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FUTURE FOOD SOURCES:
MARKET DEVELOPMENTS AND INTELLECTUAL PROPERTY LANDSCAPE

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1 EXECUTIVE SUMMARY

IP Pragmatics is a technology and IP commercialisation consultancy, with broad expertise across the Life Sciences, Human Health, Animal Health, Agritech, and Food & Nutrition. The intention of this white paper is to provide an overview of the market developments across the commercial and patent landscapes of what we are referring to as the Future Food Sources industry. The information in this report does not constitute legal advice and should not be interpreted as such.

For the purposes of this white paper the Future Food Sources industry has been segmented into three areas: Animal Product Replacements, Alternative Protein Sources and Future Farming Technologies. The academic, market and patent trends show that most market segments are at a relatively early stage but have been undergoing rapid growth and expansion over the last few years.

Within the *Animal Product Replacements* segment, the market for plant-based meat products in particular is booming. Over the last few years, there has been a step-change in plant-based meat technology as meat-eaters, as well as vegetarians and vegans, increasingly embrace meat substitutes as awareness of issues related to traditional livestock-reared meat, such as climate change and animal welfare, become ever more engrained in the public consciousness. Retailers are changing the way they merchandise plant-based meats, shelving them adjacent to conventional meat instead of in a separate vegetarian section, in the same way that moving plant-based milk from shelves to the fridge — beside conventional cow's milk – is what helped boost sales of nut, soy and oat milk products. With Beyond Meat – maker of the "bleeding" vegan burger – being valued at over $3 billion after a blockbuster initial public offering (IPO) in May 2019, some commentators believe we are only in the "second innings" of plant-based meats.

The *Alternative Protein Sources* market is being driven by largely similar forces as Animal Product Replacements. Insects and algae in particular have been parts of diets in Asia for many years, but it is only now that Western consumers are truly beginning to embrace these new products and drive technological innovation.

The number of agricultural technology start-ups has grown by more than 80% per year over the last few years. Large, well-connected companies and investors from outside the traditional agritech world are now becoming involved, in a reflection of the rapid expansion of the *Future Farming Technologies* industry.

As many of the future food and farming technologies discussed in this white paper are in development or yet to make the transition to mass production/roll out, the barriers and challenges are numerous, with all sectors/products facing a myriad of high costs from development to market launch. However, in most areas these costs are dropping quickly as technology improves and becomes more efficient. There are a number of other barriers related to consumer perception, regulation and technology readiness, among other factors, which are being addressed as development and commercialisation continues apace.

Overall, patenting of Animal Product Replacements and Alternative Protein Sources has been steady for a number of years, while Future Farming Technologies has been rising continuously. Traditionally, obtaining patent protection has been perceived as 'too slow' or too expensive, or simply not commercially sensible for the food and drink market, particularly for the fast-moving consumer goods sector, with some industry players opting for trade mark protection and confidential know-how instead. However, patents in these food technology fields, including the production method, are still considered to bring significant value to the companies operating in the industry. Despite China emerging as a leading country for patent protection across all three segments, these patent landscapes remain very diverse. A large proportion of patents are filed by commercial players with headquarters that are spread globally, particularly in the Alternative Protein Sources section where large food/nutrition and agriculture multinationals are the most prolific patent filing organisations, and which, from a commercial standpoint, continue to dominate the key markets of the USA and Europe.

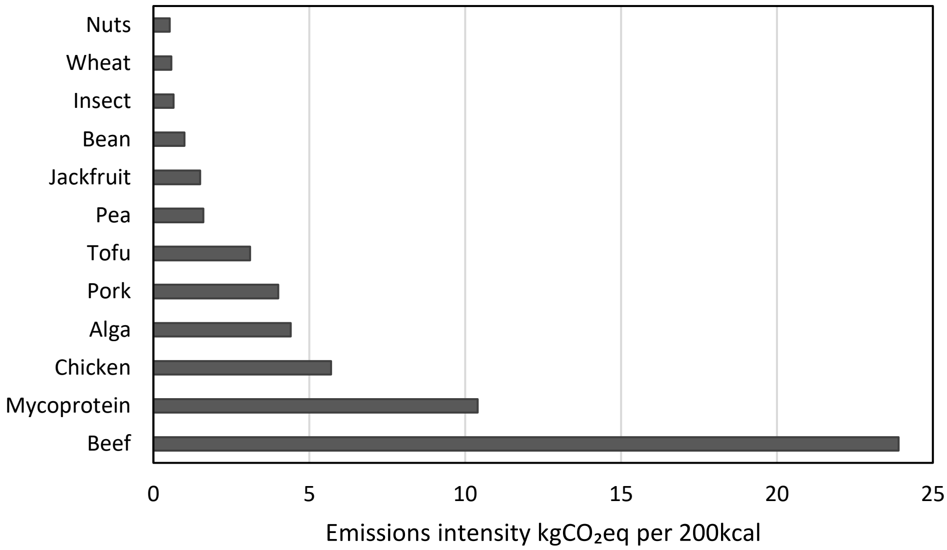
From our analysis of the broad patent searches, it is clear that all three sectors are characterised by continuous developments, in line with the fact that each has attracted notable attention from the media, consumers, academia and industry over recent years, and crucial innovations have emerged that will undoubtedly shape the farming and food industries in the future.

2 INTRODUCTION

Feeding a growing population in a sustainable, environmentally-friendly manner has become a major challenge that traditional agriculture cannot address. The growing and ageing global population, alongside increased incomes and urbanisation, is causing the demand for food, particularly protein-rich food, to significantly increase. Projections estimate that the world demand for animal-derived protein will double by 2050.[1]

A recent InterAcademy Partnership (IAP) report considers that, fundamentally, a radical, whole-scale, root-and-branch overhaul in farming and consumption, with less meat eating, is needed to avoid world hunger and climate catastrophe.

The global food system is responsible for a third of all greenhouse gas emissions. The global livestock industry in particular has come under increasing scrutiny in recent years due to the scale of its environmental, ethical, and human health impacts. Cattle, swine and poultry require large amounts of land, feed and water which cannot be sustainably maintained at a rate sufficient to meet future demands.[2]



Emissions intensities of different food types[3]

However, the livestock sector is one of the fastest growing parts of the agricultural economy. It contributes 40% of the global value of agricultural output and supports the livelihoods and food security of almost 1.3 billion people.[4] Furthermore, the average European eats 80kg of meat per year, while North Americans and Australians eat over 110kg per year. Many believe that the Western world has reached 'peak meat', but emerging economies are rapidly increasing their meat consumption and could soon catch up.

Addressing these urgent and multi-faceted problems in the world's food production system will require the global adoption of innovative, efficient crop and meat production technologies which

[1] Henchion *et. al.* (2017) *Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium*. Foods. **6**(7), 5

[2] Stephens *et. al.* (2018) *Bringing cultured meat to market: Technical, socio-political, and regulatory challenges in cellular agriculture*. Trends in Food Science & Technology, **78**, 155–166

[3] http://www3.weforum.org/docs/WEF_White_Paper_Alternative_Proteins.pdf

[4] http://www.fao.org/animal-production/en/

provide more resilient crops with higher yields, greater soil protection, better use of fertilisers, less use of pesticides and alternative sources of protein that use less antibiotics and have a lower impact on the environment. It will also require a shift in thinking across the governmental, commercial and consumer levels to support the adoption of novel farming technologies and a reduction in animal product consumption. Dietary choices control food availability and natural resource demands. In particular, reducing or avoiding consumption of low-production efficiency animal-based products can spare resources that can then yield more high-production efficiency food.[5]

This shift has already begun. The food and agricultural technology scenes are booming. Start-ups and spin-outs are developing innovative solutions to meet global food supply chain challenges. Global food companies are looking for better, sustainable technology solutions to stay ahead of competition and investors are seeking new, exciting opportunities in the food tech space.[6] From 3D printed foods[7], to insect protein, to new genetically modified plants and animals[8], various technologies are emerging from public and private sector research activities.

In assessing the commercial and intellectual property (IP) landscape for this technology area, this white paper focuses on three key areas of what we refer to as the Future Food Sources industry: Animal Product Replacements, Alternative Protein Sources and Future Farming Technologies. Where appropriate these sections of the report have been colour-coded blue, red and green, respectively.

Animal Product Replacements refer mainly to replacements for meat, as well as fish, dairy, eggs and other animal-derived products. The markets for plant-based milk and meat substitutes, such as mycoprotein, are already established and well-known. This white paper instead focuses on novel technologies which aim to more authentically replicate the taste and texture of animal products. Ultimately, products in this space aim to marry a consumer desire to eat meat with the drive to ensure global food security, a nutritious diet, and a reduction of the environmental burden of food production. This industry is attracting huge amounts of industry and consumer interest, with multi-million-dollar deals being announced on a regular basis. The two main product categories are cultured (a.k.a. clean, lab-grown, *in-vitro* or synthetic) meat and plant-based meat.

The former refers to the use of tissue engineering and fermentation principles to grow meat and other animal products in bioreactors, and was kick-started in the mind of consumers when the world's first lab-grown burger was produced in 2013.[9] However, for the time being, the cost, scale-up, public neophobia, social perception and regulatory guidelines surrounding cultured meat are limiting its commercial viability.

By contrast, sales of plant-based meats (such as Beyond Meat's 'bleeding burger', made with pea protein, coconut oil, potato starch and beetroot juice to ooze or "bleed" a meaty red hue) exceeded $760 million in 2018.[10] The actual and potential benefits of cultured and plant-based meats are summarised in the table below (adapted from BCC Research).**[11]**

[5] Shepon *et. al.* (2016*) Energy and protein feed-to-food conversion efficiencies in the US and potential food security gains from dietary*. Environmental Research Letters, **11**, 10
[6] https://foodtechmatters.com/
[7] Kodama *et. al.* (2017*) Novel Soft Meals Developed by 3D Printing*, IntechOpen
[8] https://gizmodo.com/eight-futuristic-foods-youll-be-eating-in-30-years-1790570240
[9] https://www.bbc.co.uk/news/science-environment-23576143
[10] https://www.forbes.com/sites/jennysplitter/2018/12/18/plant-based-cultured-meats-turning-point/#14a446df20a7
[11] BCC Research (2019) *Synthetic (Cultured) Meat: Technologies and Global Markets*

Benefits of Cultured and Plant-Based Meat

Parameter	Description
Designer and healthy meat	Artificial meat can be customized by changing the composition of the culture medium, fatty acid and nutrients to make it healthy. For example, replacing harmful fats with healthy fats like omega-3 can prevent cardiovascular disease.
Animal welfare	Artificial meat does not involve animal slaughtering as it takes only a small sample of muscle cells from the donor animal.
Public support	Cultured meat has a strong support from animal rights (PETA), the scientific community and environmental communities in regards to ethical issues.
Fast production	Artificial meat takes only several weeks to culture and harvest
Reproduction in resources use, environment friendly	Artificial meat production reduces the emissions of greenhouse gases whilst also reducing the use of energy, land and water resources.
Vegan meat	People who are vegetarian due to moral and health issues can eat artificial meat as it is not associated with the slaughtering of animals.
Reforestation and wild life	Reduction in land use opens the prospect for land reforestation and restoration of endangered species.
Availability of exotic meat	As production of artificial meat requires only stem cells of the desired animal, cells from endangered animals or even samples of extinct animal cells could be used to produce exotic meats.
Alternative protein source	Increasing demand for other protein sources favours artificial meats.
Space missions and settlements	Controlled ecological life support systems provide fresh food to astronauts and also deal with waste, and provide oxygen and water.

Alternative Protein Sources are distinguished from Animal Product Replacements in this white paper by the fact that they do not aim to mimic existing animal products. But like Animal Product Replacements, Alternative Protein Sources have a lower impact on the environment and will likely play a major role in the future of food by replacing meat in diets across the world. Peas, soy, nuts and pulses are amongst the main alternative sources of proteins used in variety of applications from vegan burgers to protein powders. However, several less conventional sources of proteins are gaining popularity and have been in the spotlight over the last decade. In this white paper, these novel sources focus mainly on insects, algae and bacteria.

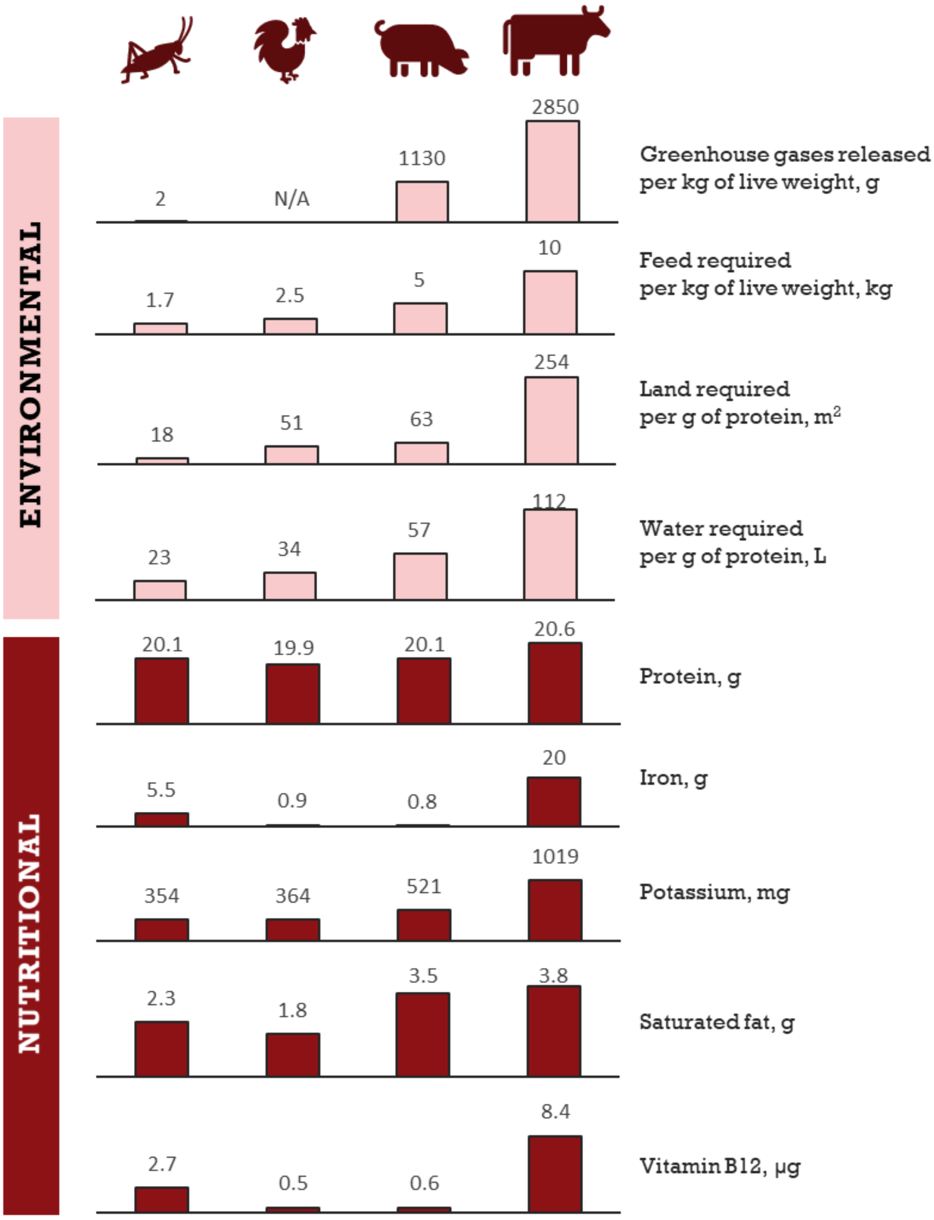
Insects and algae in particular have featured in some Asian diets for decades, but it is only now that Western consumers are truly beginning to embrace these new products. Indeed, Asia-Pacific is the biggest market for Alternative Protein Sources, while the key markets for the more expensive Animal Product Replacements are located in Europe and North America.

When comparing insects to conventionally farmed livestock such as cattle, swine and poultry, it is clear that invertebrates are superior in terms of sustainability, as shown in the Figure below. According to the United Nations' Food and Agriculture Organisation, a kilogram of crickets requires a fifth of the feed needed to produce a kilogram of beef, and mealworms require less than a tenth of the land needed for cattle to produce the same amount of protein.[12] The highly efficient feed-conversion rate (the capacity of an animal to convert food into body mass) of insects is the reason

[12] Van Huis *et al.* (2013) *Edible insects: future prospects for food and feed security*. FAO Forestry Paper 171, Food and Agriculture Organization of the United Nations

why insects require less food to produce the same amount of protein as livestock.[13] Only 23L of water is required to make 1g of insect protein, whilst it takes 112L to produce 1g of beef protein.[14]

Nutritional benefits are also evident from the fact that per 100g of edible mass, crickets contain as much protein as animal sources whilst having reduced levels of saturated fat and potassium[15] – factors that are thought to play a part in the health issues associated with over-consumption of red meat.[16]



Comparison of environmental impact and nutritional profile of insects with traditional livestock. Data from Bloomberg[17]

[13] Van Huis (2013) *Potential of Insects as Food and Feed in Assuring Food Security*. Annual Review of Entomology, **58**(1), 563-583

[14] Miglietta et. al. (2015) *Mealworms for Food: A Water Footprint Perspective*. Water, **7**(11), 6190-6203

[15] Payne et. al. (2015) *Are edible insects more or less 'healthy' than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over- and undernutrition*. Eur J Clin Nutr. **70**(3), 285-91

[16] World Economic Forum (2019) *Alternative Proteins*. Meat: the Future series

[17] https://bloomberg.org/graphics/2018-insects-as-food

In order to feed the current and projected global population, the world must produce 70% more food using less energy, fertiliser and pesticides. With available acreage estimated at just an additional 4%, it is not possible to simply plant more crops. A fourth agricultural revolution is needed; one with **Future Farming Technologies** at its heart.[18] It will need to look at both the demand and the value chain side of the food-scarcity equation, using technology to fundamentally re-engineer the value chain.

This has already begun – the number of agricultural technology start-ups have grown by more than 80% per year over the last few years and large, well-connected companies and investors from outside the traditional agritech world are becoming involved, in a reflection of the expansion of the industry. Future agriculture will include sophisticated technologies such as robots, aerial images, and temperature and moisture sensors, to name a few. These will make farms more sustainable, more proficient and safer. Emerging farming technology systems such as precision agriculture and indoor systems are moving beyond traditional greenhouse growing, attempting to replicate and modulate environmental conditions such as temperature, CO_2 levels and humidity. Crucially, the plethora of elements comprising what we are referring to as Future Farming Technologies are not mutually exclusive, but rather tend to be integrated and combined. Vertical farming, for instance can be located inside a container farm, and can use soil-based or non-soil-based systems (aeroponics, hydroponics or aquaponics). It can use LED technologies and crop sensors, along with Internet of Things (IoT) in order to integrate and analyse data for the farmer, and robotics and automation to improve efficiency.

Indeed, this wide crossover in scientific disciplines extends to other elements of Future Food Sources. Increased introduction of robotics and automation in insect farming, for instance, will reduce human intervention and minimise exposure to allergens and other risks.

This white paper aims to give an overview of Future Food Sources technologies through a combination of market research and patent landscaping, focusing on the future product developments and applications of technology in key industries. These key industries are also well-aligned with the areas of expertise of IP Pragmatics: Food & Nutrition and Agritech, and more broadly, Human Health and Animal Health. The white paper also incorporates details of key organisations, factors affecting the market, licensing, partnerships and collaborations.

[18] World Government Summit & Oliver Wyman (2018) *Agriculture 4.0: The Future of Farming Technology*

3 MARKET OVERVIEW

An overview of market sizes and developments for the three segments of the Future Food Sources industry is provided below. More detail for certain sections can be found in Appendix 1 and is noted where relevant in the main body of the text.

3.1 ANIMAL PRODUCT REPLACEMENTS

2018 was a big year for plant-based and cultured meats, with sales of the former growing over 23% to exceed $760 million.[10] This follows the upward trends of the already well-established plant-based milk and meat substitutes (e.g. tofu, mycoprotein, tempeh, seitan) markets, worth around $1.5 billion[19] and $5 billion[20] respectively. Of the $16 billion invested in plant-based protein companies over the last decade (including venture capital funding and acquisitions), $13 billion of this was invested in 2017 and 2018 alone.[21]

Though still dwarfed by the traditional meat market, 2019 is considered by some to be the start of a major shift towards plant-based and cultured meats as companies realise that potential customers are not only vegans and vegetarians: meat-eaters are also switching to meat alternatives as awareness of issues related to traditional livestock-reared meat, such as climate change and animal welfare, become ever more engrained in the public consciousness.

However, the competitive impact of cultured meat on traditional pork, beef and poultry demand is actually expected to be relatively low – future success of alternative proteins lies more with rising global protein demand rather than a battle for the existing market share of livestock and poultry protein.[22]

Companies in the nascent plant-based meat and cultured meat industries are developing increasingly realistic meat replacement products, as well as egg and dairy alternatives, and are expected to navigate new partnerships, new markets and an ever-evolving regulatory landscape. Existing players in the conventional meat industry are now moving into the plant-based meat space, with some even rebranding as 'protein companies.[10]

Cultured meat start-ups like **Memphis Meats** (USA) (which created the world's first-lab grown meatball in 2016[23]) have raised at least $22 million in investments from **Cargill, DFJ Venture Capital, Sergey Brin** (**Google**)**, Richard Branson**, **Tyson Foods** and others. Silicon Valley start-up **Impossible Foods**, maker of the plant-based Impossible Burger, has raised upwards of $750 million since 2011 from investors including **Bill Gates, Li Ka-shing, Temasek**, and **Khosla Ventures**.[19] Meanwhile, with Impossible Foods' main competitor, **Beyond Meat** (USA), being valued at over $3 billion after a blockbuster IPO in May 2019[24], some commentators believe we are only in the "second innings" of plant-based meats.[25]

In addition to plant-based and cultured meats, dairy and eggs, (which are discussed in more detail in the sections below), some other more niche innovations being developed in 2019 are listed

[19] Friends of the Earth (2018) *From Lab to Fork: Critical Questions on Laboratory-Created Animal Product Alternatives*
[20] Markets and Markets (2018) *Meat Substitutes Market - Global Forecast to 2023*
[21] https://agfundernews.com/new-report-16bn-invested-in-us-plant-based-protein-market-since-2009.html
[22] CoBANK AGB (2017) *Lab-grown Cultured Meat – A Long Road to Market Acceptance*
[23] https://metro.co.uk/2016/03/16/you-will-soon-be-able-to-eat-meatballs-and-burgers-without-killing-any-animals-5755398/
[24] http://fortune.com/2019/05/02/beyond-meat-ipo-stock-price/
[25] https://agfundernews.com/were-only-in-the-second-innings-of-plant-based-meats.html

below. These technologies are, by comparison to the above, still in a very early development stage and are therefore not discussed in any further detail in this white paper.

- Development of a proprietary recombinant protein production platform to produce animal-free gelatin (**Geltor**, USA)
- Using plants and fermentation to produce functional proteins like miraculin, a natural sweetener and taste modifier (**MiraculeX**, USA)
- Using microbial fermentation to increase the quality of coffee beans. The quality of the coffee is said to be superior to 'Kopi luwak' (or civet coffee), the most expensive coffee in the world which is fermented in the digestive tract of a small Indonesian viverrid, without exploiting animals (**Afineur**, USA)
- Designing a new set of enzymes that can efficiently convert saturated fats into unsaturated fats from most vegetable oils (**GEAEnzymes**, USA)
- Production of 'smart' cultivated fat from animal cells which enhances the flavour of low-fat vegetable or animal protein products, including cultivated meat (**CUBIQ Foods**, Spain)

Other technological innovations in the development of plant-based probiotics and nootropics is currently very niche and considered beyond the scope of this report.

