications	San Diego, CA, USA	2013	$5 Mn (Seed)	PF
Wild Earth	Fermentation-derived pet food	Berkley, CA, USA	2019	$4.55 Mn (Seed)	Biomass

Table A4. Current Competitive Landscape for the Cultivated Meat Industry as of 2019 (taken from GFI).

Company	Area of Focus	Location	Founded	Last-Stage Funding
Agulos Biotech	Cell culture media	Lake Mills, WI, USA	2017	N/A
Alepha Farms	Meat production (beef)	Rehovot, Israel	2016	$14.4 Mn (Series A)
Alife Foods	Meat production (undisclosed)	Leipzig, Sachsen, Germany	2019	N/A
Appleton Meats	Meat production (undisclosed)	Vancouver, BC, Canada	2016	N/A
Artemy Foods	Meat production (undisclosed)	San Francisco, CA, USA	2019	N/A
ArtMeat	Meat producer (horse, sturgeon)	Kazan, Russia	2019	N/A
Avant Meats	Seafood production (fish maw)	Hong Kong, China	2018	Undisclosed (Seed)
Back of the Yards Algae Sciences	Cell culture media, meat production (various), part of a larger business of algae innovation	Chicago, IL, USA	2018	N/A
Balletic Foods	Meat production (undisclosed)	San Francisco, CA, USA	2017	Undisclosed (Seed)
Because Animals	Meat production (mouse, pet food)	Philadelphia, PA, USA	2016	$2.50 Mn (Seed)
Biftek	Cell culture media, meat production (beef)	Gölbaşı, Turkey	2018	N/A
Bio Tech Foods	Meat production (undisclosed)	San Sebastián, Spain	2017	$2.77 Mn (Series A)
BioFood Systems	Meat production (beef)	Hod Hasharon, Israel	2018	Undisclosed (Seed)
Biomimetic Solutions	Scaffolding (nanomaterials), part of a larger tissue engineering business	London, United Kingdom / Nova Lima, Brazil	2017	$50,000 (Seed)
BlueNalu	Seafood production	San Diego, CA,	2017	$24.5 Mn (Series A)**

	(yellowtail tuna, salmon)	USA		
Cell Ag Tech	Seafood production (undisclosed)	Toronto, ON, Canada	2018	N/A
Cell Farm Food Tech	Meat production (undisclosed), bovine stem cell provider	Buenos Aires, Argentina	2019	$200,000 (Seed)
Cellular Agriculture Ltd.	Meat production (pork), bioreactors (hollow fiber)	Carmarthenshire, United Kingdom	2016	N/A
CellulaREvolution	Bioreactors (continuous production)	Newcastle, United Kingdom	2019	N/A
ClearMeat	Meat production (chicken)	Delhi, India	2018	Undisclosed (Seed)
Cubiq Foods	Meat production (chicken fat	Barcelona, Spain	2018	$14 Mn (private equity)
Cultured Blood	Cell culture media, bioreactors	Eindhoven, Netherlands	2019	N/A
Excell (Atlast Food Co.)	Scaffolding (mycelium cell culture kit)	Green Island, NY, USA	2019	N/A
Finless Foods	Seafood production (bluefin tuna)	San Francisco, CA, USA	2016	$3.75 Mn (Series A)
Fork & Goode	Meat production (undisclosed)	New York, NY, USA	2018	$3.54 Mn (Seed)
Future Fields	Cell culture media	Edmonton, AB, Canada	2017	N/A
Future Meat Technologies	Meat production (chicken, lamb, beef)	Jerusalem, Israel	2017	$16.6 Mn (Series A)
Gourmey	Meat production (foie gras)	Paris, France	2019	Undisclosed (Seed)
Heuros	Meat production (undisclosed)	Bisbane, Queensland, Australia	2017	Undisclosed (Seed)
HigherSteaks	Meat production (undisclosed)	London, United Kingdom	2018	$20,000 (Seed)
Innocent Meat	Meat production (undisclosed)	Rostock, Germany	2018	N/A
IntegriCulture	Meat production (chicken, foie gras), cell	Tokyo, Japan	2015	$2.73 Mn (Seed)