3.1.1 CELLULAR AGRICULTURE

Summary

Cellular agriculture is the science or practice of farming animal products from cells rather than entire animals. This includes, but is not limited to, food animal products like meat, milk, and eggs, as well as leather, silk and rhinoceros horn. The science of cellular agriculture can be broken down into two main categories:[26]

- **Tissue engineering** (growing tissues or cells outside of animals): cell-based meat, cell-based seafood, wildlife products
- **Fermentation** (using microorganisms to obtain proteins found in animal products): dairy, eggs, gelatin, leather, silk

The most well-known cellular agriculture concept is cultured meat. On the molecular level, cultured meat is identical to meat taken from an animal, and it promises a safe and disease-free way to meet the world's increasing meat demand without involving animal sacrifices. At the same time, production of cultured meat drastically reduces greenhouse gas emissions and the use of land, water and antibiotics[27] compared to production of conventional meat, as outlined in the table below.

[26] https://www.cellag.org/cellag101/

[27] Gaydhane *et. al.* (2018) *Cultured meat: state of the art and future*, Biomanufacturing Reviews, 3:1

Issue	Conventional Meat	Cultured Meat
Greenhouse gas emissions	According to the UN Food and Agriculture Organization (FAO), animal agriculture is responsible for 14.5% of the world's total GHG emissions.[28] It is therefore as bad for the environment as the combined impact of every motor vehicle in the world. Methane, whose global warming potential is 25 times greater than that of carbon dioxide, makes up 44% of the animal industry's total emissions. Most of this methane is emitted by ruminants as a natural by-product of digestion.	According to Sentience Politics (Switzerland), predictive life cycle analysis estimates that cultured meat is expected to produce 78-96% less greenhouse gas emissions. Replacing animal agriculture is also expected to eradicate the requirement of manure disposal and management. With the help of close monitoring and high quality-controlled filtration systems, the problem of maintaining a large animal population can be eliminated.[29]
Resource inefficiency	Livestock farming consumes about 70% of the total arable land across the globe and 30% of the total land surface. Moreover, 15,000 L of water is needed to produce 1 kg of beef. Also, according to the report, cows convert less than 5% of their protein and energy intake into edible meat.	Cultured meat requires 99% lower land use and has the ability to reduce water consumption by 82– 96% than animal agriculture. However, a large amount of electricity is used to provide heat during culturing process. Overall, cultured meat processing is expected to be more efficient than animal agriculture considering the future meat consumption and production costs taken into account.[29]
Infectious disease transmission	According to Sentience Politics, 60% of all human known diseases and 75% of most damaging diseases are transmitted by animals. Most of the pathogens such as bovine spongiform encephalopathy (BSE) and influenzas (swine, avian, etc.) are transmitted through livestock. Thus, increasing demand for animals and animal products have increased the risk of zoonotic disease transmission.	As cultured meat is grown in a sterile environment, it is safe and can be preferred by consumers who are more worried about food safety. Further, as cultured meat is produced in strictly controlled and monitored environment, it will help in eliminating unhealthy fats and keep the product nutritionally fortified. This is expected to fulfil the demand for healthier foods and may also help in eradicating malnourished populations. Culturing can help in developing meat of rare animals, which can be of commercial interest and also help in eliminating the illegal market of exotic animals.[11]
Antibiotic resistance	During animal raising, lots of antibiotics are used to promote tissue growth in animals and as a cost-effective measure to cope with disease transmission. However, this process has to consider antibiotic contamination of waterways and is a cause of antimicrobial-resistant pathogen strains across the globe. According to the WHO, the rise in antimicrobial resistance is the biggest threat to human health across the globe.	No antibiotic is used during the process.
Suffering in factory farms and legal protection	To meet the increasing demand and maintain the overall production cost effectively, animal wellbeing in factory farms are reduced commonly to minimum level or sometimes ignored. There are guidelines from the United Nations and European Union for animal welfare. However, actual implementation at national level are commonly weak or enforcement is poor.	No animals are farmed or slaughtered. Cells are collected with a biopsy needle, by drawing some amount of stem cells. Considering the long-term risks, this process is negligible in terms of harm compared to current meat industry conditions. One cell can multiply and produce vast number of cells and can be repeated multiple times to produce synthetic meat.

[28] Food and Agriculture Organization of the United Nations (2013) *Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities.*

[29] Sentience Politics (2016) *Cultured Meat – A pragmatic solution to the problems posed by industrial animal farming*

The market is estimated by BCC Research to be worth nearly $15.7 million and is anticipated to generate $19.8 million by 2027. The nuggets segment is expected to be valued at almost $3.9 million and dominate the market in 2021. The burgers segment is expected to grow at the highest CAGR of 4.6% during the forecast period.[11]

Global Market for Cultured Meat, by End Use, Through 2027 ($ Thousands)

End product	2021	2022	2027	CAGR %, 2022-2027
Nuggets	3,898	4,061	5,012	4.3
Burgers	3,303	3,454	4,335	4.6
Hot dogs	2,982	3,081	3,643	3.4
Sausages	2,678	2,771	3,303	3.6
Others	1,564	1,611	1,875	3.1
Meatballs	1,305	1,359	1,673	4.2
Total	**15,730**	**16,337**	**19,841**	**4.0**

However, for the time being, the cost, scale-up, public neophobia, social perception and regulatory guidelines surrounding cultured meat are limiting its commercial viability. Second-generation, lab-created animal protein replacement products are not yet proven to be safe or sustainable by regulators or via transparent, independent third-party assessments. There are questions that remain unanswered, and some critics have suggested that cultured meat products "may be problems masquerading as solutions".[19] Friends of the Earth outline a number of questions which need to be answered before cultured meat products enter the market on a large scale:

- Are second-generation animal replacement products truly sustainable?
- Are they a viable solution to the numerous problems surrounding industrial animal production?
- How do these products' environmental impact compare to sustainably produced plant-based meat and dairy alternatives and products from animals raised in sustainable, high-welfare production systems?
- Do they meet their marketing claims as sustainable and healthy?
- Should the safety of these new products be left to individual companies to determine?
- Is there adequate independent safety assessment, regulatory oversight and transparency?
- Do these products and their claims meet consumer expectations?

Nomenclature

Because cultured meat is not yet commercially available, it has yet to be seen whether consumers will accept cultured meat as meat. Partly this is an issue of nomenclature – besides cultured meat, the terms slaughter-free meat, *in vitro* meat, vat-grown meat, lab-grown meat, cell-based meat, clean meat and synthetic meat have all been used by various outlets to describe the product.

In a recent study, Faunalytics reported that up to 66% of Americans were willing to try 'clean' meat.[30] The survey was conducted online in 2018 on a group of 1185 adults. The market research

[30] http://faunalytics.org/clean-meat/

indicated that 40% of participants were willing to spend more on lab-grown meat products than conventional meat. The term ‘clean meat’ is associated with higher acceptance rates than terms such as ‘cultured meat’ or ‘*in vitro* meat’. However, Consumer Reports found that the public strongly prefers the term ‘lab-grown’ over ‘clean’ when referring to meat products grown *in vitro*. A phone survey revealed that customers expect clear labelling distinction between traditional meat products and cultured meat. The vast majority of participants (95%) stated that the *in vitro* meat should be either labelled as meat with information on production method or even as a completely different product type.[31]

Though other surveys have reported varying degrees of public willingness to eat cultured meat, in general the findings of the Faunalytics survey and others[32] have demonstrated a notable readiness amongst the public to do so, and also highlight the importance of messaging – the reduction of environmental damage is one of the benefits which resonated most strongly with potential customers.

Some players within the traditional meat industry call for a clear distinction between conventional meat products and alternatives consisting of the plant-based meat and *in vitro* (clean) meat, which are sometimes referred as ‘fake meat’ by these organisations. In 2018, the U.S. Cattlemen's Association filed a petition with the U.S. Department of Agriculture (USDA), asking it for clear definitions of terms such as ‘beef’ and ‘meat’ as a product obtained from the body of an animal that has been slaughtered in a traditional way. According to the Association, labelling of products based on alternative protein sources is misleading. On the other hand, the move by the Cattlemen's Association has been viewed by The Good Food Institute as a threat to free speech, violating The First Amendment to the US Constitution.[33]

More recently, in May 2019, a new bill (HB518), supported by the Cattlemen's Association, was proposed in Alabama which would require food manufacturers to label products derived from cell cultures being sold in Alabama as “not being real meat”[34], despite cultured meat being identical to meat on the molecular and cellular levels. The Alabama Cattlemen’s Association argue that federal laws don’t address the issue of labelling. However, this appears to be inaccurate given that there are already at least two federal laws prohibiting false and misleading labels on meat -- the Federal Meat Inspection Act and the Poultry Products Inspection Act.[34]

In 2018, companies working in the cultured meat industry agreed to form a trade association and shift from using the term ‘clean meat’ to ‘cell-based meat’. This move is intended to decrease negative connotations that the term ‘clean meat’ might imply in regards to traditional meat products being somehow ‘dirty’.[35] Adapting this nomenclature within the trade association is thought to better facilitate potential collaboration with traditional meat companies.[36]

[31] Consumer Reports (2018) Foods produced using animal cell culture technology.
[32] Wilks & Phillips (2017) *Attitudes to in vitro meat: A survey of potential consumers in the United States*, PLOSOne, 12(2)
[33] https://www.cnbc.com/2018/02/23/the-fight-against-fake-meat-has-officially-begun.html
[34] https://geneticliteracyproject.org/2019/05/03/alabama-bill-would-require-lab-grown-protein-to-carry-label-declaring-its-not-real-meat/
[35] Szejda (2018) *Cellular Agriculture Nomenclature: Optimizing Consumer Acceptance*, The Good Food Institue
[36] https://www.foodnavigator-usa.com/Article/2018/09/10/Cultured-meat-cos-agree-to-replace-term-clean-meat-with-cell-based-meat-and-form-trade-association#

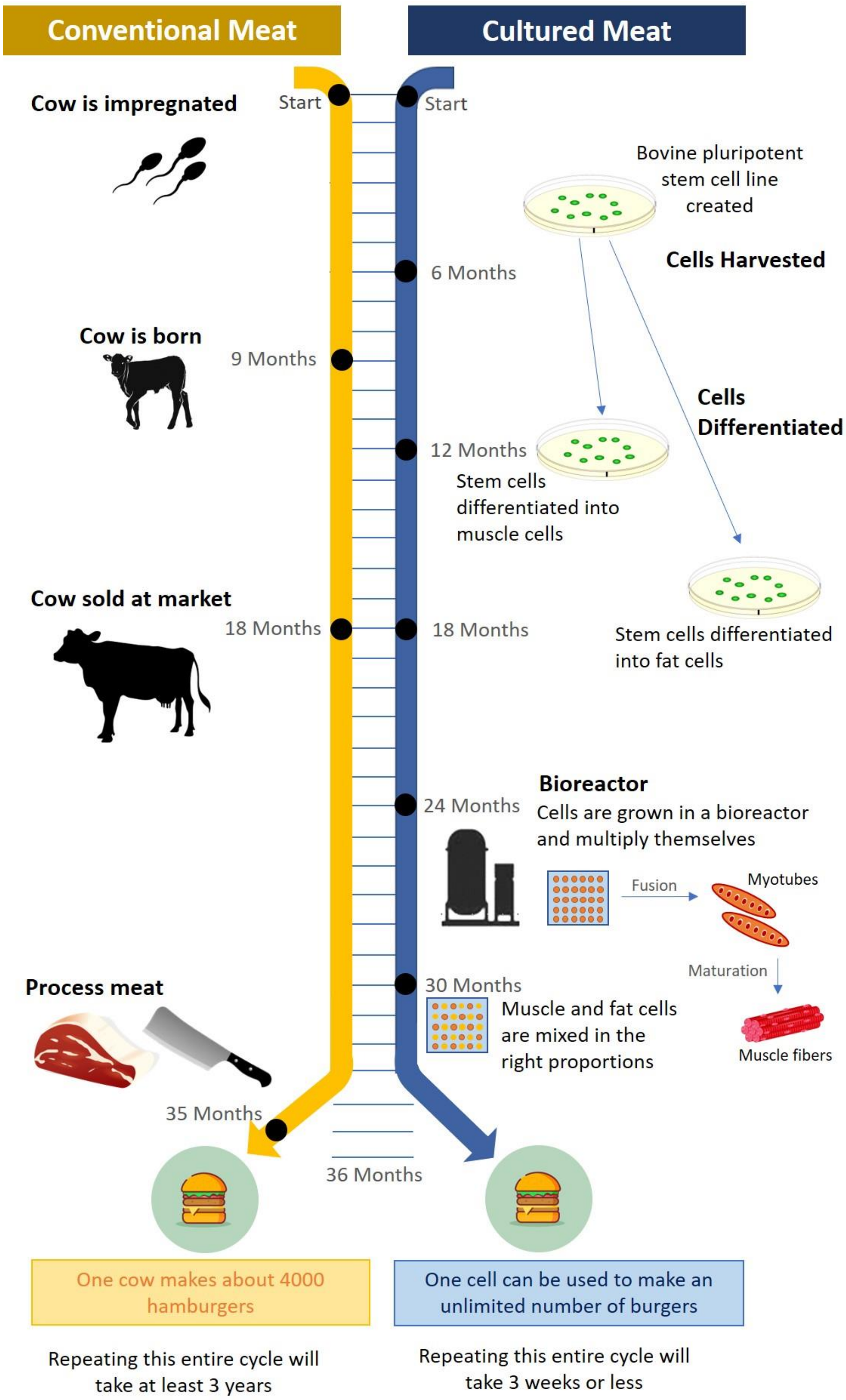
Production

A key challenge for companies is that the technology of cell culture was originally designed for medical applications. In medicine, there is no need to produce cells at the massive ton scale required to make meat, and making the production cheap is not as big a priority as with a commodity such as meat.[37]

The technologies that were originally developed for organ transplants can be used to grow tissues used for different purposes, such as human consumption. The production procedure follows some key steps, namely:

- Muscle-specific stem cells are first extracted from an animal (i.e. cows) via biopsy.
- These cells are multiplied in culture in a growth medium containing high levels of nutrients.
- Multiple muscle cells fuse into myotubes, which are later transferred to a bioreactor.
- When provided with anchor points, myotubes organise themselves into tissue - they grow around a scaffold and then join together to form strands of muscle tissue.
- These small strips of muscle can be processed to obtain products such as burgers and sausages. Some of the further development in the field include mixing the lab-grown muscle tissue together with blood and artificially grown fat to mimic texture of animal-based meat products more closely.

[37] https://labiotech.eu/features/cellular-agriculture-food-industry/



Overview of conventional beef production (left) vs cultured beef production (right). Adapted from Meatable.[38]

Production of cultured meat comprises two techniques: self-organising and scaffold-based. The scaffold-based technique segment is expected to be valued at $14.0 million and dominate the market in 2021. It is also expected to grow at the higher CAGR of 4.1% during the forecast period[11],

[38] https://thespoon.tech/meatable-claims-to-hold-the-key-to-scalable-cultured-meat-in-a-single-cell/

2022-2027. Scaffold-based techniques are unable to deliver highly structured meats such as steaks, but can produce boneless and ground meats (e.g. sausages and hamburgers) with consistency.

Global Market for Synthetic Meat, by Technique, Through 2027 ($ Thousands)[11]

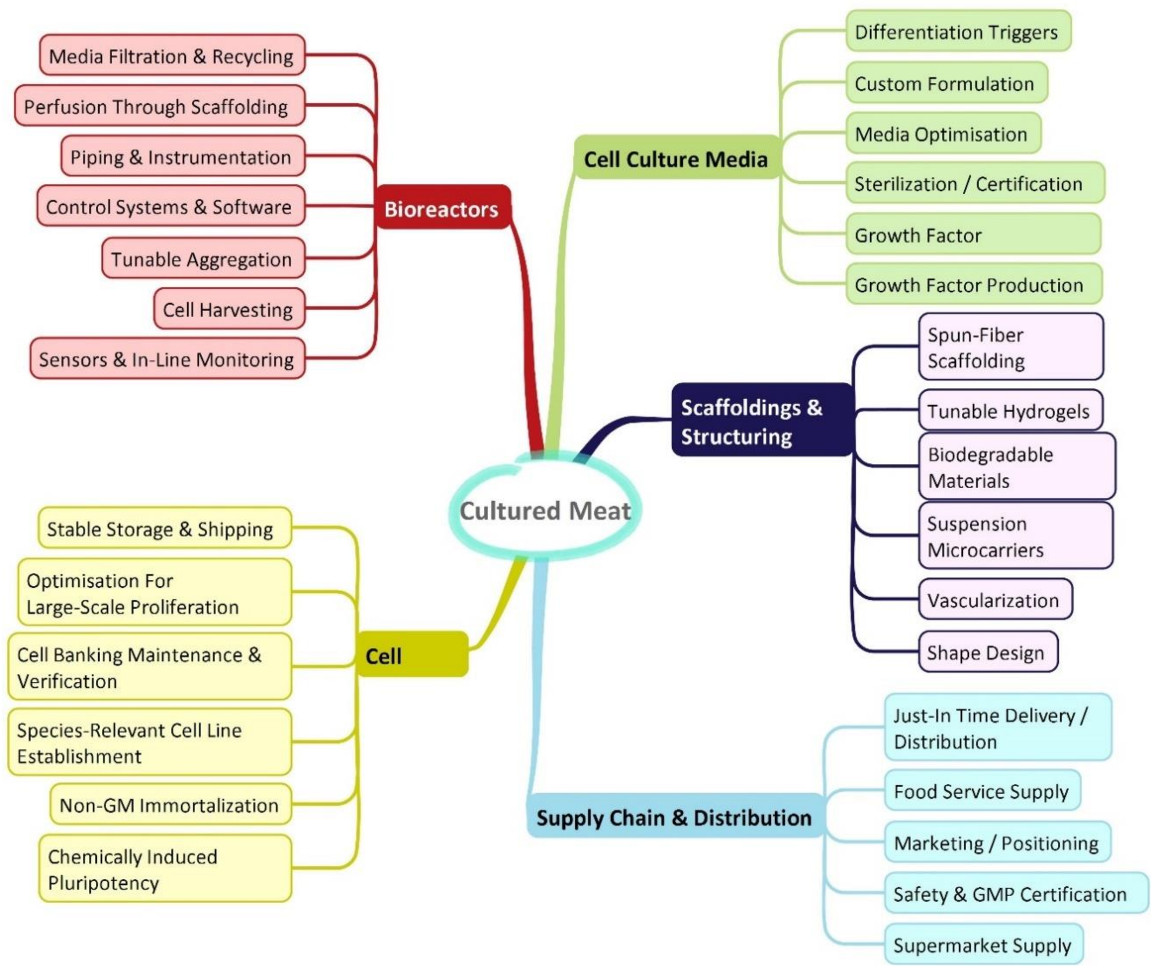
End product	2021	2022	2027	CAGR % 2022-2027
Scaffolding-based technique	14,026	14,582	17,799	4.1
Self-organising technique	1,704	1,755	2,042	3.1
Total	15,730	16,337	19,841	4.0

There are therefore four main technology elements, summarised in the Figure below, which require further research and development in cultured meat production:[39]

- **Cell lines**: At the moment, researchers are using satellite cells which have a limited number of self-replications in their lifespans
- **Cell culture media**: The development of an inexpensive and animal-free growth serum for cell lines, to allow industrial scaling of cellular agricultural processes, is still elusive
- **Scaffolds**: Further innovation is required to create scaffolding to grow complex meat tissues like steaks. Steaks consist of different amounts of muscle, fat, and connective tissue, and a complex scaffolding to make them will have to be able to replicate their appearance and composition.
- **Bioreactors**: Currently, no large-scale bioreactors exist that would accommodate commercial scaling for cultured meat. The first large-scale bioreactor for cellular agriculture could be a reality by 2020[40]. Research is currently investigating how to scale contemporary bioreactors and modify them for growing cultured meat.[41]

Each of these technology elements represents a significant area of opportunity for private industry and can draw on decades of advancement and investment in R&D.[42]

[39] https://medium.com/cellagri/cellular-agriculture-from-lab-to-market-9e31b8a1a6f7
[40] Hoogenkamp (2016) *Cellular agriculture shows future potential*. Fleischwirtschaft International, **31**, 46–49
[41] https://www.gfi.org/clean-meats-path-to-commercialization
[42] Technology Information, Forecasting and Assessment Council (2018) *Cellular Agriculture: The Future of Food*



Cultured Meat Technology Components

Product Development

Professor Mark Post (**Maastricht University**) is well-known for creating the first lab-grown burger in 2013. Since then the technology has significantly advanced, and Post aims to start selling this cultured beef burger in 2021 through the company **Mosa Meat** (The Netherlands).

His work has since inspired hundreds of people across the world to do the same with all sorts of animal products.[37] The technology advancements made by a handful of early innovators are in turn making it easier for more players to enter the field, since they can find protocols for how to make muscle from stem cells. It is also possible that when the first products arrive in the market from the early innovators, there will then be a new wave of companies and technologies entering the field.

Beef is the most common cultured meat that companies are trying to replace; it is the most inefficient meat to produce and one of the biggest contributors to global warming.[37] Beef is also one of the priciest meats, selling at two to three times the price of pork and poultry, so a premium price can be justified.

The cost of production remains high – the first hamburger patty took two years to produce and cost approximately $300,000 (USD). Part of the high production cost is thought to be associated with the growth medium – usually the foetal calf serum. The cost per litre of nutrient solution is around $250. Therefore, developing a method of artificially manufacturing growth medium is considered to be the one of the most pressing issues for technology development.

However, the cost of production has been falling dramatically. As of February 2017, the price of cultured burgers has dropped to $11.36 in just three and a half years.[43] This cost is now only nine or ten times more expensive per pound than standard ground beef.[44] As the price of lab-grown meat continues to fall, it is possible that in the future it will become cheaper than conventional meat[45], suggesting that lab-grown meat will become a viable commercial product and market force. Indeed, as part of ongoing effort to address its most pressing environmental problems, China in 2017 signed a trade agreement with Israel worth $300 million that will see China import lab-grown meats produced by three companies: **SuperMeat, Future Meat Technologies**, and **Meat the Future**.[46] Israel is a key territory for cultured meat production, with the start-up **Aleph Farms** being the first company to create a cultured steak.[47]

In terms of product launches, many cultured meat companies— including **Mosa Meat** and US-based **Memphis Meats**, the two start-ups with the most funding — have a similar timeframe in mind to launch their first product: 2021. The American start-up **JUST** (previously **Hampton Creek**) previously stated that their first meat product would be launched at the end of 2018, though this has yet to materialise. Although 2021 is the target launch for most companies, regulatory approval, commercialisation and scaleup could delay this.[48]

The first products based on cultured meat are likely to be expensive and small-scale, offered primarily to select food services providers and restaurants, with products expected to launch in supermarkets around 2022-2025.[22]

Thick, complex cuts of meat such as prime rib will probably be more expensive than minced products like ground beef initially, but Matt Ball, Media Relations Specialist at the Good Food Institute believes that once processes have matured, premium Kobe beef could be produced just as inexpensively as 'generic' beef.[49]

Indeed, in a sign of the increasing collaboration between traditional and cultured meat companies, in December 2018 **JUST** announced a partnership with **Toriyama Ranch**, a Japanese producer of Wagyu beef (a type of meat that includes the prized Kobe steaks). JUST will use the Wagyu cow cells to grow beef, initially in the form of ground meat.[37]

Non-beef Products

Besides beef, several other companies are making poultry and pork products. **JUST** is working on growing chicken nuggets[50], **Future Meat Technologies** is making chicken kebabs, **Biotech Foods** (Spain) is making pork and poultry sausages and ham, and **Higher Steaks** (UK) is growing cultured pork.