	culture media			
JUST	Meat production (chicken), included in larger business of plant-based egg production	San Francisco, CA, USA	2011	$372.53 Mn (Series E)
Lab Farm Foods	Meat production (beef)	New York, NY, USA	2019	N/A
Luyef Biotechnologies	Research and development (B2B licensing)	Santiago, Chile	2019	N/A
Matrix Meats	Scaffolding (3-D nanofibers)	Columbus, OH, USA	2019	Undisclosed (Seed)
Meatable	Meat production (pork, beef)	Leiden, Netherlands	2018	$12.5 Mn (Seed)
MeaTech	Meat production (beef, using 3-D printing)	Ness Ziona, Israel	2019	$1.99 Mn (Seed)
Memphis Meats	Meat production (beef, chicken, duck)	San Leandro, CA, USA	2015	$22 Mn (Series A)***
Mirai Foods AG	Meat production (undisclosed)	Zürich, Switzerland	2019	N/A
Mission Barns	Meat production (duck, chicken, pork)	Berkeley, CA, USA	2018	$3.49 Mn (Seed)
Mosa Meat	Meat production (beef)	Maastricht, Netherlands	2015	$9,09 Mn (Series A)
Multus Media	Cell culture media	London, United Kingdom	2019	N/A
Nanjing Zhouzi Future Food Technology Co.	Meat production (pork)	Nanjing, China	2019	N/A
New Age Meats	Meat production (pork)	San Francisco, CA, USA	2018	$950,000 (Seed)
Ospin Modular Bioprocessing	Bioreactors (automated systems), part of a larger biopress automation business	Berlin, Germany	2014	N/A
Peace of Meat	Meat producer (foie gras, fat)	Berlin, Germany	2019	$779,000 (Seed)
Planetary Foods	Seafood production	Berlin, Germany	2019	N/A

	(undisclosed)			
SiCell Bio Technologies	Cell culture media	Shanghai, China	2019	$250,000 (Seed)
Shiok Meats	Seafood production (shrimp, crab, lobster)	Singapore	2018	$5.11 Mn (Seed)
SuperMeat	Meat production (chicken)	Tel Aviv, Israel	2015	$4.22 Mn (Seed)
VOW Food	Meat production (kangaroo, other)	Sydney, NSW, Australia	2019	Undisclosed (Seed)
Wild Earth	Meat production (mouse for pet food), part of a larger business of fermentation	Berkeley, CA, USA	2017	$15.55 Mn (Series A)
Wild Type	Seafood production (salmon)	San Francisco, CA, USA	2017	$16 Mn (Series A)

**BlueNalu raised a $20 Mn Series A in Q3 of 2019, which Pitchbook records as closing in Q1 2020. This table includes the entirety of BlueNalu's Series A in 2019 statistics.

***Memphis Meats raised a $186 Mn Series B round in early 2020, bringing their total fundraising to more than $200 Mn

APPENDIX B. Key Terminology, Definitions, and Abbreviations.

Cellular Agriculture

The production of agricultural products from cell cultures. Products harvested from cultures are cellularly identical as those harvested from animals or plants, the only difference being how they were produced. Agricultural products are either *acellular* and *cellular*.

- *Acellular* products are made from organic molecules like proteins and fats and contain no cellular or living material (e.g. gelatin, vanillin, casein, omega-3 fatty acids). They can be made using microbes such as yeast or bacteria (Figure B1).
- *Cellular* products are made of living or once-living cells (e.g. meat, leather, fur, wood). Most cellular products exist in tissues, which can be made outside the body in a process called tissue engineering. Cells from a particular species and tissue type are assembled on a scaffold (to grow on) with serum (food for the cells to feed on while they grow) in an environment that promotes growth (Figure B2).

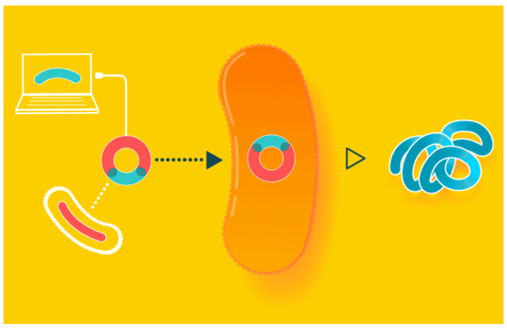

Figure B1. Acellular production.