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[43] https://modernfarmer.com/2017/10/little-lab-grown-piggy-went-market-clean-meat-interest-rise/
[44] https://www.cell.ag/cellular-agriculture-future-of-food/
[45] Kurrer & Lawrie (2018) *What if all our meat were grown in a lab?.* European Parliamentary Research Service
[46] https://futurism.com/china-signed-a-300-million-lab-grown-meat-deal-with-israel/
[47] https://labiotech.eu/food/aleph-farms-cultured-meat-steak/
[48] GlobalData Consumer (2017). *Meat without animals NPD to hit shelves in 2021.*
[49] https://labiotech.eu/features/cultured-meat-industry/
[50] https://www.bbc.co.uk/news/world-us-canada-45865403

Culturing fish cells is not as popular — so far the main players are the start-ups **Finless Foods** (USA), **Wild Type** (USA) and **BlueNalu** (USA) — but the potential is big.[37] Finless Foods hopes to continue cutting production costs in 2019 until its cultured tuna reaches price parity with conventional tuna.[10] Wild Type's first meat is salmon. Phase one is to develop a minced salmon meat that could be used in, say, a spicy salmon sushi roll, where the meat is mixed with sauce and smaller quantities are needed. From there, the company is targeting lox for bagels, and eventually, salmon fillets.[51] Cultured fish companies may have lower costs given that culturing fish cells requires lower temperatures and therefore less energy. Fish cells can also be easier to work with than mammalian cells. They can replicate indefinitely — something only stem cells can do in mammals.[37]

Founded in 2018, **Suprême** (France) is developing a method to obtain foie-gras using cells taken from duck eggs. The goal is to be offering this gourmet product by 2023.

Everyday commodities such as eggs and milk will also soon have counterparts that are created from cells rather than an animal. The egg substitute market is currently dominated by JUST Egg (discussed further below), made from mung beans. However, the company **Clara Foods** (USA) is taking an alternative, cellular agriculture-based approach to growing egg white, with products expected to launch at the end of 2019.

Plant-based milks such as almond milk have been widely available for many years, but innovators in this field are aiming to produce increasingly convincing products which 'taste just like the real thing'. San Francisco-based **Perfect Day Foods** (previously Muufri) use genetically-modified yeast which codes for dairy proteins. Casein and whey protein are then produced via microbial fermentation. In November 2018, the company announced that they have partnered with **Archer Daniels Midland** (USA) to further develop and commercialise their technology, using ADM's fermentation infrastructure to reduce the cost of making the animal-free whey protein. The animal-free dairy products are expected to reach the market in 2019.[52]

Regulation

One of the biggest factors influencing the potential market entry of cultured meat products is regulation. This is an area of ongoing development by regulatory bodies worldwide, but as the situation stands currently, the regulatory frameworks which will be applied to cultured meat are unclear. European companies are thought to be fortunate in that the regulation will fall under EU's novel food regulations[53], which has sped up the process so it may be faster than in the US. The European Food Safety Authority's regulation on novel foods, which specifically includes cultured meat, establishes a process of around 18 months in which a company has to prove the product is safe.[37]

In the US, the situation is still not clear[54], so the cultured meat industry will be paying very close attention to U.S. regulators in 2019.[10] The U.S. Food and Drug Administration (FDA) will only govern cultured meat if it meets one of the definitions of FDA covered products. Even though cultured meat does meet the definition of food as it is an "article used for food or drink for man or other animals" it may not fit in any relevant subcategories. Cultured meat does not fit well into the meat

[51] https://techcrunch.com/2018/03/29/wild-type-raises-3-5m-to-reinvent-meat-for-the-21st-century/

[52] https://www.forbes.com/sites/lanabandoim/2018/11/16/perfect-day-partners-with-adm-to-make-milk-without-cows/#44f0c9d66ca0

[53] https://ec.europa.eu/food/safety/novel_food_en

[54] Congressional Research Service (2018) *Regulation of Cell-Cultured Meat*

category, because cultured meat is not grown as a result of the lifecycle of an animal. Another possibility for regulation is under the U.S. Department of Agriculture (USDA) provisions for genetically modified organisms (GMOs) because such regulations already account for food products produced in a laboratory. The problem with applying these regulations to cultured meat, however, is that they are designed specifically for plants.[55]

In November 2018, the USDA and the FDA released a statement on the agreement that both organisations would jointly oversee lab-grown meat products derived from cell lines. A joint regulatory framework has been agreed between the agencies, under which FDA and USDA would have distinct scope of responsibilities at different stages of the product lifecycle.[56] Though the framework has not been published, it has been made clear that the technology will not require any additional regulations to what is already in place.

In other locations, the technology is not as advanced and neither are regulations surrounding it. But some regions do accept products approved abroad, such as China, which will accept European regulatory approvals to commercialise certain products.[49]

Besides beef and chicken, there are still questions of what regulation would look like for other cellular agriculture food products. What about cell-based fish, which is solely regulated by the FDA? Will cell-based fish start-ups be required to follow a similar regulatory process even if the USDA is not involved?

In addition, there are questions over how acellular products, like animal-free gelatin, egg whites, and dairy proteins, will be regulated. Will they be regulated under current systems that allow products Generally Recognized as Safe (GRAS)? Or would their novel production methods require those start-ups to take their products through a different type of regulation?[57]

While there are still many questions (and details) to address, it is considered promising that the USDA and FDA both agreed upon the basic regulatory framework for cell-cultured meat. It is now important that regulators communicate clearly with all the respective companies and industries to help grow and support the future of cultured food. Given the engagement that both regulatory bodies have shown, some believe that the regulatory path will be quicker in the US than in Europe, but that remains to be confirmed in the coming months.[49]

3.1.2 PLANT-BASED ‘ANIMAL PRODUCTS’

Many of the markets, trends and issues being addressed by cultured meat technologies are also shared by plant-based meat alternatives. **Impossible Foods** (USA), for example, was founded by Prof Patrick Brown (**Stanford University**) as a fundamental way to tackle the environmental damage of animal agriculture.

The wider $5.2 billion meat substitute market[58] is already well-established. This is dominated by well-known soy- and mycoprotein-based products, as well as traditional “veggie burgers” made from – and with a texture closer to – beans or chickpeas, for instance. The focus of plant-based

[55] Penn (2018) *"Cultured Meat": Lab-Grown Beef and Regulating the Future Meat Market*., UCLA Journal of Environmental Law and Policy, 36(1)

[56] FDA (16 November 2018). *Statement from USDA Secretary Perdue and FDA Commissioner Gottlieb on the regulation of cell-cultured food products from cell lines of livestock and poultry*

[57] https://www.cell.ag/cell-based-meat-regulation-is-coming

[58] Allied Market Research (2018) *Meat Substitute Market - Global Opportunity Analysis and Industry Forecast, 2018-2025*

'meat' in this report, however, is on more recent technology developments which more closely mimic the fibrous structure, bite, and flavour of conventional meat products, and which form a small but rapidly-growing segment of the meat substitute market.

Over the last few years, there has been a step-change in plant-based meat technology as meat-eaters, as well as vegetarians and vegans, increasingly embrace meat substitutes. Retailers are changing the way they merchandise plant-based meats, shelving them adjacent to conventional meat instead of in a separate vegetarian section, in the same way that moving plant-based milk from shelves to the fridge — beside conventional cow milk – is what helped really boost sales for those products.

The two most well-known examples of plant-based meat are the flagship 'bleeding' burgers produced by **Impossible Foods** and **Beyond Meat** (USA). The Impossible burger contains a range of ingredients including wheat protein, coconut oil, potato protein, and "heme". Heme is a key component in meat that usually comes from myoglobin responsible for 'meaty' flavours. Impossible Foods' production process is based on genetically modified yeast cells that express leghemoglobin, a heme-containing soy protein, which is functionally identical to myoglobin. The Beyond Burger, meanwhile, is also known for its 'bleeding' effect created by beetroot juices used in production to better mimic the appearance and colour of red meat.

Although regulation is more straightforward for plant-based meat than for cultured meat, there are still some unexpected hurdles which can emerge in this nascent field. Impossible Foods was informed by the FDA that it had not provided adequate proof of safety for the genetically engineered soy leghemeglobin (SLH; "heme"), that gives the burger its meat-like taste and colour. This novel protein had never previously been introduced to the human diet. Furthermore, FDA documents showed that manufacturing SLH with genetically engineered yeast resulted in 46 unexpected additional engineered proteins. Some of these surprise proteins were unidentified and none were assessed for safety in the Impossible Foods dossier provided to the FDA. Impossible Foods presented that SLH is substantially similar to real heme found in the root of a soy plant, but not identical.[19]

SLH was ready for approval in 2018 after the FDA, following years of back-and-forth, declined to challenge findings voluntarily presented by the company that the cooked product is "Generally Recognized as Safe," or GRAS. Such a "no questions" letter means the FDA found the information provided to be sufficient.[59]

However, in late 2018, the FDA then directed that heme, which is red in hue, needs to be formally approved as a colour additive before individual consumers can purchase the uncooked product. The colour additive FDA filing won't affect the continued sale of cooked Impossible Burgers in restaurants, and approval by the regulator could come in time for the company to roll out the raw product in 2019.

Beyond Meat is already selling its burger patties, and other heat-and-eat meals and frozen foods, at grocery chains such as Whole Foods Market and Amazon. The company has recently opened a 26k square foot research facility, which will enable the company to greatly expand distribution and develop new products.[10]

The growing industry presence of plant-based products as a meat-like replacement for conventional burgers in restaurants is evidenced by the fact that the Impossible Burger is now on

[59] https://www.bloomberg.com/news/articles/2018-12-26/why-the-bloody-impossible-burger-faces-another-fda-hurdle

the menu at major chain restaurants in the USA, such as **Burger King, Qdoba**, and **White Castle**, while the Beyond Burger is sold at **Carl's Jr**., **Del Taco** and **A&W** (Canada only). **McDonald's**, meanwhile, is now selling a vegan burger, the Big Vegan TS, in Germany, one of its five leading international markets.[60]

While Impossible Foods recently unveiled a co-manufacturing collaboration with global food provider **OSI Group** for its Impossible Burger[61], **Nestlé** (Switzerland) is making the meatless patty for McDonald's, which first started selling the burger in April 2019. Nestlé also plans to launch a vegan burger as a 'cook from raw' product for consumers, initially in Europe in 2019. Sold under the **Garden Gourmet** brand, the Incredible Burger is made with soy and wheat protein, with plant extracts – beetroot, carrot, and bell pepper – to help create the look of a beef burger. In late 2019, Nestlé will also roll out a plant-based burger in the USA under the **Sweet Earth** brand, "customised for the American consumer". Called the Awesome Burger, this new burger, to be sold raw, will complement Sweet Earth's existing, traditional vegetarian burger products.

In the wake of the success of Beyond Meat and Impossible Foods, start-up companies continue to emerge with new and innovative technologies to tap into the growing plant-based meat market. Companies like **NovaMeat** (Spain) and **Jet Eat** (Israel), both founded in 2018, are employing bioengineering principles to 3D print plant-based meat. NovaMeat claims to have discovered a way to "bio-hack" plant-based proteins to produce a meaty texture. The product is made from ingredients such as rice, peas and seaweed.[62] The process is claimed to give the product a good amino acid profile and the lipids, fibres, minerals and vitamins required to mimic the nutritional properties of animal meat.[63]

In addition to Nestlé, other large companies are also attempting to enter this market. For instance in 2020, **Kellogg Co**. is planning to launch its "Incogmeato" burger – a plant-based, refrigerated patty made with non-GMO soy. It will also start offering new versions of its vegetarian "Chik'n tenders" and "Chik'n nuggets" that the company bills as an improvement over its current chicken-substitute products.[64] Other food giants including **Kroger**, **Perdue** and **Tyson Foods** are also planning similar product launches.[65]

Tyson Foods is particularly notable for having recently invested in **New Wave Foods**, a San Francisco-based start-up that will be one of the first companies to debut plant-based shrimp early next year.[66] Plant-based alternatives to chicken is another area that is so far conspicuously absent from mainstream outlets, compared to red meat alternatives. However, it seems the tide is starting to turn. Tyson has recently launched nuggets made partially from pea protein under a new brand, Raised and Rooted. Chicken company **Perdue** has partnered with **The Better Meat Co**. to develop nuggets, tenders and patties made from a blend of animal meat, cauliflower, chickpeas, and plant-based protein that will be available later this year. Perdue's Chicken Plus line may not be a 100%

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[60] https://edition.cnn.com/2019/05/07/business/mcdonalds-meatless-burger-germany/index.html
[61] https://agfundernews.com/impossible-foods-teams-up-with-osi-to-ramp-up-production.html
[62] https://www.foodnavigator.com/Article/2018/10/18/Italian-researcher-on-3D-printing-tech-for-plant-based-meat-We-re-bio-hacking-plant-protein-structure-at-micro-and-nano-scale
[63] https://www.newprotein.org/news/2018/12/3/3d-printed-steaks-one-step-closer
[64] https://www.arkansasonline.com/news/2019/sep/08/kellogg-s-beefs-up-meatless-20190908/?business
[65] https://www.cbsnews.com/news/tyson-kelloggs-kroger-hormel-kroger-jumping-into-fake-meat-and-competing-with-beyond-meat-and-impossible-foods/
[66] https://www.washingtonpost.com/business/2019/09/05/tyson-launches-alt-shrimp-made-plants-it-could-be-jumbo/?noredirect=on

plant-based alternative, but it signals a shift towards the company expanding into plant-based foods. [67]

Besides meat and burgers, plant-based egg and dairy replacements are also continuing to gain traction. As outlined previously, there are cellular agriculture approaches being taken to produce dairy products, which often tout both the environmental and health benefits: **Perfect Day**'s products are promoted as being free from cholesterol, lactose, hormones and antibiotics. Health benefits are an angle taken by many of the other innovators in the alternative, plant-based milk market. **Soylent** (USA) offers plant-based, milk-like drinks which aim to provide an entire meal's worth of nutrition in one serving, containing 20 grams of soya protein isolate, Omega 3 oils from sunflower oil, complex carbohydrates and added vitamins and minerals.

Animal-free egg products are dominated by **JUST**, which sells a scrambled egg alternative made from water, mung bean protein isolate, canola oil, gums, and seasonings, and is designed to look, cook, and taste like scrambled egg. The product is now widely available and in February 2019, the company shipped what would be equivalent to its three millionth egg.[68] Combined with its interests in cultured meat products described previously, JUST is expanding globally. US customers will soon be able to find Just Egg in the egg aisle at supermarket chains like **Kroger**, **Ralphs** and **QFC**.[69] JUST says it is the first food tech company to enter mainland China, selling its JUST egg product in supermarkets, restaurants and through e-commerce companies as a result of relationships with Chinese companies like Alibaba. JUST will also be selling in Europe, thanks to its new partnership with **Eurovo**, a European producer of packaged and pasteurized egg products that will sell JUST Egg alongside its conventional products in supermarkets.[10] However, JUST is not yet at a point where the JUST Egg production costs are lower than they are for conventional eggs – the construction of efficient mung bean processing facilities around the globe, and finding a ready market for by-products, such as starch, will be crucial in achieving this.[68]

3.2 ALTERNATIVE PROTEIN SOURCES

Many of the market drivers of alternative protein sources are shared with the Animal Product Replacements technologies discussed in the previous section. In addition to the environmental implications, replacing meat with alternative protein sources may result in improvements in health. Various aspects of red meat in particular have been linked with an increase in mortality including high levels of heme iron and sodium, whereas non-meat alternatives may confer health benefits by having an increased fibre content, lower cholesterol and the presence of polyunsaturated fatty acids (PUFAs) omega-3 and omega-6.

Alternative protein sources found in nature have long been used by vegetarians and vegans with increasing interest from consumers aiming to reduce their carbon footprints. The global alternative protein market is predicted to hit $6.6 billion in 2024 growing at a CAGR of 6.8% from $4.5 billion in 2019. Currently North America is dominating the alternative protein market accounting for 31% of the total amount consumed with Asia-Pacific following closely with a share of almost 27%.[70]

Peas, soy, nuts and pulses are amongst the main alternative sources of proteins used in variety of applications from 'burgers' to protein powders. However, several less conventional sources of

[67] https://www.salon.com/2019/06/29/big-chicken-wants-in-on-the-plant-based-meat-options-and-thats-a-good-thing/

[68] https://www.foodnavigator-usa.com/Article/2019/02/12/Plant-based-JUST-Egg-is-already-outselling-established-liquid-egg-brands-at-retail-claims-Just-CEO

[69] https://agfundernews.com/table-talk-the-scramble-for-plant-based-eggs-is-just-about-to-reach-europe.html

[70] Market Research Insights (2019) *Global Neutral Alternative Protein Market 2019 by Manufacturers, Regions, Type and Application, Forecast to 2024*

proteins are gaining popularity and have been in the spotlight over the last decade. In this section we will be mostly focusing on these novel sources, mainly insects, algae and bacteria.

Start-ups focused on developing and selling such alternative protein sources are springing up all over the world and have been successfully raising money. Edible insect companies have been particularly well funded with the International Platform of Insects for Food and Feed (IPIFF) estimating that 50 insect farming groups that have collectively raised $480 million to-date.

Ÿnsect, the French start-up farming mealworms for animal feed, broke records in the Europe agritech scene by raising a $125 million Series C round in 2019. **Agriprotein** (UK) and **InnovaFeed** (France), two other insect-based animal feed start-ups, also raised huge amounts of money in 2018 at $105 million and $62 million, respectively. There has also been notable interest from major foodstuffs corporations with the likes of **Maple Leaf Foods** (Canada) and **PHW Gruppe** (Germany) investing in insect consumer food start-ups **Entomo Farms** (Canada) and **Bugfoundation** (Germany), respectively.

There has also been significant investment and interest from industry outside of the insect arena in the algae and single cell protein areas. **TerraVia** (previously Solazyme), a US company selling algae-based food ingredients, was acquired by Dutch food and biochemicals giant **Corbion** in 2017 for $20 million. **3F BIO**, a Scottish start-up using fungi to convert sugars into mycoprotein, has raised a total of $28.3 million since its inception in 2015.

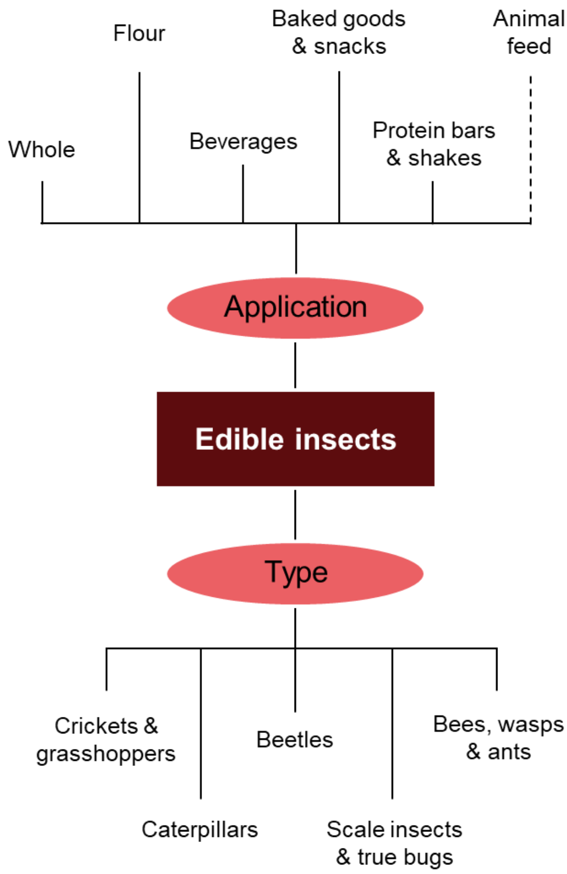
3.2.1 INSECTS

Insects are, in fact, not such a novel source of protein for much of the world; the Food and Agriculture Organization of the United Nations estimates that two billion people (more than a quarter of the world's population) eat insects already as part of their standard diet. Just under 2,000 species of insect are edible with over 500 consumed across the world with some of the main markets including China, Japan, Peru and Thailand.[71] Until recently, insects were rarely consumed in North America and Europe, however awareness of their nutritional and environmental benefits is causing an entomophagic revolution across the West.

When comparing insects to conventionally farmed livestock such as cattle, swine and poultry, it is clear that the invertebrates are superior nutritionally and in terms of sustainability. According to the United Nations' Food and Agriculture Organisation, a kilogram of crickets requires a fifth of the feed needed to produce a kilogram of beef and mealworms require less than a tenth of the land needed for cattle to produce the same amount of protein.[12] The highly efficient feed-conversion rate (the capacity of an animal to convert food into body mass) of insects is the reason why insects require less food to produce the same amount of protein as livestock.[13] Additionally, insects require significantly less land and water per g of protein than cattle and swine. Only 23L of water is required to make 1g of insect protein, whilst it takes 112L for 1g of beef protein.[14]

Companies selling insect products are springing up all over the world and marketing their wares at those with both health and sustainability in mind. Per 100g of edible mass, crickets contain just as much protein as animal sources whilst having reduced levels of saturated fat and potassium[15], aspects that are thought to play a part in the health issues associated with over consumption of red meat.[16] Insect flour has recently become popular as a high protein additive for foodstuffs ranging from pasta to crisps.

[71] Y. Jongema, World List of Edible Insects, Laboratory of Entomology, Wageningen University, Wageningen (2015)



Edible insect market segmentation by application and type

Whilst many companies are producing insects for direct consumption by humans, a popular route for commercialisation of insect products has been in animal feed. Traditional livestock feed often consists of land intensive crops, such as soy and wheat, and it has been reported that the livestock sector already uses over a third of the global croplands for animal feed.[72] Most consumers would be happy to eat animals that have been fed insects whilst many would refuse eating insects directly[73]. Additionally, regulations around using waste to feed insects purposed as animal feed are more favourable than for human food. The animal feed market is therefore an easier route to market which is reflected by the larger investments in animal feed companies.

Numerous reports have been published about the edible insect market with all reports forecasting significant growth. A 2018 report from Global Market estimated the global market to be over $55 million in 2017 with the market predicted to grow by over 43.5% by 2024.[74] Persistence Market Research forecasts revenues in the edible insect market to reach $722.9M in 2024[75] whereas Meticulous Research estimates larger growth at a CAGR of 23.8% with a forecasted market size of $1,182 million in 2023.[76] Mordor Intelligence aligns more closely with Meticulous Research by forecasting a CAGR of 22.3% over the period 2018 – 2023.[77] Looking further ahead, a recent report

[72] Cassidy, *et. al.* (2013) *Redefining agricultural yields: from tonnes to people nourished per hectare*. Environ. Res. Lett. 8, 034015

[73] Verbeke et. al. (2015) *Insects in animal feed: acceptance and its determinants among farmers, agriculture sector stakeholders and citizens*. Animal Feed Science and Technology, **204**, 72-87

[74] Global Market Insights (2018) *Edible Insects Market Size & Forecast, 2018 – 2024*

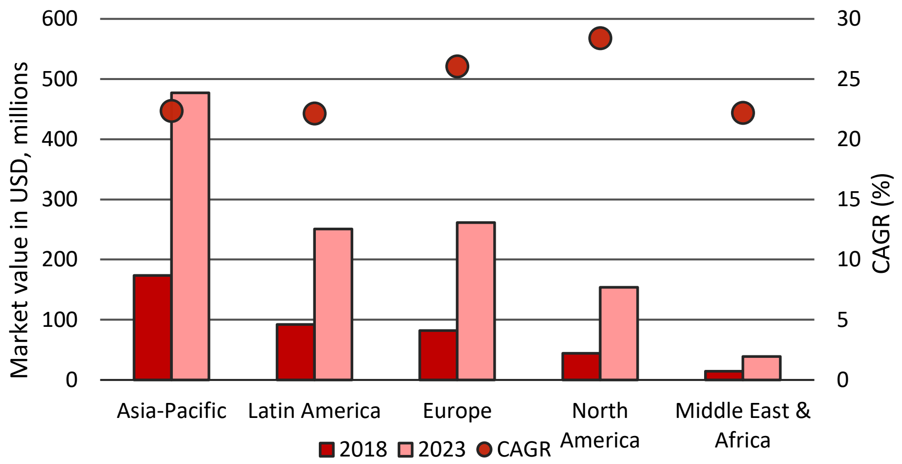
[75] Persistence Market Research (2018) *Global Market Study on Edible Insects: Consumption of Insects as a Whole to Gain Maximum Traction During 2017-2024*

[76] Meticulous Research (2019). *Edible Insects Market – Global Forecast to 2030.*

[77] Mordor Intelligence (2019) *Edible Insects Market Size, Growth Analysis – Trends and Forecast (2019-2024)*

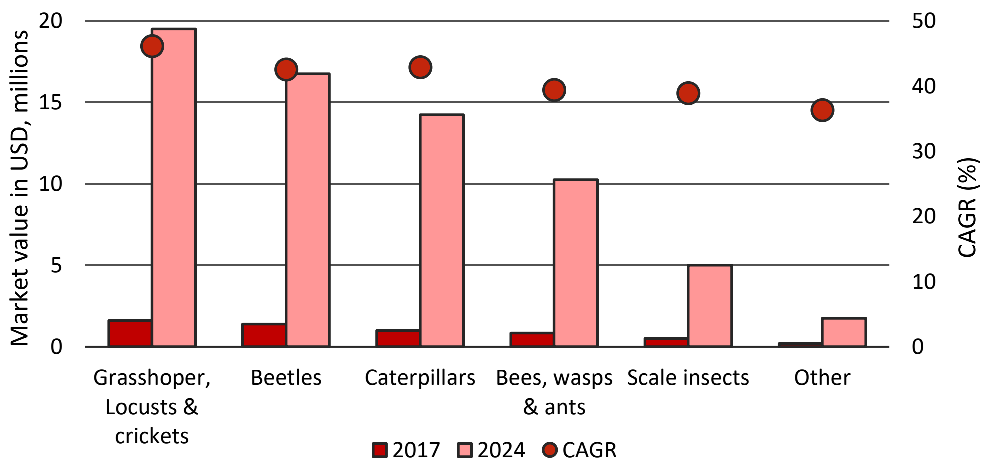
from Research and Markets predicts the edible insect market to reach almost $8 billion by 2030 by growing at a CAGR of 24.4%.[78]

The Asia-Pacific region has, and will continue to have, the largest market share with a significant CAGR of 22.4% over the period 2018-2023.[76] Insects have been historically consumed in Asia with whole insects making up the majority of the market. North America and Europe are the regions with the highest forecasted growth with CAGRs at 28.4% and 26.1%, respectively. The increasing interest in insects as sustainable and healthy sources of protein has led to an increasing number of start-ups in these regions.



Edible insect market size and growth by geography. Source: Meticulous Research.

According to the Food and Agriculture Organisation, the most commonly consumed insect types include beetles, crickets and caterpillars.[12] Crickets have the largest market share by insect type globally and are expected to continue dominating the edible insect market. Their expected growth in market share is due to their ease of farming and processing, high nutritional benefits and flexibility in applications.



US edible insect market segmentation by insect type 2017 & 2024. Source: Global Market Insights.

[78] Research and Markets (2018). *Edible Insects by Type and Product – Global Opportunity Analysis and Industry Forecast (2018-2023)*

Production

The increase in demand for insect products has created a challenge for scaling up to mass production in an economical, safe and sustainable manner. The relatively high prices of insect containing products are in part due to most insect farms not being scaled up to mass production yet. There are a number of issues discussed in more detail in **Appendix 1**.

Products

Various forms of insect products are available to purchase either as a business (B2B) or a consumer (B2C). Products marketed at businesses, likely consumer product businesses, are often either in whole insect or flour form which provides the purchasing company with flexibility to incorporate the product into their own products. **Entomo Farms** (Canada) are a major supplier of crickets and cricket flour to businesses across the world but also have a few consumer products available for sale. **Aspire Food Group** (USA) also supply a large amount of the market with their crickets and cricket flour. More processed B2B products are also available including **Protifarm's** (The Netherlands) textured, tofu-like insect protein which can be used in meat alternatives.

Consumer facing products sold B2C are more varied due to the addition of processed foods such as snack bars, crisps, baked goods, pasta, meat alternatives and so on. **Bugsolutely** (Thailand) sell cricket pasta whilst various cricket-containing snacks such as crisps and cookies sold by **Bitty Foods** (USA) and **Chirps** (USA). Products marketed at those looking for high protein snacks and beverages are sold in the form of protein powders or protein bars and are marketed by Exo, the brand acquired by **Aspire Food Group** and **Chapul** (USA). **BugFoundation** and **Bold Foods** (Germany) have created insect burgers as a meat alternative product using the textured insect protein from Protifarm.

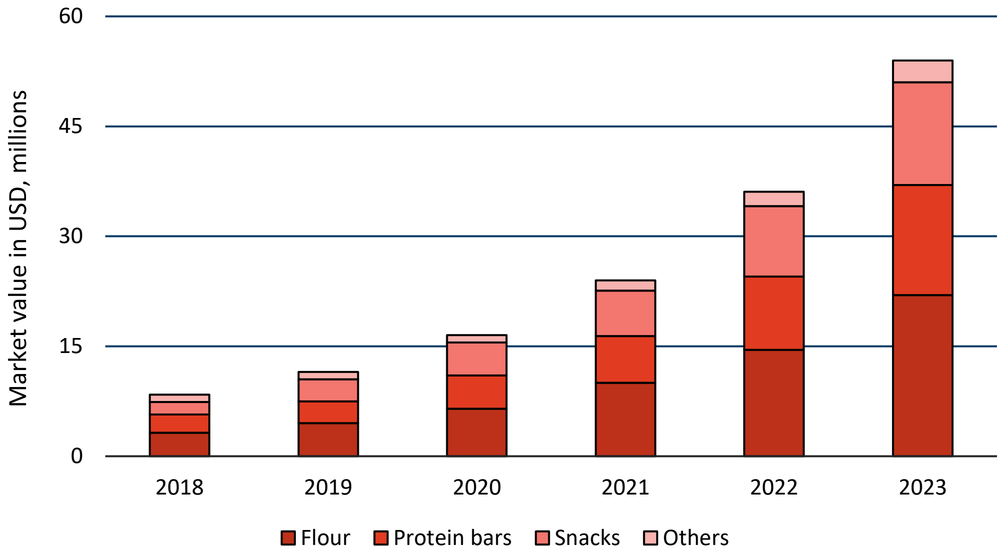
Flour is still a popular product though as this allows consumers to experiment with the new ingredient. Many consumer-facing companies sell flour in addition to their processed snack and meal replacements. Whole crickets usually roasted and seasoned can also be purchased and can now even be found in supermarkets across Europe.

The majority of consumer products use crickets because of their subtle, nutty flavour but a few have explored other insect species. Grasshopper powder is sold by **Hargol FoodTech** (Israel) because of their kosher status whilst **Protifarm** specialises in buffalo mealworms. Protifarm sells a protein concentrate and fibre powder as well as whole buffalo powder.

Products marketed for consumption by animals typically use different insects than those marketed for human consumption. Black soldier fly larvae are very popular with companies such as **Entocycle** (UK), **Enviroflight** (USA), **Protix** (The Netherlands) and **Agriprotein** (UK). Various forms of animal feed using insect protein can be purchased for aquaculture, livestock and companion animals. **Ÿnsect** (France) specialises in premium protein and oil products for feeding pets and for aquaculture using mealworm larvae.

According to Global Market Insights, the global market demand from insect flour was valued over $19.5 million in 2017 and will likely witness significant growth until 2024.[74] The protein bars application will see particularly high growth at a CAGR of 43.5%.

The US market for products marketed for human consumption has also been analysed by Global Market Insights to breakdown by the market by application. The market can be segmented by application into whole insects, animal feed, powder, protein bars & shakes, baked products and snacks, confectioneries, and beverages. Insect protein bars and shakes are expected to be the quickest growing application in the US whilst insect flour continues to make up the majority of the market.



US edible insect market segmentation by application 2018 - 2023. Source: Global Market Insights.

Regulation

On 1 January 2018, new legislation in Europe, Regulation EU 2015/2283 on Novel Food, entered into application. This new regulation is designed to provide a simpler, clearer and more efficient authorization procedure which is centralized at EU level. This will hopefully enable safe and innovative food to be placed on the European market faster. From now on, applications will be assessed centrally by the European Commission with the help of the European Food Safety Authority (EFSA). This new regulation clarifies that whole animals, such as whole insects (if not already consumed to a significant degree in 1997) fall under the definition of Novel Food. Parts of insects (legs, wings) are also considered as Novel Food.

The new EU legislation on novel food does not yet specifically address if final products should be included in the application for a novel food dossier. A novel food dossier shall cover the 'novel' ingredient and not the final product which will be composed of the novel food (e.g. a burger or other food product composed of the insect ingredient). However, information on the future use of the 'novel food ingredient' is preferred for evaluation of its dietary and nutritional significance and to carry on the risk characterization (by EFSA). The EFSA has released a guidance document to help clarify such issues.[79]

In some countries, insect products are already 'lawfully placed on the market' and so certain transitional measures apply. This makes it possible for insect-foods to continue being sold until approval of the Novel Food application.

The International Platform of Insects for Food and Feed (IPIFF) – an umbrella organization for the European insect production sector – has published a guidance document on EU food labelling standards ("FIC Guidance") applicable to insects and insect-based products.

[79] https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2016.4594

3.2.2 ALGAE

Algae, consisting of seaweed and microalgae, represents another promising and novel source of protein. Despite being collectively termed algae, seaweed and microalgae differ greatly; seaweed is a complex, multicellular organism whereas microalgae are single celled organisms that grow in a multitude of environments. Included organisms range from unicellular microalgae, such as *Chlorella* and the diatoms, to multicellular forms, such as the giant kelp, a large brown alga which may grow up to 50m in length. Algae are some of the most common organisms inhabiting the Earth and can be capable of growing in extreme conditions with an estimated 72,500 algal species worldwide.[80]

Algae have been exploited for centuries as both food and feed with suggestions of algae as a candidate for alternative protein as early as the 1950s. In the following years, Japan began the first industrial scale production of the microalgae *Chlorella* which is now one of the most widely consumed algae across the world. By the 1980s, major algae production facilities had been established across Asia, the US, Australia and Israel. In recent years, new designs for production systems and developments in biotechnology more widely have allowed the use of algae in the production of high-value compounds for nutrition and health. Recently, algae have been forecasted to play an important role in supplying the European food and feed market in the next decade.[81] Some predict algae to make up 18% of the alternative protein market by 2050.[82]

Algae produce a broad spectrum of valuable substances including protein, carbohydrates, lipids, polyunsaturated acids including omega-3s, and pigments. It has been shown that the quality of algal protein is comparable or even superior to other plant sources and that algae is a better source of fibre than animal sources of food.[83]

In 2018, the global algae products market was estimated at $2.5 billion and is predicted to grow at a CAGR of 4.2% to reach $3.45 billion by the end of the forecast period of 2018-2025.[84] This market size includes macro- and micro-algae derived products across the applications pharmaceutical and nutraceutical, food and beverage, cosmetics, feed, chemicals and fuel. The food and beverage application is projected to lead the market whilst the personal care segment will likely be the fastest growing application. Asia-Pacific was the largest market for algae products and will see the greatest growth at a CAGR of 6.2%.

A report from the European Commission estimated that roughly 78% of the global algae market can be attributed to macroalgae (seaweed) with the remaining 22% from microalgae.[85] Microalgae in particular have gained interest recently as a promising sustainable alternative protein source thanks to their low land-use, high nutritional benefits and innovations in biomass cultivation.

Microalgae-based proteins have low land requirements compared to animal-based proteins: <2.5 m^2 per kg of protein[86] compared to 47–64 m^2 for pork, 42–52 m^2 for chicken, and 144–258 m^2 for beef production. Land requirements are also lower than for some other plant-based proteins used

[80] Guiry (2012). "*How Many Species of Algae Are There*?" Journal of Phycology. **48** (5), 1057–1063

[81] Vigani et. al. (2015) *Food and feed products from micro-algae: Market opportunities and challenges for the EU*. Trends in Food Science & Technology, **42**, 81-92

[82] Stice & Basu (2015). *The great protein shift: Re-thinking one of the fundamental building blocks of the human diet*

[83] Becker (2006) *Microalgae as a source of protein*. Biotechnology Advances, **25**, 207-210

[84] Allied Market Research (2018). *Algae Products Market: Global Opportunity Analysis and Industry Forecast, 2018-2025*

[85] https://ec.europa.eu/docsroom/documents/13424/attachments/1/translations/en/renditions/native

[86] Krimpen *et. al.* (2013) *Cultivation, Processing and Nutritional Aspects for Pigs and Poultry of European Protein Sources as Alternatives for Imported Soybean Products*. Wageningen UR Livestock Research

for food and feed such as soybean meal, pea protein meal, and others. Microalgae does not need fertile soil or large amounts of fresh water which reduces competition with other food sources such as crop plants through the use of arable land and waste streams.

The growth rate of microalgae is significantly faster than land plant crops with certain species picked specifically for the high growth rates.[87] In closed systems, conditions can be easily optimised to ensure maximum rates of growth which is harder to achieve with the open systems generally required by land crops.

Although the number of microalgae species in nature is estimated between 200,000 and 800,000, only a few are used in food applications.[88] *Nostoc, Arthrospira* (commonly known as *Spirulina*) and *Aphanizomenon* are protein-rich microalgae that have been part of the human diet for thousands of years whilst large scale *Chlorella* production was pioneered in Japan in the 1970s.[89]

Chlorella and *Arthrospira* produce high-quality proteins that are well-balanced in essential amino acids as outlined by the WHO/FAO/UNU recommendations.[90] The quality of microalgae protein has been compared to that of eggs and soybean.[83] Certain species of *Chlorella* have a high protein content of 51-58% dry weight.

Besides proteins, microalgae are source of several valuable compounds with health benefits such as carbohydrates, polyunsaturated fatty acids, essential minerals, and vitamins. Omega-3 polyunsaturated fatty acids are valuable compounds found in abundance in algae. α-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) are some of the omega-3 acids found in microalgae that have reportedly significant health benefits. Additionally, the high levels of polysaccharides and oligosaccharides present in many microalgae are proposed as potential prebiotic candidates.

Persistence Market Research estimated the microalgae market size at $50 million in 2017 and forecasted the market to grow at a notable CAGR of 4.6% over the period 2018-2026.[91] Global sales from *Spirulina* alone are estimated to be close to $40 million by the end of 2026, making up over half of the predicted microalgae market. The food and feed industry will continue to prevail as the leading application of microalgae.

In addition to the high protein content, low land use and nutritional benefits associated with microalgae, the potential source of protein is improved further by its ability to capture carbon. Autotrophic microalgae use CO_2 as a carbon source which reduces the amount of the greenhouse gas in the environment thereby making protein production carbon neutral or even negative.

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[87] Costa *et. al.* (2000) *Modelling of growth conditions for cyanobacterium Spirulina platensis in microcosms*. World J Microbiol Biotechnol **16**, 15–18

[88] Wolkers *et. al.* (2011) *Microalgae: the green gold of the future?* In: Large-Scale Sustainable Cultivation of Microalgae for the Production of Bulk Commodities. Wageningen: Propress; p. 1–34.

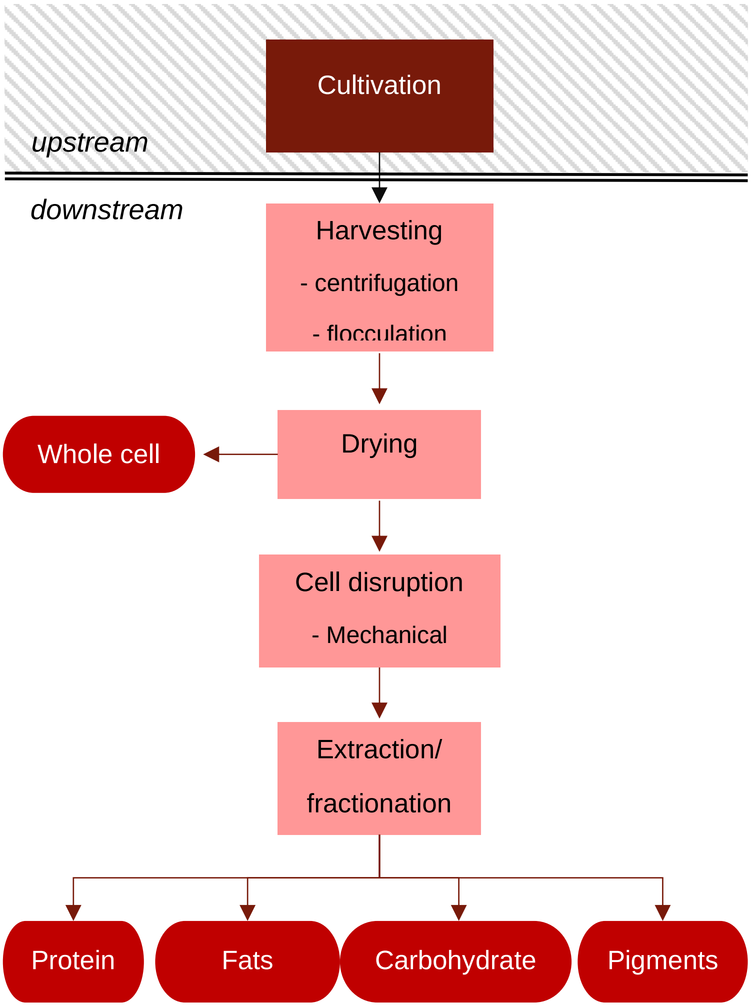
[89] Spolaore *et. al.* (2006) *Commercial applications of microalgae*. J Biosci Bioeng. **101**, 87–96

[90] Chronakis & Madsen (2011) Algal proteins. Handbook of food proteins. In: Phillips GO, Williams PA, editors. Woodhead Publishing Series in Food Sciences, Technology and Nutrition. p. 353–94.

[91] Persistence Market Research (2018) *Global Market Study on Microalgae 2017-2026*

Production

The processing of algae is summarised in the figure below. There are a number of challenges associated with the various steps of production and processing. These are summarised in **Appendix 1**.



Algae processing steps and products

Products

Despite growing research activity around microalgae, the products on the market for food are currently still limited. The current products generally fall into one of two categories, the first of which is dried algae and the second is isolated, high value supplements.

Dried whole cell products made from *Spirulina* and *Chlorella* have the largest production volumes, but their market value is not very high (estimated at $40 million and EUR 34 million in 2005, respectively). *Spirulina* products are sold widely with some of the main sellers including **Hainan Simai Pharmacy** (China), **Earthrise** (USA), **Cyanotech** (USA), **FEBICO** (Taiwan) and **Myanmar Spirulina Factory**. *Chlorella* is sold by **Taiwan Chlorella Manufacturing**, FEBICO and **NOW Foods** (USA). Products derived from Aphanizomenon flos-aquae are also available on the market and sold by **Blue Green Foods** (USA), **Klamath Valley Botanicals** (USA) and **E3Live** (USA).

Microalgae are mainly sold in the form of supplements, available in tablet, capsule or liquid form, but they are increasingly processed as fortifying ingredients which can be included in pastas, baked goods, snacks, and more to increase protein content. **The Algae Factory** (The Netherlands) sells algae-based chocolate bars containing *Spirulina*. **Onemeal** (Denmark) is an instant meal containing *Spirulina, Chlorella* and miso with seasoning developed by Michelin star chefs. *Chlorella* cookies and crackers are sold by **Allma** (Portugal). **Bounce Foods** (UK) have recently introduced a product range using *Spirulina* to increase the protein content of their 'energy balls'. AlgaVia, the brand originally developed by **TerraVia** (USA) and now owned by **Corbion** (The Netherlands), sells whole *Chlorella* ingredients either high in protein or lipids for use in different food formulations ranging from beverages, cereals, condiments, snacks and bakery items. **Odentella** (France) has even developed a microalgae 'smoked salmon' product and aims to expand into other seafood alternatives.

High-value microalgal products including polyunsaturated fatty acids, vitamins and pigments make up a large percentage of the market by revenue but a low portion of the market's volume. For example, products such as β-carotene, astaxanthin, and phycocyanin cost between hundreds to thousands of euros per kg depending on their purity.

Various edible seaweeds products are also sold across the world with the most common varieties including Nori, Carrageen, Kombu, Dulse and Wakame. These products are generally dried or roasted before sale. For example, *P. tenera* (nori) is commonly used as a sushi wrap. Major suppliers of these products include **Acadian Seaplants** (Canada), **North American Kelp** (USA), **Ocean Organics** (USA), **VitaminSea Seaweed Co**. (USA), **Mendocino Sea Vegetable Company** (USA), **Dulse & Rugosa** (USA) and **Irish Seaweeds** (UK).

A number of companies are taking an innovative approach in how they incorporate seaweed into food products. **SeaMore Food** (The Netherlands) have created a number of seaweed-containing foodstuffs including pasta, bacon, wraps and bread. **New Wave Foods** (USA) are developing sustainable 'shrimp' using seaweed, utilising the salty umami taste to recreate seafood.

Regulation

Regulatory restrictions on novel food and novel food ingredients, food safety, nutrition and food health claims can delay the pace of commercialization of algae. Furthermore, the lack of publicly available economic and market information makes it difficult to evaluate their industrial potential which is a hindrance in terms of seeking funding for research and development and for influencing policy. Further territory-specific regulations are discussed in **Appendix 2**.

3.2.3 SINGLE-CELL PROTEIN

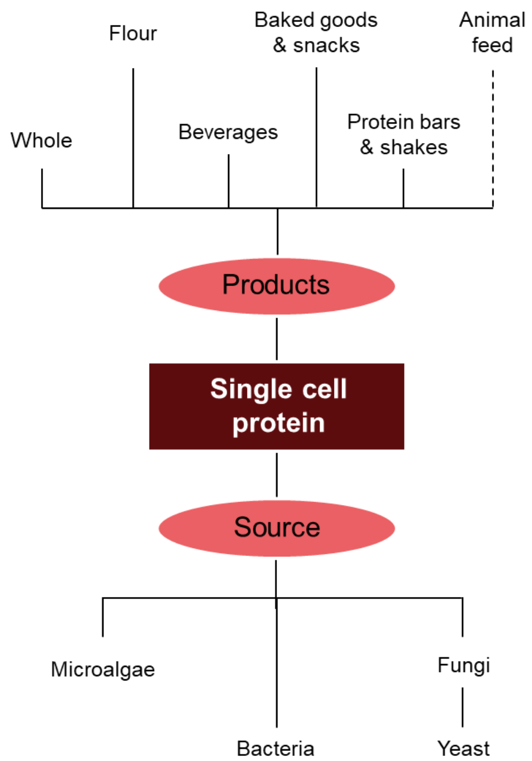
Microalgae are not the only unicellular source of protein being explored to bridge the protein gap predicted over the coming years; bacteria and yeast are also promising food factories. Protein produced in such microorganisms, named single-cell protein (SCP), provides a promising option which allows the use of side streams and carbon capture along with high growth rates to create feed and food.