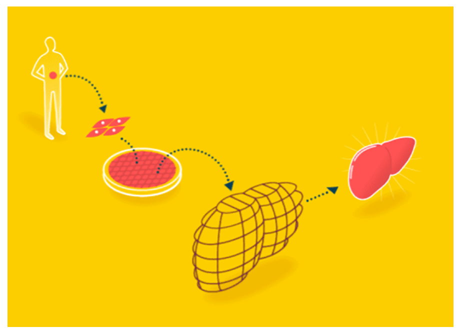

Figure B2. Cellular production.

Further Reading: [New Harvest]

Fermentation Tank

A piece of equipment also known as a **bioreactor** – a stainless steel cylindrical vessel, that facilitates various types of biochemical reactions by providing agitation, aeration, sterility, and regulation of other factors (e.g. temperature, pH, pressure, nutrient feeding) in a closed-system environment. Precision fermentation uses *fermentation tanks*, while cultivated or cell-based meat uses *bioreactors*.

Figure B3. Fermentation tanks.

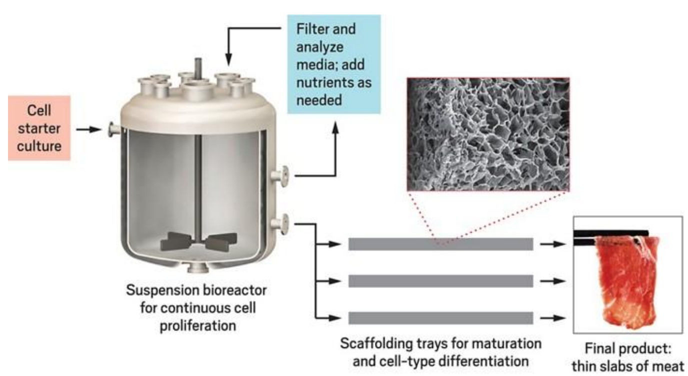

Figure B4. Bioreactor process.

Food-as-Software Model
A new model of food production and consumption that adopts certain principles of modern computing. Similar to software, food products are continually improved through multiple iterations as technology improves (in both cost and capability) and as food component databases grow. Food is thus designed using massive databases of molecules and tweaked for variations such as taste and texture based on consumer preferences or nutritional requirements. Integration with information technology means that improvement in production methods and/or ingredients can be downloaded and incorporated almost instantaneously, allowing production to be fully distributed and decentralized.

Microorganism
An organism that can only be seen with a microscope, also known as **microbes**. Many different types of organisms can be classified as microbes, including bacteria, archaea, fungi, protists, viruses, plants, or animals. A more specific and common example of a microbe is *yeast*, which is a fungus.

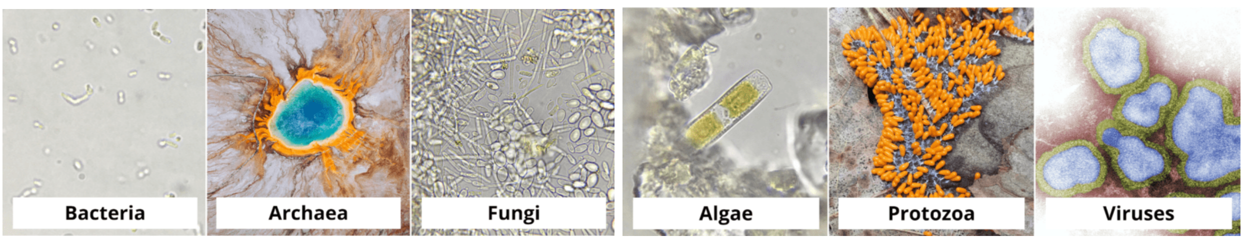

Figure B5. Different types of microbes.

Precision Agriculture
Agricultural activity that is characterized by a strong focus on high-resolution data collection via analysis and specific manipulations. It is distinct from **precision biology** and **precision fermentation** as it represents only an incremental improvement in the efficiency of industrial agriculture.

- *Examples include:*
    - Site-specific fertilizer (optimized for a certain location);
    - Pesticide application for crop farming;
    - Timed, detailed control of animal care and feeding

Precision Biology
The combination of modern information technologies with modern biotechnologies

- *Information technologies:* artificial intelligence (AI), machine learning (ML), cloud computing and storage
- *Modern biotechnologies*: genetic engineering, synthetic biology, metabolic engineering, systems biology, bioinformatics, computational biology

Precision Fermentation (PF)
Fermentation combined with **precision biology** – a process that allows us to program microorganisms (usually bacteria or yeasts) to produce almost any complex organic molecule.