Products derived from microalgae, fungi (including yeast) and bacteria are all in use or under development. SCP for human consumption is currently limited to a small number of microbial species whilst the range of sources for animal feed SCP is broader and expanding.

A report from Prescient & Strategic Intelligence estimates that the global single cell protein market generated $5.3 billion revenue in 2017 and forecasts the market to grow by a significant CAGR of

8.6% over the period 2018-2023.[92] Applications included in the market size estimation include human food, animal feed, biotechnology and agriculture.

SCP for human consumption is generally produced from food grade substrates, but there is hope that processes will be developed to produce SCP from inexpensive waste materials from the food and beverage processing industries, as well as directly from forestry and agricultural sources. However, regulatory issues must always be taken into account. With the introduction of algae to microbial protein providers, production from CO_2 has become possible, while the greenhouse gas methane can be a source of carbon for SCP from bacteria.



Single cell protein market segmentation by source and product type

Much like the case for insects and algae, single cell protein is particularly popular in the application of animal feed. Palatability and regulatory issues are more easily overcome in feed applications making it an easier route to market. Due to these issues, a circular economy in which waste streams are used as a substrate is more achievable. The animal feed segment therefore makes up a significant portion of the market with several products available to purchase for both livestock and companion animals.

Microalgae, fungi (filamentous fungi and yeast), and bacteria can all be used as SCP. Thus, the distinction between SCP and other protein becomes blurred. Microalgae currently makes up the largest portion of the SCP market at 33% in 2017 with yeast coming in second and bacteria in third.[92]

The definition of SCP is also becoming blurred as products secreted by engineered microorganisms or even animal and plant cell cultures are being developed. Several proteins of animal origin including enzymes as well as food products have been expressed by microorganisms which allows for increased yields without the need for animals.

[92] Prescient & Strategy Intelligence (2018) *Protein extracts from single cell protein sources market (2013-2023)*

Bacteria

Bacteria have long been used as a source of SCP, particularly for animal feed, due to the high protein content (50–80% protein dry weight[93]) and the desirable balance of essential amino acids.[94] Bacterial SCP is particularly high in the amino acid methionine which is often lacking from other SCP sources. However, bacterial SCP has a high nucleic acid content, particularly RNA, which requires further processing steps prior to use. Bacterial SCP also provides some lipids and B vitamins.

Many developments in bacterial SCP have focused on using waste streams as substrates or to valorise waste water treatment. **Nutrinsic,** now owned by **iCell Sustainable Nutrition** (China), uses waste water from the food and beverage industry as a source of nutrients for their bacterial SCP.

Additionally, interest has recently increased in the use of bacterial SCP to combat climate change whilst acting as an important source of protein. **Unibio,** a Danish fermentation specialist company**,** use methane as a carbon source for their methanotrophic bacteria to reduce the amount of natural gas that is flared and therefore, the amount of CO_2 released. Companies such as **Solar Foods** (Finland) and **Novonutrients** (USA) are using bacteria to directly capture CO_2 from industrial emissions as their carbon source for a protein production process that is carbon neutral or even negative.

Fungi

Fungi grown for SCP will generally contain between 30-50% protein and also exhibit a favourable amino acid composition with particularly high levels of threonine and lysine.[95] SCP from fungal sources are also often rich in vitamins from the B-complex group and fibre. Fungi have a moderate nucleic acid content at 7-10% which is still too high for human consumption and therefore requires further processing.

Perhaps the most well-known example of fungal SCP is Quorn from **Marlow Foods** (UK), launched in 1985. Quorn products contain mycoprotein from the filamentous fungus *Fusarium venenatum* which gives a meat-like texture making the protein particularly amenable for meat substitutes. Quorn is likely the only SCP product exclusively marketed for human nutrition and received FDA GRAS designation in 2002. In 2015, Marlow Foods was acquired for £550 million by **Monde Nissan Corp** (The Philippines).

Saccharomyces cerevisiae has been sold for more than a century in yeast extract products such as Marmite (**Unilever** and **Sanitarium Health Food**), Vegemite (**Bega Cheese Ltd**.) and Cenovis (**Gustav Gerig AG**). Yeast extracts are a good source of vitamin Bs as well as protein. The yeast Torula (*Candida utilis*, renamed as *Pichia jadinii*), a widely used flavouring agent high in protein, is sold by **Ohly** under the brand name Provesta. The high levels of amino acid glutamate give Torula its umami salty taste, much like monosodium glutamate (MSG).

Yarrowia lipolytica is another species of yeast source of SCP initially pioneered for animal feed by British Petroleum in the 1970s by using paraffins from oil refineries as a substrate. The American-based **Nucelis,** a subsidiary of **Cibus,** sells a high protein Yarrowia flour for human consumption as well as vitamin D and oils products.

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[93] Anupama & Ravindra (2000). *Value-added food: single cell protein*. Biotechnol. Adv. **18**, 459–479.

[94] Erdman *et. al.* (1977). *Amino acid profiles and presumptive nutritional assessment of single-cell protein from certain Lactobacilli*. Appl. Environ. Microbiol. **33**, 901–905.

[95] Nasseri *et. al.* (2011). *Single cell protein: production and process*. Am. J. Food Technol. **6**, 103–116

Processing

The production steps for SCP are generally the same for different sources and biomass cultivation methods. Production generally include (a) cultivation i.e. fermentation, (b) separation and concentration of SCP and (c) final processing of SCP into ingredients and products.

Further processing such as drying, cell wall degradation and nucleic acid removal may be required. Some SCP requires the cell wall to be broken down to make the protein more accessible. Various methods can be used to disrupt the cell wall including by mechanical force (grinding, homogenisation, sonication), enzymatically or chemically. The appropriate disruption technique should be used to maintain the quality and quantity of the protein. Other SCP such as Quorn and *Euglena* do not need to have their cell walls disrupted with cell wall components adding to the level of fibre.

SCP from bacteria and fungal species usually has a high nucleic acid content which can lead to gout and kidney stones in humans. Therefore, the RNA content of SCP needs to be reduced before consumption is considered safe. RNA degrading enzymes (ribonucleases) are used in Quorn whilst alkali treatment is used in the Pekilo process for *P. varioti*.

Products

There are few SCP products marketed at human consumption with Quorn from Marlow Foods perhaps being the most well-known. Quorn is a texturized meat-substitute made from a single-celled, filamentous fungus and is sold as a range of over 100 products including burgers, sausages, breaded nuggets and ready meals. Quorn products are able to compete with the price of meat products, making SCP more accessible to the general consumer. Other products available to purchase, although not explicitly sold for their high protein content, include yeast extract products Marmite, Vegemite and Cenovis.

In the coming years, we expect to see the launch of products from **Solar Foods**, **Prime Roots** (USA) and **3F BIO** (UK). Solar Foods is currently developing bacterial SCP flour, Solein, with intention to start commercial production by 2021 with the hope to scale to 50 million meals per year by the end of 2022. Prime Roots is aiming to launch its consumer product line consisting of meat and seafood alternatives from ‘lobster’ to ‘chicken tenders’ in 2020, hoping to capture some of the growing meat alternatives market. 3F BIO aims to provide its ABUNDA mycoprotein to food producers to incorporate the alternative protein into consumer products. A consortium of 10 partners including 3F BIO and food producers **Mosa Meat**, **Vivera** (The Netherlands) and **APB Foods** (UK), alongside biorefinery operator **Alcogroup** (The Netherlands), **Wageningen University** (The Netherlands), and ingredients suppliers **IFF** (USA), amongst others, aims to further develop 3F BIO’s technology to create affordable and sustainable high-quality protein.[96]

Proteins derived from microbes which do not fall under the traditional definition of SCP are also coming to market soon. For example, **Perfect Day Foods** (USA) are using genetically modified *Trichoderma* fungus to create the milk proteins casein and whey for animal-free dairy. The milk proteins are separated from the fungus through simple filtration so the final product is acellular. The company ran a successful trial run for its animal-free ice cream during 2019 and plans to market products including cheese, yoghurt and milk in the near future. **Clara Foods** (USA) is developing an animal-free egg white by producing the protein albumen also using genetically modified yeast. It hopes to bring the product to market in the next year or two and use their

[96] https://www.foodnavigator.com/Article/2019/07/23/Affordable-and-scalable-3F-Bio-s-first-of-its-kind-mycoprotein-biorefinery

proprietary microbial fermentation technology to expand to other animal proteins. Animal-free gelatin is being developed by **Geltor** (USA) by producing animal collagen in microbes to replace the commonly used food ingredient traditionally made from the connective tissues of animals. Geltor has also used its platform to create human collagen for use in the cosmetics industry.

Products for animal feed are more common as the regulatory process is simpler and the possibility to use waste streams is more likely. The high nucleic acid content of certain SCP sources is also less of an issue in shorter lifespan animals and so downstream processing is reduced. Marketed products include ProFloc and HiTechPro for swine, poultry and aquaculture from **iCell Sustainable Nutrition**, FeedKind for aquaculture, livestock and pets by **Calysta** (USA), and UniProtein from **UniBio** (Denmark).

Regulation and safety

Regulations differ depending on the intended purpose of the product, and although SCP is expected to be either food or feed (providing nutrition), some products may enter the market as additives (e.g., providing colour), rather than as SCP, even though protein is present in the product, limiting the extent to which they are added and their value as SCP.

Whilst the same route to market approval and regulations for insects and algae apply to SCP, certain additional considerations must be taken into account. Key concerns are the RNA content, toxins produced by microbes (production hosts or contaminants), potential allergy symptoms, and harmful substances derived from the feedstock such as heavy metals.

Some fungi can produce mycotoxins under certain conditions. The initial safety testing for Quorn mycoprotein involved 16 years, with many more years required to gain approval for sale outside the UK.[97] The particular strain of *F. venenatum* does not produce mycotoxins under production conditions, but the process is still carefully monitored to ensure their absence. *Y. lipolytica* is another fungus whose safety has been extensively assessed, demonstrating that it would be safe to use in a variety of food applications, including as SCP.

Bacteria can also produce toxins which can limit their use as SCP. For example, both *Pseudomonas* spp. and *Methylomonas methanica* produce high levels of protein and have been assessed for use as SCP but they can produce dangerous endotoxins. High temperatures can however be used to breakdown the toxins rendering the SCP safe.

The ability to use waste streams to feed SCP sources is one of the main reasons for renewed interest as microorganisms could be used to create a circular economy. However, the origin of feedstock for food for human consumption is heavily regulated. Quorn is produced in a chemically defined medium from glucose, in a well-defined process, which meets good laboratory practice standards. The use of waste streams in creating feedstock for animals however may have slightly reduced safety requirements, hence many of the innovators in the SCP are initially marketing their products at animal feed applications.

Use of genetically modified organisms (GMO) in food and feed has not yet found public acceptance in Europe, although there is more acceptance elsewhere in the world with GMO yeast from bioethanol factories being used as cattle feed in some countries. A wide range of advantages in SCP products from genetic modification has been considered. There is considerable scope for creating SCPs with tailor made, personalized, nutritional composition through genetic modification.

[97] Solomons GL (1987) *Mycoprotein: safety evaluation of a novel food*. Archives of Toxicology 11: S191–S193

3.3 FUTURE FARMING TECHNOLOGIES

The third agricultural revolution, also called the green revolution, saw a huge increase in agricultural productivity due to new agricultural practices, better performance and land efficiency, and selective breeding.[98]

However, the increase in efficiency and production rates has been plateauing. With world population predicted to reach nine billion by 2050, another green revolution will be needed in order to provide food to an extra two billion people while matching the dietary changes in the developing world, and under the threat of climate change.[99] The world must produce 70% more food using less energy, fertiliser and pesticides. With available acreage estimated at just an additional 4%, it is not possible to simply plant more crops.

A fourth agricultural revolution is needed, one with science and technology at its heart.[18] It will need to look at both the demand and the value chain side of the food-scarcity equation, using technology not only for the sake of technology, but to reengineer the value chain.

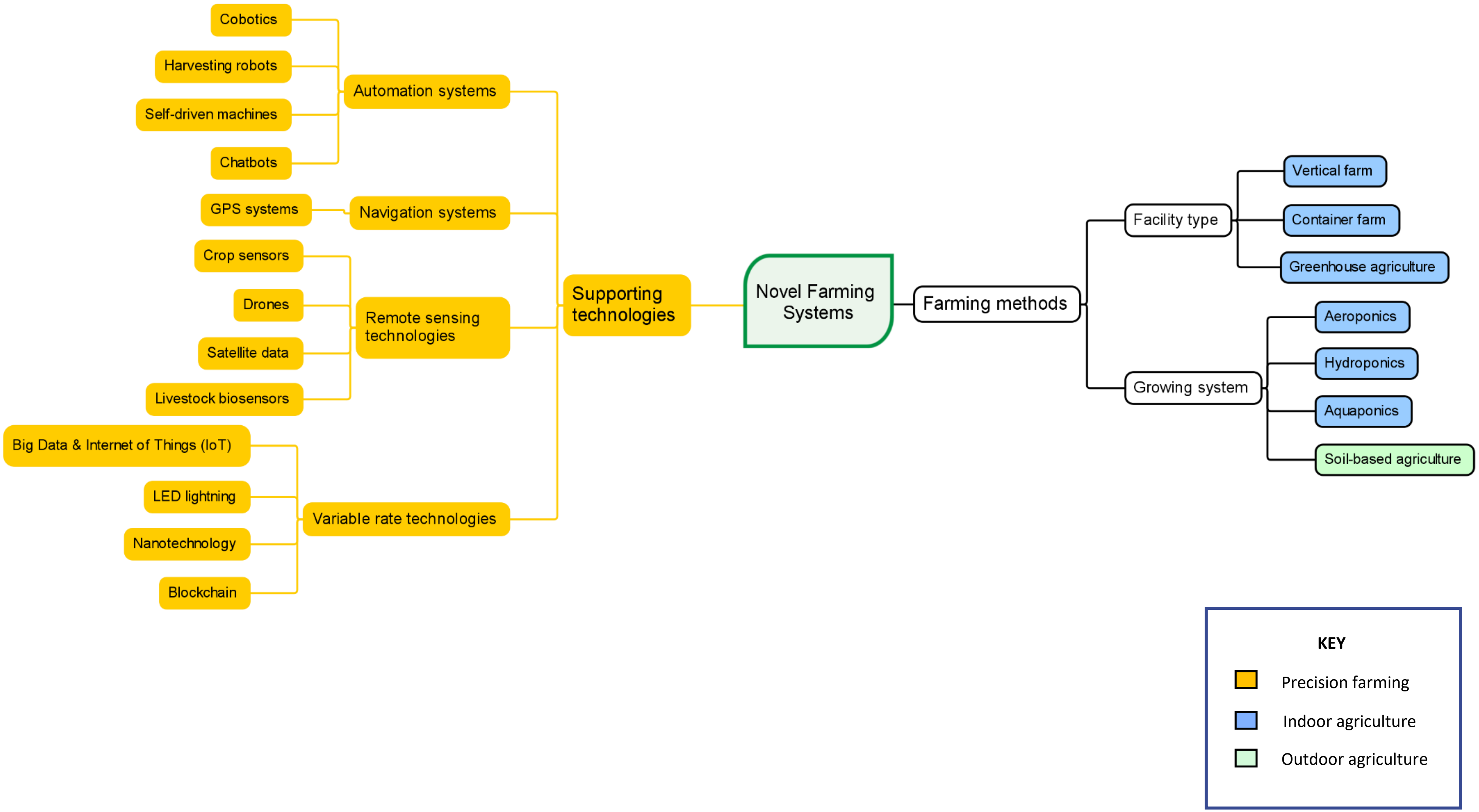
This has already begun – the number of agricultural technology start-ups have grown by more than 80% per year over the last few years and large, well-connected investors from outside the traditional agritech world are becoming involved in a reflection of the expansion of the industry. South Francisco's vertical indoor farming company, **Plenty,** has received funding from **SoftBank Vision Fund**, Amazon's **Jeff Bezos** and former Google CEO **Eric Schmidt**. **AeroFarms** (USA), and aeroponic growing systems company, has received investment from **IKEA**, **David Chang** and the ruler of Dubai, while the US-based global investment company **KKR** has invested $100 million in an arid agriculture firm, **Sundrop Farms** (Australia).[100]

So, will all of our vegetables and greens be grown on stacked shelves in temperature-controlled rooms lit by LED lamps in the near future? This is certainly becoming more likely. Technological advances will change how farms look and operate. Future agriculture will include sophisticated technologies such as robots, aerial images, and temperature and moisture sensors, to name a few. These will make farms more sustainable, more proficient and safer.

The section below discusses some of the leading emerging farming technology systems such as precision agriculture and indoor systems that move beyond traditional greenhouse growing and attempt to replicate and modulate environmental conditions such as temperature, CO2 levels and humidity. This is summarised in the figure below, divided into farming systems and supporting technologies that will enhance the development and adoption of these systems. It is important to note that these elements are not mutually exclusive, but rather tend to be integrated and combined – e.g. vertical farming can be located inside a container, and can use soil-based or non-soil-based systems (aeroponics, hydroponics or aquaponics). Furthermore, it can use LED technologies and crop sensors, along with Internet of Things (IoT) in order to integrate and analyse data for the farmer.

A brief summary of the various technologies and market sectors within the Future Farming Technologies landscape is provided in the sections below**. More detail is provided in Appendix 1**.

[98] https://www.nationalgeographic.com/foodfeatures/green-revolution
[99] http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf
[100] https://www.reuters.com/article/kkr-sundrop-idUSL3N0TO07R20141204


Cobotics
Harvesting robots
Self-driven machines
Chatbots
Automation systems
GPS systems
Navigation systems
Crop sensors
Drones
Satellite data
Livestock biosensors
Remote sensing technologies
Big Data & Internet of Things (IoT)
LED lightning
Nanotechnology
Blockchain
Variable rate technologies
Supporting technologies
Novel Farming Systems
Farming methods
Facility type
Vertical farm
Container farm
Greenhouse agriculture
Growing system
Aeroponics
Hydroponics
Aquaponics
Soil-based agriculture
KEY
Precision farming
Indoor agriculture
Outdoor agriculture

3.3.1 PRECISION AGRICULTURE

Precision agriculture is the use of a broad range of modern technologies in order to tailor resources and conditions more accurately to smaller groups, or even individual crops; rather than to the whole field.

Technologies including satellite position data, remote sensing devices and proximal data gathering technologies are used.[101] This involves using crop sensors to measure temperature and humidity, satellite and/or drone aerial images, robots for harvesting or fruit picking, tractors with GPS controlled routes, and livestock biosensors. The combination of all these with agricultural sciences improves crop health and yield, and reduces weed generation, while using less fertiliser and a reduced human workload.

The use of precision farming technologies is most prevalent in the USA.[102] Use is also growing in other territories around the world, but has a low penetration rate in developing countries due to the technological know-how requirement. While the market is experiencing growth across all regions, Asia-Pacific is expected to show the greatest increase in growth rate. The majority of growth will come from relatively technologically advanced countries like India. However, disorganised agricultural sectors and low technical know-how will halter the adoption of new technologies.

The table below summarises the market size and expected growth rates by technology type to 2021.[102]

Global Market for Precision Farming Technologies, by Type of Technology ($ Millions)

Technology	2016	2021	CAGR %, 2016-2021
Guidance systems	1,280	2,680	15.9
Sensing and control systems	980	1,560	9.7
Variable rate technology	1,010	1,620	9.9
Total	3,270	5,860	12.4

Precision farming is predicted to see new developments and the introduction of new technologies in the near future. Three key future technology developments which will increase the adoption of precision agriculture are:

- Further adoption of autonomous machines
- High-throughput plant phenotyping
- Cobotics – the collaboration between people and robots.[103] In agriculture and farming, this can involve collaboration on tasks including dairy and poultry farming, egg collection and sorting, autonomous milking and feeding, and autonomous cleaning.[104]

Key stakeholders in the precision agriculture market involve industries in a variety of sectors: agricultural original equipment manufacturers (OEMs), seed companies, big data companies, advanced solution providers, suppliers, and research centres. This differs from a past landscape in

[101] https://www.nesta.org.uk/feature/precision-agriculture/
[102] BCC Research (2017) *Precision Farming Technologies and Global Markets*
[103] https://www.vinci-energies.com/en/its-already-tomorrow/towards-smart-industry/cobotics-when-people-and-robots-work-together/
[104] https://cobotintel.com/collaborative-robots-market-finds-use-in-the-food-industry/

which OEMs and suppliers solely dominated the market. It is the emergence and growing usage of new technologies that have created space for additional players to enter. Technologies such as software solutions, GPS and data analytics have made space for big data companies, advanced solutions providers and research companies in the agricultural technology space.

3.3.2 URBAN FARMING

Urban farming is the practice of cultivating, processing and distributing food in or around urban areas. This can also involve animal husbandry, aquaculture, agroforestry, urban beekeeping, and horticulture. Urban farming has been proposed as one ideal solution for the growing population and food security threat, by providing opportunities to produce food locally and reducing the need for food refrigeration, storage and transportation.

The most significant benefits include: freshness of produce, automation-enabled farming and reduced usage of resources. 'Local' produce is becoming increasingly popular, and a younger, new generation of farmers is more likely to want to live in urban areas close to amenities and services rather than in remote rural areas.[105] According to the Food and Agriculture Organisation of the United Nations (FAO), 800 million people worldwide are urban farmers.[106] Furthermore, the Worldwatch Institute reports that this accounts to an astonishing 15 – 20% of the world's food.[107]

While in developing nations most city farmers grow for subsistence, in developed countries urban farming is more often driven by convenience, market opportunity or ideology. The US Department of Agriculture (USDA) affirms that business is booming, judging by demand for its urban ag-related projects.[108]

Some of the high-concept technologies helping to drive this market are reflected by one of the global key players, **Sasaki**, an American design firm which is looking to reinvent the way that 24 million people in Shanghai produce food. It is planning a project that will see a 250-acre agricultural district in Sunqiao produce food more sustainably. The project involves the use of LED lights and nutrient-rich water to grow vegetables.

Some other key players in the urban farming market include **Gothams Green** (USA), **Brooklyn Grange Farms** (USA), **Garden Fresh Farms** (USA), **SproutsIO**, **Edenworks** (USA), **Pasona O2** (Japan) and **Sky Green** (UK).

3.3.3 INDOOR AGRICULTURE

Indoor agriculture is nothing new – the greenhouse industry has been a significant part of the global agricultural supply chain for many years. However, new technologies are revolutionising the sector.

The new wave of innovation has achieved a wider control over variables such as water, carbon dioxide, temperature, moisture, nutrients, and a variety of other factors. These systems are predominantly soil-less, using instead growth media or aeroponic, hydroponic or aquaponic growth techniques.

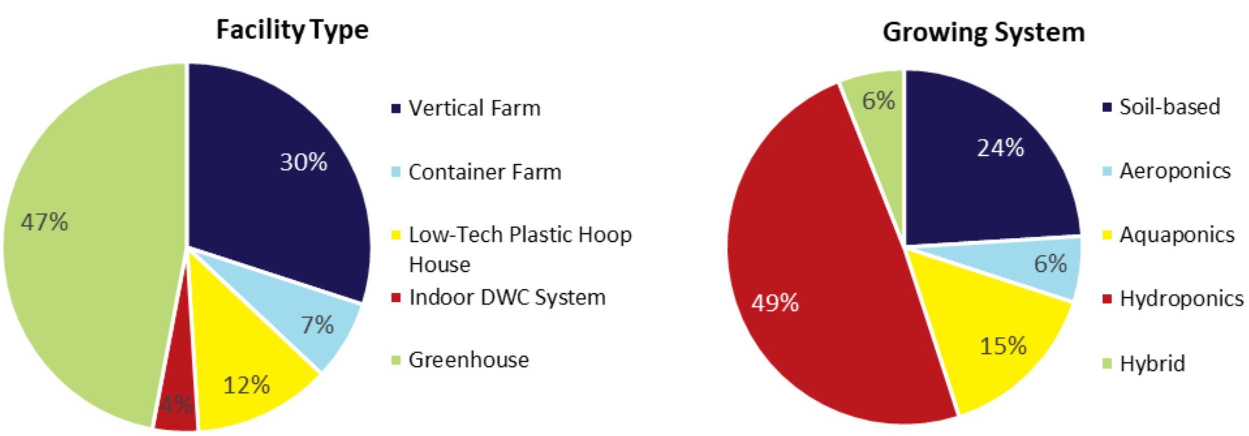
[105] https://ensia.com/features/urban-agriculture-is-booming-but-what-does-it-really-yield/
[106] http://www.fao.org/urban-agriculture/en/
[107] http://www.worldwatch.org/sow11
[108] https://billionfarmers.com/urban-farming-is-booming-but-what-does-it-really-yield/

It is a common misconception that indoor agriculture equates to urban farming – indoor farms usually locate close to the point of sale or where efficiency can be maximised.[109] This can mean locating a rural area close to a distribution centre, or in an urban area close to a grocery shop. This will depend on the crop being grown and specific priorities or needs of the farmer. Because climate is not limiting, there is more freedom to choose the location of a farm.

Indoor agriculture is a blossoming market and there are many types of indoor farms. These include:

Indoor Agriculture Farming Method	Description
Glass or poly greenhouses	Transparent, enclosed structures made out of glass or polycarbonate
Low-tech plastic hoop houses	Semi-circular, tunnel-shaped structure made of steel and polyethylene
Soil-based	Plants are grown in soil
Vertical farms	Fully enclosed opaque rooms with stacked growing systems
Container Farms	Self-contained growing units with (usually) vertical farming and artificial lighting
Aeroponics	Plant roots are suspended in the air and misted with a nutrient solution
Hydroponics	Plants are grown in water instead of soil
Aquaponics	Plants are grown in water that has been used to cultivate aquatic organisms
Indoor DWC	Enclosed and opaque rooms where plants are grown in a deep-water culture system

The indoor farming technology market was valued at $23.75 billion in 2016, and is projected to grow at a CAGR of 9.65% until at least 2022, driven by a growth in demand for fresh and nutritious food and the need for higher yield using limited space.[110] The figures below show the market breakdown in the US in 2017.[109]



US market breakdown of agricultural systems by facility type and growing system, adapted from Agrilyst (2017)

[109] Agrilyst (2017) *State of Indoor Farming*
[110] Markets and Markets (2016*) Indoor Farming Technology Market - Global Forecast to 2022*

One of the big market constraints facing indoor farming is the high cost of operating facilities, which poses a great challenge for farmers. It takes about seven years for an indoor farm to be profitable, and operational costs are often underestimated. The challenges for reaching profitability in this industry is summarised by the profitability breakdown in the charts in Appendix 2.

In order to secure broad market penetration, indoor crop production must become cost-competitive with outdoor crop production.[111] So far, price parity has been achieved for a few high-value crops in certain markets, particularly out of season (e.g. during the winter). As technologies continue to advance, the primary cost drivers of the industry – capital equipment, labour, electricity, and nutrients per harvested plant – will continue to decrease. The industry is expected to see expansion in the near future as existing farmers switch to indoor farming, and grocers, restauranteurs and state entities begin to grow their own produce.

Indoor agriculture will also play an important part in the ongoing reintegration of farms into urban and suburban life. In the future, office atriums could provide food for in-building cafeterias and local restaurants. Green buildings such as **Urbanarbolismo**'s vertical gardens in Spain continue to grow in popularity, complete with rooftop farms, green walls and balcony gardens. Automated in-home systems will be capable of providing families with fresh vegetables and herbs. Indoor farming, however, is not likely to replace outdoor farming at least in the near future. Instead, it will augment the food chain to create a more diverse, distributed system that is more resistant to supply shocks and better prepared to meet the demands of a growing population.[112]

Indeed, as one of the Europe's leading agricultural producers, Spain is also maintaining this position as a key market for indoor farming. For example, Cultivation Management Platform (CMP) company **Artemis** (USA; previously Agrilyst), a leading agritech start-up, is expanding globally. In particular, the company is targeting Spain, where one region (in the province of Almeria) has a complex of plastic greenhouses so large that it reportedly can be seen from space.

The various Indoor Agriculture farming methods are discussed in more detail in Appendix 1 and are summarised briefly below.

3.3.4 SMALL SCALE AND IN-HOME SYSTEMS

Most new farming methods described in this report are adaptable to and even slightly more targeted towards smaller-scale production systems. There is a growing awareness of the health and environmental benefits of consuming local produce. This not only drives up demand for such products, but it has also driven the willingness of people to grow their own produce at home or at work.

The attractiveness of the localised food production concept continues to drive new innovations. For example, Swedish food company **Plantagon** pioneered the idea of a building that provides enough food to feed its occupants. This 'Plantscraper' (also known as the World Food Building), which is planned to be constructed in Linkoping, Sweden, relies on natural and LED light but it is one of the first that plans to cover the entire length of an office building with plants. These vertical farms are integrated directly into the office buildings with the functionality of hydroponic farming.[113]

[111] Newbean Capital *et. al* (2015) Indoor crop production: feeding the future

[112] https://www.urbanarbolismo.es/blog/fachadas-vegetales-urbanarbolismo/

[113] https://www.businessinsider.com/swedens-world-food-building-farm-offices-plantscraper-2017-11?r=US&IR=T

Back in 2015, a USDA report to Congress reported that local and regional food sales in the US totalled \$6.1 billion in 2012 – an increase from the reported \$4.8 billion in 2008.[114] In 2018, BBC Good Food reported 'hyper-local food', referring to dishes created with ingredients sources from walking distance, as one of the 15 food trends for the year.[115]

Small, urban farming systems are predicted to increase, and as a result, it could increase the popularity of new indoors farming methods that can be located in urban areas and within close proximity of their sale point. The main small-scale or in-home systems are container gardening (described above) and raised bed gardening.

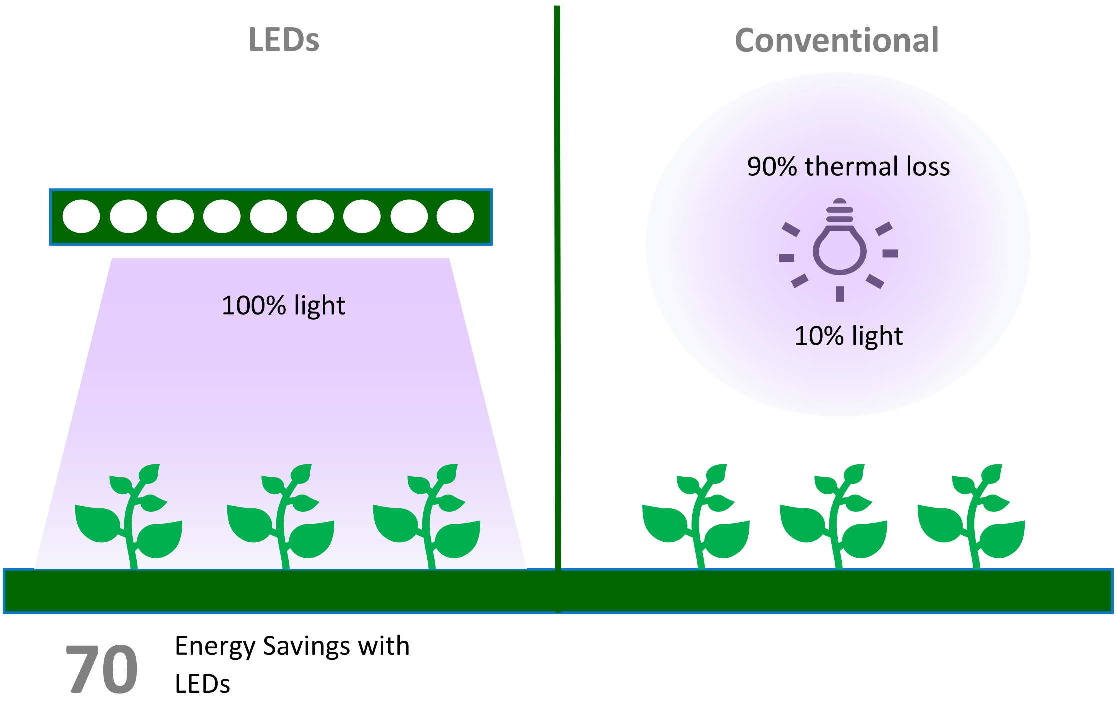
3.3.5 SUPPORTING AND EMERGING TECHNOLOGIES

The growth and diversification of agricultural methods seen in the last few years have been made possible, of course, by the development and cost reduction of new technologies. These include both pre-existing technologies which have been adapted to an agricultural environment, and completely novel innovations which have been designed with this sector in mind to create new methods of growing crops, reduce the use of resources and environmental impact, and will be more sustainable and use less space.

For example, indoor farming has been revolutionised by LED lighting. LED lamps consume less energy and generate less heat compared to traditional lamps, have longer shelf lives and lower maintenance costs.

In 2017, the company **Agrivolution** (USA) announced that its LEDs were chosen for integration into aeroponic vertical systems of the company **Indoor Farms of America**.[116] In order to achieve their goal of growing pesticide-free fruit and vegetables year-round, they have selected some ultra-thin, lightweight triple-band bar-type LEDs. These LED models can not only emit the characteristic blue light of LEDs; but can also emit red and green bands covering all photosynthetically active radiation (PAR) between the wavelengths of 400 to 700 nm. They have been shown to grow larger tomatoes, squashes and cucumbers.

[114] https://www.ecowatch.com/growing-trends-in-the-local-food-movement-show-industry-is-thriving-1882021174.html
[115] https://www.bbcgoodfood.com/howto/guide/15-food-trends-2018
[116] http://www.solidstatelighting.net/indoor-farms-america-selects-led-grow-lights-agrivolution/



Other supporting technologies include:

- Crop sensors and livestock biometrics
- Drone technology and satellite data
- Nanotechnology and enhanced efficiency fertilisers
- The internet of things
- Automation of skills and workforce
- Eco-friendly and sustainable methods of obtaining resources
- Blockchain

These are discussed in more detail in **Appendix 1**.

4 DEALS

A combination of internet-based searching and deal information from subscription databases was used to collate information on collaborations, licensing agreements, investments and acquisitions in the Future Food Sources sectors. In this industry, there are deals being announced on a seemingly daily basis, so the below information should not be considered exhaustive; rather it is an overview of the types of deals being completed.

4.1 ANIMAL PRODUCT REPLACEMENTS

Deal-making for cultured and plant-based meat, is dominated by investments by large food producers or venture capital in innovative start-up companies, rather than, say, public-private research partnerships or licensing deals. New plant-based and cultured meat investment programs are being announced, such as AgFunder's $20m New Carnivore Fund in October 2019 which will be aiming to invest in start-ups between pre-seed and pre-IPO stages.[117]

One notable quirk observed from investments in this space, compared to Future Farming Technologies or Alternative Protein Sources, is that clean meat companies have been attracting investments from high-profile, celebrity backers, such as the actor Leonardo DiCaprio, basketball player Shaquille O'Neal and snowboarder Shaun White, all of whom have invested in Beyond Meat. The company's ambassadors include the musician Snoop Dogg and actor Jessica Chastain. This is a vivid reflection of how technologies in this space are capturing the interest of the public (through the proxy of celebrities) as well as industry players.

4.1.1 CELLULAR AGRICULTURE

The Good Food Institute (GFI) found that 12 cell-based meat companies raised capital worth $50 million in 14 deals in 2018. This was double the capital invested in 2015-2017 combined. At the end of 2018, a total of $73 million in capital had been invested since the field emerged as a commercial industry in 2015. In 2018, 11 new cell-based meat companies were founded, bringing the total number of companies to publicly announce themselves to 27.[21]

Companies working in the cultured/synthetic meat market are investing huge amounts of capital to develop synthetic meat cost-effectively with low fat and high protein content. Companies are focusing on the development of alternative media to foetal bovine serum for growing cultured meat, which is one of the biggest expenses in production. Companies are also trying to modify biorector technology to make it more efficient and able to perform large-scale production. A huge amount of financing is required to overcome these barriers.

The main recipients of these investments comprise just a handful of industry-leading companies, such as **Mosa Meat** and **Memphis Meats**. An overview of these investments is provided in the table below.[11]

[117] https://agfundernews.com/invest-with-us-in-the-protein-revolution.html

Major Funds Raised in the Synthetic Meat Market, 2016-2019

Company	Total Funds Raised ($ M)	Year	Investors
Memphis Meats (USA)	17	2017	DFJ, KBW Ventures, Cargill, Bill Gates, Fifty Years and others
Memphis Meats (USA)	2.8	2016	Westcott LLC, New Crop Capital, Fifty Years and others
Finless Foods (USA)	3.5	2018	Draper Associates, Harrison Blue Ventures, Hemisphere Ventures and others
Future Meat Technologies (Israel)	2.2	2018	Tyson New Ventures, HB Ventures, Agrinnovation fund and others
Future Meat Technologies (Israel)	14	2019	S2G Ventures, Emerald Technology Ventures and others
SuperMeat (Israel)	4	2018	Stray Dog Capital, Starlight Ventures, PHW Group and others
MosaMeat (The Netherlands)	8.64	2018	M Ventures and Bell Food Group
Integriculture Inc. (Japan)	2.72	2018	Real Tech Fund, MTF Co. Ltd., and others

Some governments are proactively investing in cultured meat. However, this investment is not being made available as research funding, which some argue is needed.[118] In 2007 the Netherlands authorities announced an investment of €2m in cultured meat, which ultimately helped lead to the production of the world's first lab-grown burger, and the creation of **Mosa Meat**, but dedicated research funding in other territories has generally not been forthcoming. Rather, the Japanese government, for example, formed part of the seed funding round for **Integriculture** (Japan), which was used for construction of the company's first pilot plant.[119]

In China, consumption of beef production has increased by 20% during 2011–2016. However, domestic production of beef increased only by 8% during the same period. To compensate for rising demand, China is investing in the synthetic meat market, for example, by signing a $300 million "clean-tech" trade agreement deal with Israel to import Israel's lab-grown meat products from companies including **Meat the Future, SuperMeat**, and **Future Meat Technologies**.

Outside the product categories of red meat (burgers in particular) and chicken, other notable investments include:

- **Wild Type** (USA) in 2018 secured a $3.5 million seed round led by **Spark Capital**, with participation from **Root Ventures, Mission Bay Capital**, and a group of angels. Wild Type are developing a synthetic minced salmon that could be used in sushi rolls, where the meat is mixed with sauce and smaller quantities are needed. From there, the company is targeting smoked salmon for bagels, and eventually, salmon fillets.[51]

[118] Ford (2014) *Impact of Cultured Meat on Global Agriculture*. World Agriculture
[119] https://www.livekindly.co/japanese-government-part-of-2-7-million-investment-in-new-clean-meat-brand/

- **BlueNalu** (USA), a synthetic seafood company, received an undisclosed (but "significant") investment from New Crop Capital in 2018[120], and a $20 million investment in September 2019 from Agronomics, an Aim-listed food investment backed by billionaire Jim Mellon, and green venture funds.

Though most deal-making in the industry is focused around investments in start-up companies, there is some evidence of industry-academic partnerships. For example, Professor Yaakov Nahmias is the inventor named on patent application EP3481191 (*Systems and methods for growing cells in vitro*), which has been exclusively licensed from the **Hebrew University of Jerusalem** to **Future Meat Technologies**, a spin-out company founded by Yaakov. Other academic links are evident in prominent companies such as **Mosa Meat** (**Maastricht University**) and **Impossible Foods** (**Stanford University**) which were founded by academics based at these universities.

4.1.2 PLANT-BASED MEAT

The deal-making landscape for plant-based meat is similar in structure to cultured meat, but dwarves it in terms of the level of investment. Plant-based protein companies have attracted $16 billion in investment over the last 10 years, including venture capital funding and acquisitions. In 2017 and 2018 alone, some $13 billion was invested in the sector, according to new reports from **The Good Food Institute**. The number of plant-based deals saw a 39% increase to 46 during 2018 compared to 2017.[21] This figure does include deals in plant-based milks, and other product categories not included in this report, but it does provide an indication of the level of activity in the industry.

In 2018, investors poured $673 million of investment into plant-based meat, egg, and dairy start-ups. As outlined above, the trailblazers in this industry are **Impossible Foods** and **Beyond Meat**. Impossible has raised over $300 million in 2019, and $750 million since its formation, from investors including **Bill Gates**, **Li Ka-shing** (the Hong Kong magnate behind Horizons Ventures), **Temasek** (the Singapore government's investment fund), and **Khosla Ventures**. Other backers of the company include GV, Viking Global Investors, Sailing Capital and the Open Philanthropy Project. **Beyond Meat**, meanwhile, floated with a share spike of 163%, reaching a staggering valuation of over $3 billion in 2019.[121]

Some other recent investments, which are noteworthy on account of being made in products other than burgers, include:

- **Just Inc** raised growth funding in 2019, reportedly around $200 million, mainly from Chinese investors including **CLSA**, the international affiliate of Beijing-based **Citic Securities**.[122]
- **Tyson Foods**, through its corporate venture subsidiary, **Tyson Ventures**, invested an undisclosed amount in **New Wave Foods,** a plant-based shellfish company in 2019.[123]
- **Geltor** (USA), the bio-design company behind plant-based protein Designer Collagen, raised $18.2 million in Series A financing in 2018, led by **Cultivian Sandbox Ventures**. The round includes investment from **GELITA**, the leading global supplier of collagen proteins, and **ADM**

[120] https://www.foodnavigator-usa.com/Article/2018/06/16/BlueNalu-enters-cellular-aquaculture-space-with-funding-from-New-Crop-Capital

[121] https://agfundernews.com/impossibles-whopper-300m-round-opens-doors-to-asia-europe.html

[122] https://pitchbook.com/news/articles/just-inc-raising-200-million-amid-controversial-past

[123] https://ir.tyson.com/news/news-details/2019/Tyson-Ventures-Invests-in-New-Wave-Foods/default.aspx?mod=article_inline

Ventures, the venture investing arm of global food and feed ingredient provider, **Archer Daniels Midland Company**.[124]

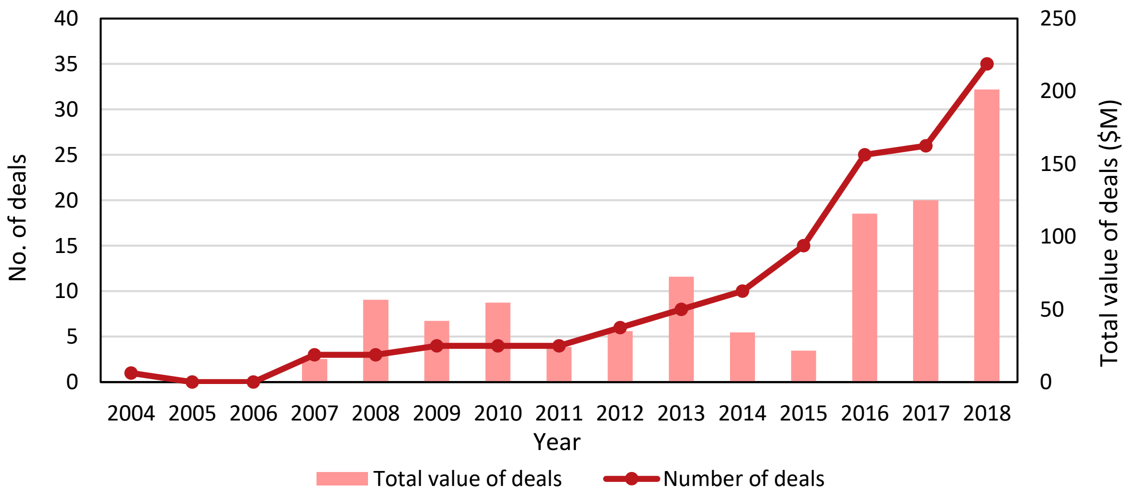
However, despite the booming investments in plant-based meat, there is scepticism amongst some investors regarding the sustainability of enterprises receiving “too much” money or growing too quickly. To some, the concern is that “most start-ups die of indigestion not of starvation”.[125] In an industry growing “too quickly”, as soon as a start-up hits a bump in the road, it will be “the first money out the door.” As a result, follow-on investments will be rare, and start-ups are likely to see demotivating and bad term sheets in their next funding rounds. Following the bumper valuation of **Beyond Meat**, some commentators have suggested that Beyond Meat’s competitors now imagine that their valuations have tripled, and now want three times as much money or give three times as little of their company to the investor.[125]

Indeed, three months after its valuation, Beyond Meat’s mixed earnings results sent stock of the New York Stock Exchange-listed company down 15%, and had investors betting against it.[126]

Tom Mastrobuoni of **Tyson Ventures** has stated that, for investors, “there is no choice but to walk away when faced with excessive valuations”.[125] It is perhaps telling, then, that soon after Beyond Meat’s IPO, **Tyson Foods** had ended its investment in the company, selling its 6.52% share to an undisclosed buyer. However, the reason for this divestment may be that Tyson is creating its own line of private label alternative meat products.[127]

4.2 ALTERNATIVE PROTEIN SOURCES

Interest in alternative sources of protein has waxed and waned numerous times in the last few decades but the substantial increase in deal number per year over the last 10 years suggests that investors are taking this wave more seriously and are willing to get involved.

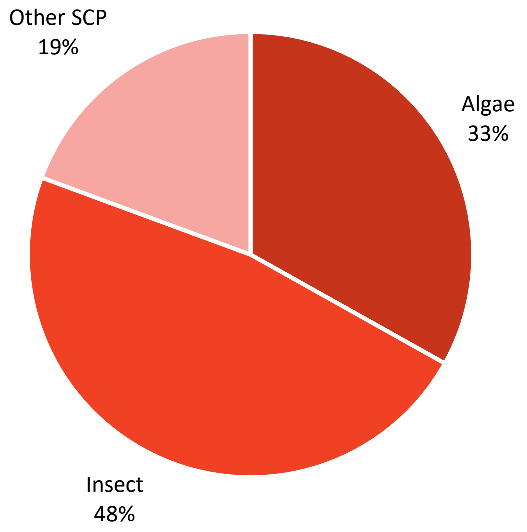


The number and total value of deals from 2014-2018. Deals include venture funding, grants, acquisitions and crowdfunding

[124] https://www.globenewswire.com/news-release/2018/10/25/1626988/0/en/Geltor-Announces-Series-A-Funding-from-Cultivian-Sandbox-Ventures.html
[125] https://agfundernews.com/can-alternative-protein-startups-justify-their-climbing-valuations.html
[126] https://www.cnbc.com/2019/07/30/beyond-meat-sinks-after-earnings-missseven-experts-on-what-comes-next.html
[127] https://agfundernews.com/beyond-meat-ipo-30x-oversubscribed-as-financial-losses-tyson-exit-fail-to-phase-investors.html

The majority of these deals have taken place in the insect space with some record-breaking investment rounds, particularly in the insects for animal feed application. Some of these major deals include:

- **Ÿnsect**'s $125 million series C in 2019
- **AgriProtein**'s $105 million fundraising in 2018 from undisclosed investors
- **InnovaFeed**'s $44.5 million round in 2018



Proportion of deal numbers segmented by protein source

According to the insect manufacturer Protix, the worldwide insect protein market reportedly generated a total of $300 million worth of investments in 2018 alone.[128]

Whilst the insects for human consumption have seen a smaller degree of investment, both in terms of deal numbers and size of deals, fundraising and grants have still been received in this area including:

- **Exo's** $4 million series A in 2016 and $1.2 million seed in 2014
- **Bitty Foods** raised a $1.2 million seed round in 2016

Consumer facing products companies such as **Crik Nutrition**, **Entomo Farms** and **Chapul** were successful in using crowdfunding to grow their businesses using platforms such as **IndieGoGo**, **Sowefund** and **Kickstarter**, respectively. Entomo Farms successfully raised over $1 million through the French crowdfunding platform Sowefund in 2016.

The growing interest in the insect protein market is further reflected by the involvement of major food and feed companies investing or partnering with companies in the space.

- **PHW Gruppe** invested an undisclosed amount into **Bugfoundation** and **EnterraFeed** in 2018
- **Maple Leaf Foods** invested an undisclosed sum into **Entomo** Farms in 2018

[128] https://www.foodingredientsfirst.com/news/the-buzz-around-insect-protein-protix-inaugurates-%E2%82%AC45-million-facility-in-the-netherlands.html

- **Cargill** Animal Nutrition's strategic partnership with **InnovaFeed** started in 2019

Several acquisitions have taken place in the insect space, largely involving one larger insect producer acquiring a smaller insect company to either expand into a different market, i.e **Proti-farm**'s acquisition of **Kreca** in 2014 to serve both the human and animal markets, or to own a consumer facing brand as was the case in **Aspire**'s acquisition of **Exo** in 2018. Companies far outside of the insect market have bought into the market too, for example **Intrexon**, an American biotechnology company focused on human and animal health, acquired **EnviroFlight** in 2016 to create black soldier fly larvae-based feed for aquaculture and livestock.

It is not just the insect area that has been successful in raising funds however, with over a third of the deals found involving algae companies. Some of the most interesting deals include:

- **Solazyme** $52 million series D in 2010 following a $45 million series C in in 2008
- **EnerGaia** $3.65 million series A in 2019
- **Triton Algae Innovations** $5 million for both their series A and series B rounds in 2013 and 2015, respectively
- **Corbion's** acquisition of **TerraVia** (previously **Solazmye**) assets in 2017 for $20 million
- **AlgaTechnologies** acquisition by **Solabia** in 2019 for an undisclosed sum

Single cell protein outside of microalgae has also seen a recent uptake in investment and other deals with some of the major deals including:

- **Calysta** $40 million Series D in 2017 to add to their many other big raises
- **Sustainable Bioproducts** $33 million Series A in 2019
- **Nutrinsic's** $12.7 million series C in 2014 following a $12.7 million series B in 2013

The recent investment round by Sustainable Bioproducts in 2019 included the venture arms of Archer Daniels Midland, one of the world's largest food commodities and processing companies, and Danone, a multinational food products company. The involvement of such major food products and processing companies in a large round signal an interest from industry in single cell protein for human consumption.

For the whole alternative protein market, both grants and accelerator programmes have been important for the growth of companies in this space. For example, the **Bill and Melinda Gates Foundation** have supplied grants to **All Things Bugs**, **EnergGaia** and **AgriProtein** whilst **Innovate UK** have supported **Entomics**, **Entocycle**, **Beta Bugs** and **Feed Algae**. Accelerator programmes **RebelBio, IndieBio** and **Food-X** from venture capital firm **SOSV** have supported a number of companies through education, mentoring and seed money including the likes of **Hexafly**, **New Wave Foods**, **Prime Roots**, **Spira** and **Nonfood**.

Partnerships have been and will continue to be key to overcoming barriers that alternative protein sources face such as consumer perception, palatability and scalability. 3F BIO recently became part of a consortium of 10 partners including 3F BIO and food producers Mosa Meat, Vivera and APB Foods, alongside biorefinery operator Alcogroup, Wageningen University and ingredients suppliers IFF amongst others which aims to create sustainable and appetising food from mycoprotein.[96]

4.3 FUTURE FARMING TECHNOLOGIES

The rapid growth of the market has resulted in many deals, funding and collaborations taking place. In many cases these collaborations are between a novel agri-tech company and a supermarket or other food production company. For example, in October 2019, UK retailer **Marks & Spencer** signed a deal with German start-up **InFarm** to sell some of its fresh produce. In June 2019, **Ocado**, the online supermarket, confirmed it would invest £17 million in developing indoor farms, and in doing so created a venture with US vertical farming company **80 Acres Farms** and the Netherland's-based technology supplier **Priva**.[129]

Investment in urban indoor farming is rapidly growing. Indoor farming start-ups growing fruits and vegetables globally have raised $285 M since the start of 2017, with particularly large rounds for US-based vertical farms pushing the sector to its highest ever investment levels, according to AgFunder data.[130] There is an increase in investment firms which are focused specifically on vertical farming and controlled environment agriculture, such as AgFunder. From 2016 to 2017, venture capital funding for vertical farming increased by 653% from $36 million to $271 million.[131]

Increased funding can be partly attributed to cost reductions across the life sciences and technology sectors, which have allowed toolsets that were previously cost-prohibitive to be applied to agriculture.[132] Furthermore, there is a growing recognition that the challenges facing global agriculture, as a result of climate change and population increase, represent a significant opportunity for innovation, investment and commercial growth.[133] However, notably, the indoor farming sector is littered with bankruptcies as a result of companies underestimating the running costs of these types of farm.[129] According to venture capitalists, energy costs tend to be difficult to mitigate unless you have a deal with a power utility. Most of the companies that have succeeded in the sector are limited to production of high-end herbs and leafy greens, in order to be able to be profitable despite the high energy costs.

Some of the notable investments in indoor/vertical farming companies that are poised to transform agricultural practices are outlined below.

The indoor farming company **Plenty** has attracted more than $200 million in investment from global investors including Softbank, in what is the largest technology investment in the agricultural industry to date.[134],[135] These funds will be used to expand globally, including the construction of a 9,300 m^2 farm in Washington, twice the size of their San Francisco farm.

AeroFarms is another company in this space that has been particularly active. It has raised $142.9 million to date. In November 2017, they closed a US$40 million Series D round to increase staff and expand globally.

BrightFarms (USA) and **Bowery Farming** (USA) have raised a total of $112.9 and $141 million to date, respectively. During their latest Series D round in 2018, BrightFarms has raised US$55 million which

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129 https://www.ft.com/content/56f49550-d617-11e9-a0bd-ab8ec6435630
130 https://freshboxfarms.com/2017/10/06/invest-leafy-green-indoor-agriculture/
131 https://i3connect.com/tag/vertical-farming
132 https://www.futurefarming.com/Smart-farmers/Articles/2018/12/2-billion-expected-to-be-invested-in-agtech-in-2018-368075E/
133 https://innovateuk.blog.gov.uk/2016/10/25/agri-tech-a-growing-opportunity/
134 https://www.bloomberg.com/news/articles/2017-07-19/softbank-s-vision-fund-leads-200-million-bet-on-indoor-farming
135 https://www.businessinsider.com/food-investment-vertical-farming-2017-8?r=US&IR=T

will largely go toward building more greenhouse facilities and expanding the company's geographical footprint.[136]

Infarm (Germany) has recently raised $25 million in Series A funding (Feb 2018) and received a further €2.5 million grant from the European Commission as part of the Horizon 2020 program. This brings the total raised by the Berlin-based company to $34.1 million. The new capital will be used for international expansion and to further develop its 5 000 m^2 R&D centre. The aim for Infarm is for 1000 farms to be operational across Europe by the end of 2019.

Agricool (France), a company that grows and produces fruits and vegetables inside shipping containers, has raised a total of $41.4 million in funding over four rounds, most recently in December 2018. Competitors **Freight Farms** has raised a total of $12.2 million in funding over five rounds.

[136] https://agfundernews.com/breaking-brightfarms-doubles-funding-55m-series-d.html

5 KEY PLAYERS

The key players in the Future Food Sources industries were identified using information from subscription databases, market reports, press articles, internet-based searching, and academic and patent literature. The landscape is dominated by relatively young start-ups, several of which are rapidly expanding and leading their industry segments.

In the case of the Animal Product Replacements segment in particular, leading companies are securing huge investments and are often partnering (rather than competing) with multinational corporations and food chains.

The relatively early stage of many of the Future Food Sources market segments means that in some respects the early market leaders represent something of an acid test for the industry, and continue to be watched with interest by many industry observers.

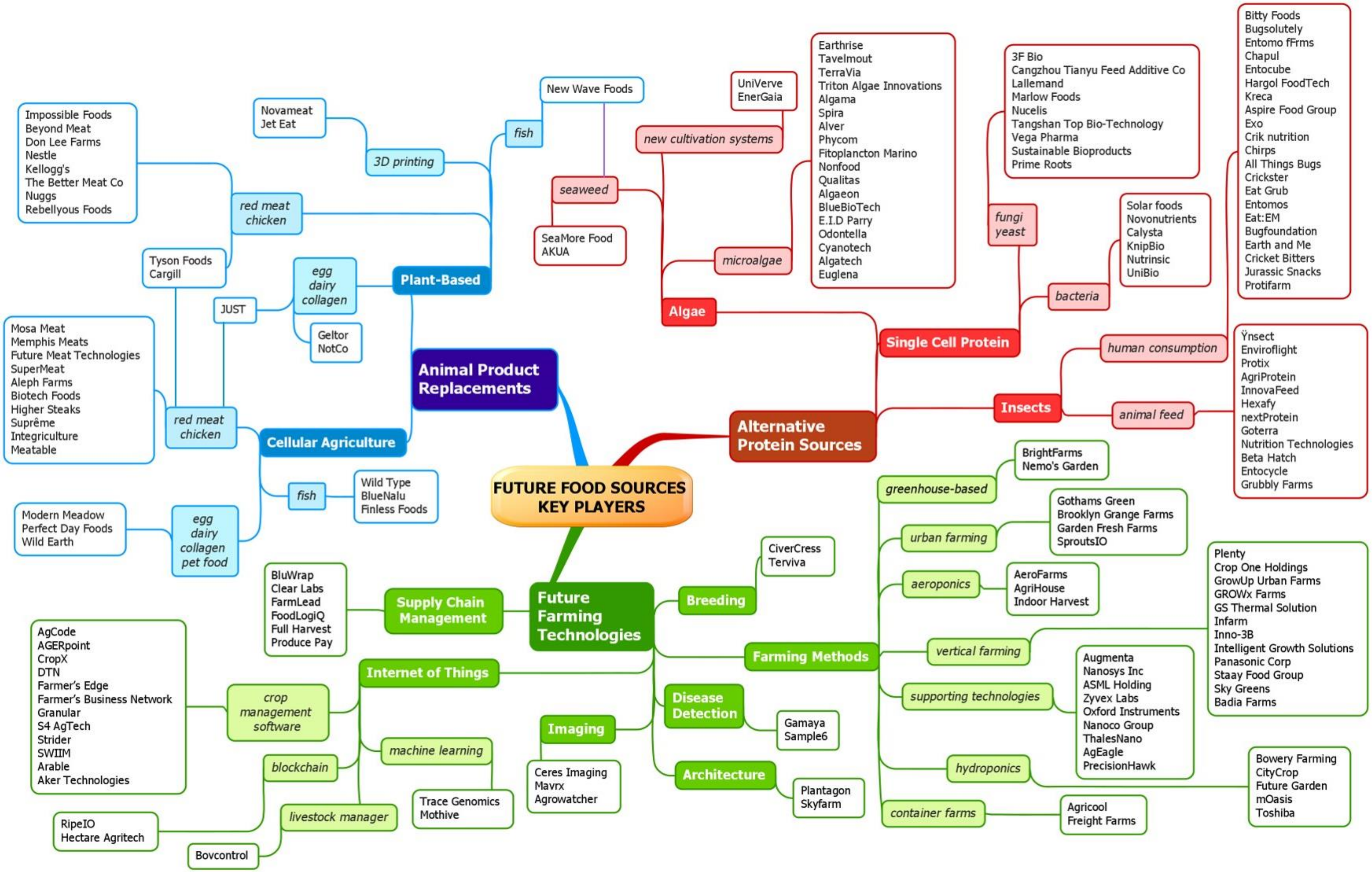
The key players are mapped according to sector and main technology areas in the Figure below. For the purposes of this white paper, we have provided more detail on a few prominent companies in each industry sector in the sections which follow. It should be noted that for Future Farming Technologies, many companies are working in more than one sector. For instance, **CityCrop** (UK) works across the hydroponics, vertical farming and software sectors. In order for the Figure below to be as clear as possible, we have categorised such companies under what we consider to be their main discipline.

An increasing number of multinational companies are moving into the industry. For instance, **McCain Foods** recently invested in plant-based chicken nugget company, **Nuggs** (USA).[137] Many other examples of similar deals are listed throughout this report. The extended network of industry players is large and growing. Therefore, for the purposes of this paper, the key players featured below are those most actively involved in product or company development.

The list of investors in the Future Food Sources industry is extensive and diverse, and is not the main focus of this report. Investors are discussed throughout the above sections and are not included the summary below. Academic players are also discussed separately, in the Research Landscape section below.

New companies and products are appearing on a regular basis, so the below summary should not be considered exhaustive.

[137] https://www.gigabitmagazine.com/big-data/meet-future-plant-based-lab-grown-meat-industry-tomorrow


FUTURE FOOD SOURCES KEY PLAYERS
Animal Product Replacements
Plant-Based
red meat chicken
Impossible Foods
Beyond Meat
Don Lee Farms
Nestle
Kellogg's
The Better Meat Co
Nuggs
Rebellyous Foods
3D printing
Novameat
Jet Eat
fish
New Wave Foods
egg dairy collagen
JUST
Geltor
NotCo
Tyson Foods
Cargill
Cellular Agriculture
red meat chicken
Mosa Meat
Memphis Meats
Future Meat Technologies
SuperMeat
Aleph Farms
Biotech Foods
Higher Steaks
Suprême
Integriculture
Meatable
fish
Wild Type
BlueNalu
Finless Foods
egg dairy collagen pet food
Modern Meadow
Perfect Day Foods
Wild Earth
Alternative Protein Sources
Algae
seaweed
SeaMore Food
AKUA
new cultivation systems
UniVerve
EnerGaia
microalgae
Earthrise
Tavelmout
TerraVia
Triton Algae Innovations
Algama
Spira
Alver
Phycom
Fitoplancton Marino
Nonfood
Qualitas
Algaeon
BlueBioTech
E.I.D Parry
Odontella
Cyanotech
Algatech
Euglena
Single Cell Protein
fungi yeast
3F Bio
Cangzhou Tianyu Feed Additive Co
Lallemand
Marlow Foods
Nucelis
Tangshan Top Bio-Technology
Vega Pharma
Sustainable Bioproducts
Prime Roots
bacteria
Solar foods
Novonutrients
Calysta
KnipBio
Nutrinsic
UniBio
Insects
human consumption
Bitty Foods
Bugsolutely
Entomo fFrms
Chapul
Entocube
Hargol FoodTech
Kreca
Aspire Food Group
Exo
Crik nutrition
Chirps
All Things Bugs
Crickster
Eat Grub
Entomos
Eat:EM
Bugfoundation
Earth and Me
Cricket Bitters
Jurassic Snacks
Protifarm
animal feed
Ÿnsect
Enviroflight
Protix
AgriProtein
InnovaFeed
Hexafy
nextProtein
Goterra
Nutrition Technologies
Beta Hatch
Entocycle
Grubbly Farms
Future Farming Technologies
Supply Chain Management
BluWrap
Clear Labs
FarmLead
FoodLogiQ
Full Harvest
Produce Pay
Internet of Things
crop management software
AgCode
AGERpoint
CropX
DTN
Farmer's Edge
Farmer's Business Network
Granular
S4 AgTech
Strider
SWIIM
Arable
Aker Technologies
machine learning
Trace Genomics
Mothive
blockchain
RipeIO
Hectare Agritech
livestock manager
Bovcontrol
Imaging
Ceres Imaging
Mavrx
Agrowatcher
Breeding
CiverCress
Terviva
Disease Detection
Gamaya
Sample6
Architecture
Plantagon
Skyfarm
Farming Methods
greenhouse-based
BrightFarms
Nemo's Garden
urban farming
Gothams Green
Brooklyn Grange Farms
Garden Fresh Farms
SproutsIO
aeroponics
AeroFarms
AgriHouse
Indoor Harvest
vertical farming
Plenty
Crop One Holdings
GrowUp Urban Farms
GROWx Farms
GS Thermal Solution
Infarm
Inno-3B
Intelligent Growth Solutions
Panasonic Corp
Staay Food Group
Sky Greens
Badia Farms
supporting technologies
Augmenta
Nanosys Inc
ASML Holding
Zyvex Labs
Oxford Instruments
Nanoco Group
ThalesNano
AgEagle
PrecisionHawk
hydroponics
Bowery Farming
CityCrop
Future Garden
mOasis
Toshiba
container farms
Agricool
Freight Farms

5.1 ANIMAL PRODUCT REPLACEMENTS

Most companies within the cultured meat industry are racing to develop quality meat at reasonable prices. Companies are acquiring funding from venture capitalists, banks and industry partners. Companies are using venture capital funding to acquire new advanced bioreactor technologies for large scale production facilities, with the aim of products reaching the market in 2021 or sooner. Some of the leading companies within the synthetic cultured meat market include **Mosa Meat, Memphis Meats, Modern Meadow, Future Meat Technologies** and many more summarised above.

The plant-based meat substitute market is already well-established.[58] This is dominated by well-known soy- and mycoprotein-based products, as well as traditional "veggie burgers" made from – and with a texture closer to – beans or chickpeas, for instance. The focus of plant-based 'meat' in this report, however, is on companies developing products which more closely mimic the fibrous structure, bite, and flavour of conventional meat products. This market is, for the time being, completely dominated by **Impossible Foods** and **Beyond Meat**, and their flagship burger products.

5.1.1 IMPOSSIBLE FOODS

Impossible Foods (USA) was founded in 2011 by Prof Patrick Brown (**Stanford University**) as a fundamental way to tackle the environmental damage of animal agriculture. The company's signature product, the plant-based Impossible Burger, was launched in July 2016, after years of research and development. The company also makes a plant-based sausage product that started being tested on pizzas sold by Little Caesars restaurants in May 2019.

The FDA approval of the company's heme ingredient was initially limited to products cooked in restaurants because soy leghemoglobin needed approval as a new food colorant for uncooked products. An FDA rule change that approves the colourant and allows the sale of Impossible Burgers in grocery stores took effect on September 4, 2019.

In March 2017, Impossible Foods announced it would build its first large-scale plant in Oakland, California to produce 1 million pounds of plant-based burger meat per month, and then in 2019 unveiled a co-manufacturing collaboration with global food provider **OSI Group** to further ramp up production of the Impossible Burger.

The company has raised upwards of $750 million since 2011 from investors including Bill Gates, Li Ka-shing, Temasek, and Khosla Ventures. In 2019, the total valuation of the company was raised to $2 billion.[138] The public profile of Impossible Foods is being further raised by recent celebrity investors, such as the musicians Jay-Z and Katy Perry, tennis player Serena Williams and comedian Trevor Noah.

The leading industry position of the company in the plant-based meat industry is cemented by the fact that the Impossible Burger is now on the menu at major chain restaurants such as Burger King, White Castle and numerous others.

5.1.2 BEYOND MEAT

Beyond Meat was founded in 2009 as a California-based start-up by vegan Ethan Brown, who had previously worked as a clean energy and environment analyst. The company received initial venture funding from Kleiner Perkins, Obvious Corporation, Bill Gates, Biz Stone, the Humane Society and

[138] https://www.reuters.com/article/us-impossible-foods-fundraising-exclusiv-idUSKCN1SJ0YK

Tyson Foods, and in total has now raised close to a quarter of a billion dollars to grow its line of plant-based meats.

Beyond Meat was valued at over $3 billion after a blockbuster IPO in May 2019. Though this is regarded as a massively inflated valuation by some analysts, the company has continued to grow, upping its sales forecast to exceed $240m in the current fiscal year, an increase of more than 170% against 2018.[139]

The company began selling its plant-based, mock-chicken products in Whole Foods supermarkets across the US in April 2013. In 2014, it developed a simulated beef product, which would become its Beyond Burger, for which it is now best known. The burger is known for its 'bleeding' effect created by beetroot juices used in production to better mimic the appearance and colour of red meat.

Like its competitor Impossible Foods, the Beyond Burger is sold at multiple nationwide grocery chains and fast food restaurants in numerous countries, and also like Impossible Foods, Beyond Meat has achieved huge visibility through its celebrity investors and endorsements, and the company has recently opened a 26k square foot research facility, which will enable the company to greatly expand distribution and develop new products.

However, Beyond Meat is currently being sued by **Don Lee Farms** for fraud, negligence and breach of contract.[140] The Beyond Burger was solely manufactured by Don Lee Farms under an exclusive supply agreement in 2016. After the success of the new burger, Beyond Meat walked away from the agreement in 2017 and transferred all production and processes developed under the agreement to other food manufacturers. During its agreement, Don Lee Farms claims to have shared trade secrets, know-how and technology which the family food company developed over 35 years. Don Lee Farms has, in November 2019, now started selling its own Better Than Beef Burger through a partnership with wholesale chain **Costco**.[141]

5.1.3 MEMPHIS MEATS

The California-headquartered company aiming to grow sustainable cultured meat was co-founded in 2015 by Uma Valeti, a cardiologist and a professor at the University of Minnesota. In August 2017 the company announced that it had raised a $17 million Series A funding round led by **DFJ**, and also included investment from Richard Branson, Cargill, and serial clean meat investor, Bill Gates.

As of June 2017, the company had reduced the cost of production of cultured beef to below $2,400 per pound ($5,280/kg), and anticipates cost reductions and commercial release of its products by 2021. Using its recent investment, Memphis Meats expects to scale up its production process, develop new products and reduce production costs with the funding received. Indeed, following on from producing the world's first cultured beef meatball, the company has now succeeded in making "clean" chicken and duck.

In 2018, the company received an undisclosed investment from **Tyson Foods Inc**. Tyson Foods is one of the major suppliers of conventional beef in the country and is expected to advise Memphis Meats on scaling up its business to achieve its goal of going commercial in 2021.

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[139] https://www.ft.com/content/baf27eba-b21c-11e9-bec9-fdcab53d6959

[140] https://www.businesswire.com/news/home/20190307005952/en/Meat%C2%AE-Sued-Fraud-Negligence-Breach-Contract-Don

[141] https://www.businessinsider.com/costco-to-sell-plant-based-burger-rivals-beyond-meat-2019-9?r=US&IR=T

5.1.4 JUST

JUST Inc is headquartered in San Francisco, and was founded in December 2011, formerly in the name of Hampton Creek Foods Inc. The company has the widest portfolio interests of all the companies discussed in this white paper producing both plant-based and cultured foods that are sold globally. Products also include cookie dough, cookies, dressings, breakfast proteins and mayonnaise. Just Meat (and seafood) is made from cells instead of the slaughter of animals.

Its best-known product is possibly JUST Egg, made from water, mung bean protein isolate, canola oil, gums, and seasonings, and is designed to look, cook, and taste like scrambled egg. The product is now widely available and in February 2019, the company shipped what would be equivalent to its three millionth egg.[68] Combined with its interests in cultured meat products described previously, JUST is expanding globally. US customers will soon be able to find Just Egg in the egg aisle at supermarket chains like **Kroger**, **Ralphs** and **QFC**.[142] JUST says it is the first food tech company to enter mainland China, selling its JUST egg product in supermarkets, restaurants and through e-commerce companies as a result of relationships with Chinese companies like **Alibaba**. JUST will also be selling in Europe, thanks to its new partnership with **Eurovo**, a European producer of packaged and pasteurized egg products that will sell JUST Egg alongside its conventional products in supermarkets.[10]

In terms of cultured meat, **JUST** announced a partnership with **Toriyama Ranch**, a Japanese producer of Wagyu beef (a type of meat that includes the prized Kobe steaks) in 2018. JUST will use the Wagyu cow cells to grow beef, initially in the form of ground meat.[37] **JUST** is also working on growing chicken nuggets.

The company has raised around a quarter of a billion dollars in funding since its formation. It has had a somewhat controversial past, such as food safety concerns and a formal warning from the FDA demanding Hampton Creek alter its labels over inaccurate health and nutrition claims. The company was also investigated over an alleged buyback scheme, in which JUST workers visited grocery stores to buy the company's products in bulk and generate artificially higher sales numbers.[122]

However, the company has rebranded, raised a Series D funding in 2017 and achieved a valuation of $1.25 billion that year. It has further raised a reported $200 million in 2019, mainly from Chinese investors including **CLSA**, the international affiliate of Beijing-based **Citic Securities.**[122]

5.2 ALTERNATIVE PROTEIN SOURCES

The edible insect market is highly fragmented with many companies seeking to capitalise on the predicted rapid growth of the market. The human consumption section of the market is structured with companies either specialising in insect production and B2B trading or consumer products creation and B2C. However, a few companies do both, including **Entomo Farms** and **Aspire**, but use different branding for their B2C products or have acquired a consumer brand, such as **Exo**. Conversely, companies operating in the insect markets for animal feed generally both farm and sell insect -based products such as **Ÿnsect**, **Enviroflight**, **AgriProtein** and **InnovaFeed**.

Most companies sell their products online or in small health stores but recently some insect products have gone mainstream. **Eat Grub** are now selling cricket-based snacks in UK supermarkets and **Bugfoundation** burgers are available in supermarkets across Germany and other European countries.

[142] https://agfundernews.com/table-talk-the-scramble-for-plant-based-eggs-is-just-about-to-reach-europe.html

Key players in the algae market are generally split into two categories; those that have been operating for quite some time, specialising in selling either *Spirulina* or *Chlorella* as health supplements such as **Earthrise** and **Cyanotech**, or innovative start-ups that are developing new processes, exploring new species and finding new applications to unlock algae as a mainstream protein source including **Triton Algae Innovations**, **Odontella**, **New Wave**, **Algama** and **Alver**.

The single cell protein market is still young and so is largely made up of small, innovative start-ups such as **Sustainable Bioproducts**, **Solar Foods**, **KnipBio** and **3F BIO**. **Marlow Foods**, acquired by **Monde Nissin Corporation** and owners of the brand Quorn, are perhaps the only long-standing company in the SCP market for human consumption.

5.2.1 ENTOMO FARMS

Canadian start-up Entomo Farms (previously named New Millennium Farms) was founded in 2014 by brothers Jarrod, Darren and Ryan Goldin and has since grown to become North America's largest edible insect producer.[143] Entomo produces cricket and mealworm powders and snacks in addition to supplying over 50 food companies across 8 companies who incorporate the insect ingredients into a wide variety of foods ranging from protein bars, smoothies, crackers, pasta and baked goods.

Entomo's consumer offerings include whole, seasoned or powdered crickets and mealworms which it sells through its website. In addition to their food-grade insects, Entomo also sell cricket and mealworm flour for livestock and companion feed and fertiliser made from 'Frass'.

In 2018, Entomo raised an undisclosed series A investment from **Maple Leaf Foods**, Canada's largest consumer packaged foods company. Entomo hope to use the funds to expand production and Maple Leaf's knowledge of the industry to guide the company in its aim to become the largest insect supplier in the world.[144]

Entomo primarily farms crickets with a smaller mealworm operation that they aim to ramp up. The crickets that Entomo farm live in 'cricket condos', cardboard partitions similar to those used to separate wine bottles, allowing them plenty of space to burrow and hide. Entomo experiment with enhancing the flavour of insects by feeding them different foods including basil and cinnamon, to create flavour undertones. Recent investment will allow the start-up to increase mealworm production and further broaden their insect portfolio.

5.2.2 ŸNSECT

French based start-up Ÿnsect farms mealworms for animal feed, particularly aquaculture, hoping to capture some of the $500 billion animal feed market. In early 2019, Ÿnsect broke records by raising $125 million in Series C funding – the largest early-stage funding deal in Europe – indicating the interest from investors in the promise of insects as an alternative source of protein.[145] The significant amount of funding will be used to construct what Ÿnsect claim will be the world's largest insect farms with capacity to produce over 20,000 tonnes of insect protein a year.

143 https://www.agritechcapital.com/ideas-you-can-use-food-beverage/2019/6/22/the-buzz-about-insect-protein
144 http://www.globenewswire.com/news-release/2018/04/11/1468559/0/en/Entomo-Farms-Raises-Series-A-Funding-from-Maple-Leaf-Foods-for-Expansion-of-Cricket-Farm.html
145 https://agfundernews.com/breaking-french-insect-farming-startup-ynsect-raises-125m-series-c-breaking-european-agtech-record.html

Ÿnsect have optimised its farming and downstream processes by incorporating high-tech solutions such as sensor technology, automation, data analysis and predictive modelling, operating much like a vertical farm. Separation and extraction methods enable better harvesting of insects and higher yields.

The Tenebrio Molitor beetle is Ÿnsect's insect of choice, chosen for its high nutritional value and its compatibility with large-scale industrial production; it is a non-flying, communal insect that naturally live in close quarters in large colonies that happily feeds on crop-based by-products.[146]

Ÿnsect's current portfolio of products include ŸnMeal, a protein concentrate powder and ŸnOil, an oil rich in polyunsaturated fatty acids, for both fishmeal and pet food. Additionally, Ÿnsect sell ŸnFrass, a fertilizer made from the larvae castings which are rich in organic matter and essential nutrients for plant growth.

Ÿnsect has raised a total of over $172 million from venture funding and grants since 2011 including the $125 million series C and a €20 million grant from the European Commission in 2019.

5.2.3 TRITON ALGAE INNOVATIONS

The San Diego-based company spun out from **UC San Diego** in 2013 to create a production platform for food from *Chlamydomonas reinhardtii,* a heterotrophic microalga. Triton is aiming to be a B2B ingredient producer rather than a consumer product producer.

Triton claims that *Chlamydomonas reinhardtii* has a superior taste to other microalgae and that the cell wall is fully digestible, unlike *Chlorella*, therefore simplifying downstream processing. Classical breeding has been used to customize the nutritional profile and taste of strains without using genetic modification. FDA GRAS status has been granted for its non-GMO *Chlamydomonas reinhardtii* based ingredient in a variety of foods.

One new *Chlamydomonas reinhardtii* strain has the ability to produce large amounts of heme – an iron-containing molecule that is largely responsible for the meaty taste. Triton plans to use this strain to supply heme for plant-based burgers that 'bleed' such as those from Impossible Foods and Beyond Meat.

In addition, Triton aims to use genetic modification to create a recombinant protein expression platform using *Chlamydomonas reinhardtii.* The platform will be used to produce difficult to express human proteins such as those found in mammalian milk for use in infant formula.

Since 2013, Triton has raised a total of $10 million including a $5 million series from **Heliae**, a leader in the production of high-value products from microalgae.

5.2.4 3F BIO

3F BIO spun out from the **University of Strathclyde** (UK) in 2015 and aims to pair biorefinery and single cell protein production processes to create a single, highly efficient and zero-waste protein solution. 3F BIO uses its patented process to make mycoprotein, which is already widely sold across the world and has regulatory approval across many markets including the EU and US. Its product, ABUNDA mycoprotein, will be supplied as a high-scale B2B ingredient for inclusion in consumer products

[146] http://www.ynsect.com/en/ynsect-2/expertise/

ranging from burgers, sausages and chicken-like products. 3F BIO plans to use collaborations and partnerships to create and rollout these products.

In 2019, a cross-sector collaboration named Plentitude, which includes 3F BIO, as well as a biorefinery operator, food producers and technology providers, was launched. The project is being run by a consortium of 10 synergistic partners that bring different skill sets to optimise a new bio-based value chain and create sustainable, high-quality consumer products and has been funded by the European Union's Horizon 2020 programme for €17 million.[147] 3F BIO is bringing its expertise in biotechnology and **Alcogroup** is bringing its experience in biofuels to create an integrated biorefinery. End-user companies **Mosa Meat** (cultured meat), **Vivera**, (plant-based meat), and **APB Foods**, (conventional meat), alongside **Interational Flavors and Fragrances** (IFF), will create products and bring them to market.

The company has raised a total of $28.3 million since inception including a £6.2 million series A funding round in 2018 which saw a pre-money valuation of £6.2 million, and a €17 million Horizon 2020 grant awarded in 2019.

5.2.5 SOLAR FOODS

Finnish start-up Solar Foods is creating singe-cell protein from carbon dioxide, water, air and renewable energy using bacteria. The use of renewable electricity and carbon capture in its fermentation processes make Solein, Solar Foods' branded ingredient, a carbon-neutral and highly environmentally friendly food. Solar Foods claims that producing 1kg of Solein uses just 10 litres of water, compared to 2,500 litres required to make the same amount of soy, and that Solein is 10 times more land efficient. According to the company, Solein is 100 times more climate-friendly than animal or plant-based sources of protein.[148]

Solein is a flour-like substance with 50% protein content, 5-10% fats and 20-25% carbohydrates. In terms of taste, Solein has a neutral organoleptic profile which makes it amenable to adding in numerous food products. Solar Foods is currently testing Solein in a variety of foods, from ice-cream to meat analogues, and plans to collaborate with food producers to reach the market. The start-up also aims to help feed cultured meat cells to enable the industry to completely disconnect from traditional agriculture to overcome its limitations.

Solein is created by fermenting a proprietary microorganism that can use carbon dioxide and hydrogen as a source of carbon and energy, and air as the nitrogen source. Liquid is continually removed from the reactors and dried to produce the Solein powder. The powder can then be added directly to foodstuffs as an ingredient or can be texturized through 3D printing.

The company was founded in 2017 as a spinout from the **VTT Technical Research Centre of Finland** with an initial mission to make food suitable for space travel. They continue to work with the European Space Agency to supply astronauts on a mission to Mars whilst it generates data to submit for its EU novel food licence by the end of 2019, aiming for commercialisation in 2021 by partnering with Finnish food manufacturer **Fazer**.[149] The company has already raised $2.8 million over 2 rounds to continue development and scale up for commercial production, and is currently raising series A investment.

[147] http://www.3fbio.com/plenitude_bbi/
[148] https://www.foodnavigator.com/Article/2019/07/15/Solar-Foods-makes-protein-out-of-thin-air-This-is-the-most-environmentally-friendly-food-there-is
[149] https://solarfoods.fi/our-news/solar-foods-go-to-market-execution-begins/

5.3 FUTURE FARMING TECHNOLOGIES

In future farming technologies, there are many new and niche companies that are leading the industry. These include agritech companies which are revolutionising farming practices with novel technologies, such as LED lights or contained farming systems. The youth of the technologies and the fast pace of innovation in the sector means that most players are start-up and spin-out companies, which in many cases have grown dramatically in a short space of time. An example of this is the company **Plenty**, which was founded in 2013 and is now one of the top global players in the agritech field.

Governments have actioned many initiatives around indoor agriculture technology, which is expected to see mainstream adoption by 2027. Governments can support the adoption of vertical agriculture by offering tax incentives such as power subsidies as the main limiting factor in vertical agriculture is the high electricity cost. Countries with a highly educated population, low energy costs, and a government willing to engage in public-private partnerships will ultimately become leaders in this space.

For example, **Crop One Holdings**, the company behind the US container farming group **FreshBox Farms**, and the world's largest vertical farm operator, announced in February the opening of a new regional office in Dubai.[150] This office is part of Crop One's plans to strengthen the company's global presence and lay the foundations for a long-term expansion strategy. The opening of this office follows the company's June 2018 announcement of a $40 million joint venture with **Emirates Flight Catering** to build the world's largest vertical farm. The new facility will produce 3 US tons of leafy greens, using 99% less water than outdoor fields.

FreshBox Farms is among the few commercial indoor farms that are "gross margin positive". Experimentation with its supply chain and manufacturing methods has enabled it to reduce its cost per container unit from $380k to $55k, allowing it to expand even further across the country. Its farms are modular, built mainly in 320 square-foot containers, which allow temperature, humidity, and airflow to be customised to the needs of the particular crop. FreshBox differentiates itself from competition by being equipment-agnostic and integrating with third-party technologies.

Intelligent Growth Solutions, a Scottish vertical farm technology start-up, has developed a growing system that can cut power usage by up to half.[151] This company, which has already raised £5.4 million in funding from US investors (including **S2G Ventures**), offers what could be a solution to vertical farming challenges such as high energy usage and costs arising from running LED lights for 24 hours on a large scale. Its innovative, patented system allows large-scale LED lighting to be run on high power loads ("three-phase power supply"), which reduces both energy expenditure as well as costs.

However, it is not only agricultural companies that dominate this young market. Future farming will see engineering, blockchain, big data, software and even architectural companies become highly relevant to the sector. Some of the most novel and disruptive technologies include hydraulic-driven vertical farms; state-of-the-art tower farms; and undersea farms. This technological change to farming practices is also allowing for more sustainable and environmentally-friendly solutions.

Technologies being developed are becoming increasingly ambitious and cross-disciplinary. Notable examples include:

[150] https://www.globenewswire.com/news-release/2019/02/14/1725767/0/en/Crop-One-Solidifies-Global-Presence-with-Dubai-Office.html
[151] https://www.ft.com/content/11ba3c3c-919e-11e9-b7ea-60e35ef678d2

- Singapore-based **Sky Greens** has developed a revolutionary vertical farming system which is also the world's first low-carbon, hydraulic-driven farm.[152] Vegetables are grown on rotating frames – the plants at the bottom receive water, while those at the top receive sunlight. This approach minimises the use of water, land and energy compared to traditional farming; all while producing up to 10 times more yield.

- The architectural firm, **Rogers Stirk Harbour & Partners** (UK), presented its Skyfarm concept during the World Architectural Festival in 2014.[153] Skyfarm would involve building a hyperboloid tower that makes use of different farming techniques including aquaponics and traditional soil-based planting methods to produce crops within densely populated urban areas, or at places where land availability is scarce. This tower is an example of a sustainable solution for growing produce with a short shelf-life around the year, by integrating capabilities from different sectors and technologies. It will be formed of multi-storey towers, designed to support several layers of aquaponic, hydroponic and aeroponic agricultural production. The structure will be zoned to make the best use of water and nutrients, with the tensegrity structure made up of light bamboo to create a circular frame and maximise sun exposure. The ground floor will contain space for a market or restaurant, situated above a large transparent tank with freshwater fish for farming. In the middle of the structure, plants will be grown hydroponically. Above this, there will be an aeroponic environment, and finally water tanks and wind turbines to power the tower. The hyperboloid form of the tower will enable it to be easily scaled – a 10-metre version could be built in a school, or an 80-metre one constructed in a larger urban area.

- In what is the world's first ever underwater farm, **Nemo's Garden** (Italy) grows an estimated 700 plants including basil, tomatoes, salad, strawberries, aloe vera, mint, marjoram, and liquorice, in six underwater greenhouses.[154] The greenhouses are equipped with LED lamps, with electricity powering these coming from sustainable sources including solar panels and a small wind turbine onshore. Although to this date the farm still relies on fresh water from land, the founder, Leo Gamberini, has stated that in the future this could be done by desalination. The greenhouses are not completely sealed, allowing seawater to come into part of the structures. Inside the greenhouse, it comes into contact with warm air and evaporates, losing its salt, and eventually condenses into droplets that can be collected and used for irrigation.

We have profiled some of the top agritech companies (**Plenty**, **AeroFarms** and **Bright Farms**) in more detail below. By the nature of this sprawling industry, however, many of the most innovative and fast-growing players are not actually involved in farming, but rather in upstream technologies. We discuss two representative examples (**Augmenta** and **Hectare Agritech**).

5.3.1 PLENTY

Plenty takes an innovative approach to farming by bridging different disciplines for cross-functional collaboration, with its employees being a collective of growers, engineers, scientists and artists. Established in San Francisco (USA) in 2014, it aims to produce crops in a sustainable way, in a pesticide-free and GMO-free environment.

[152] https://www.skygreens.com/technology/
[153] https://www.rsh-p.com/projects/skyfarm/
[154] https://www.atlasobscura.com/articles/are-there-underwater-farms

Plenty has undergone three funding rounds which in total amount to $226 million. This includes a $1.5 million seed round in 2016, a $24.5 million Series A round in 2016, and a $200 million Series B round in 2017. Its investors include SoftBank Vision Fund, Louis Bacon, Bezos Expeditions, Finisterre Ventures, Innovation Endeavors, DCM Ventures, Group 11, Data Collective (DCVC) and Pete Flint. In 2017, it acquired **Bright Agrotech**, a company with which Plenty has been collaborating since 2013.[155] Bright Agrotech's Zipfarms is a space-saving functional vertical farming system that can reportedly save up to 95% more water over other growing practices, in addition to saving time and labour and maximising crop production.[156]

With an estimated annual revenue of $5 million, and the largest total amount of funding in the sector[157], we can expect Plenty to become an even larger player in the near future. It has attracted a lot of public attention, featuring in articles in The Economist, The Financial Times, and PRNewswire, and many others.

5.3.2 AEROFARMS

Established in 2004 in New Jersey (USA), AeroFarms provides environmentally-friendly aeroponic vertical farming. Its patented, award-winning growing systems are able to grow plants in a soil-free, fully-controlled indoor environment with faster harvest cycles, predictable results and minimal environmental impact. This system is able to use 95% less water than field farming and 40% less than hydroponic systems. Adjustable LED lights are configured to give each plant the spectrum, intensity and frequency they need in order to provide maximum photosynthetic efficiency in the most energy-efficient way possible. Furthermore, constant monitoring of nutrients makes sure every plant can grow as much and as fast as possible in order to increase productivity, which is 390 times greater than that of a commercial field farm.

In addition to its farming technology, AeroFarms uses smart data with remote monitoring in order to monitor crops. It has also developed a patented growth medium, which is made out of recycled, BPA-free plastic (and is reusable); and which it claims can each remove 350 water bottles from the waste stream. Other technologies it has invested in include smart pest management and smart scaling.

AeroFarms has an estimated annual revenue of $50 million per year, and has managed to raise a total of $238 million in funding, through several funding rounds, including: a Seed Round, a Series A round, and an Equity Crowdfunding round in 2010; a Venture Round in 2014; a Series B round in 2015; Series C and D rounds and a grant in 2017; and a Series E round in 2019.[158] Its investors include MissionPoint Capital Partners, GSR Ventures, Wheatsheaf Group, ADM Capital, Ingka Group, Cibus Fund, Meeras, David Chang and Alliance Bernstein. The company has also gained huge amounts of attention from the media, being featured in articles in the Financial Times, PBS, Fortune, World Economic Forum, Time and Forbes, amongst others.

5.3.3 BRIGHTFARMS

BrightFarms is an urban agriculture company that aims to provide communities with fresher produce that has a lower environmental impact. Its systems use 80% less water, 90% less land and 95% less shipping fuel than long-distance field-grown produce – and is delivered to supermarkets in 24 hours.

[155] https://edgy.app/plenty-what-the-biggest-agrotech-deal-ever-means-for-future-farms
[156] https://zipgrow.com/zipfarm/
[157] https://www.owler.com/company/plentyinc
[158] https://www.crunchbase.com/organization/aerofarms#section-funding-rounds

It produces herbs and salad in greenhouses that are designed to take advantage of natural sunlight and conserve water. These greenhouses are equipped with hydroponic systems that use a mineral-based nutrient solution in a soil-less environment.

BrightFarms has an annual revenue of around $11.5 million, and is classified as a late-stage venture. It has undergone a total of 6 funding rounds, in total raising $112.9 million.[159] These funding rounds include: a Series A round in 2011; three Series B rounds between 2014 and 2015; a Series C round in 2016 and a Series D round in 2018. Their main investors include Cox Enterprises, WP Global Partners, Catalyst Investors, NGEN Partners and Emil Capital Partners.

In September 2019, it was announced that BrightFarms had partnered with the organic produce distributor **Crosset** in order to expand its production into the Midwest.[160] BrightFarm's founder Paul Lightfoot has highlighted independent retailers in Ohio as a key opportunity in order to bring transparency to the food production field.

5.3.4 AUGMENTA

Augmenta, founded in 2016 and based in Athens, Greece, is a company that provides automatic precision application of farm inputs in real-time; boosting yield, enhancing quality and reducing input spend using deep learning. Augmenta's signature field analyser is retrofitted to agricultural equipment, in order to scan and analyse crops as you move across the field. It controls sprayers and spreaders to automatically apply the required amount of crop input for every spot in the field.

Augment raised $600K in seed funding in July 2018 from Marathon Venture Capital. Its field analyser, which is currently in beta testing, could theoretically improve yields by up to 12%, improve crop quality by up to 20% and reduce fertiliser use by 15%.

5.3.5 HECTARE AGRITECH

UK-based company Hectare Agritech, founded in 2012 in Hampshire, has developed a blockchain technology platform that has the ability to link into farming software and databases to provide real-time insight into the supply chain. In the time the company has been active, it has raised over £5 million through several founding rounds, including two seed rounds in 2017 and 2018, and two equity crowdfunding rounds in 2019.[161] Investors include best-selling author Richard Koch and UK tennis pro Andy Murray.

Its blockchain technology aims to bring transparency to the sector and reduce intermediaries. Its two trading platforms, SellMyLivestock and Graindex, allow farmers to sell their produce directly. SellMyLivestock currently has over 2,000 listings and over 50,000 head of livestock for sale; while Graindex has 8 out of the top 10 UK grain traders actively trading. Payments are handled through the company's digital payment system, FarmPay. Hectare's innovative system has gained attention from the press, with the company appearing in The Telegraph, BBC, ITV, The Times, New York Post, Sky News, Bloomberg, CNN and Time. In addition, its platform has won awards from Solent Local Enterprise Partnership, The Spectator, Barclays, and DEFRA.

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[159] https://www.crunchbase.com/organization/brightfarms#section-investors

[160] https://www.perishablenews.com/produce/brightfarms-partners-with-crosset-company-to-expand-distribution-into-over-100-independent-retailers-throughout-midwest/

[161] https://www.crunchbase.com/organization/hectare-agritech#section-recent-news-activity

6 RESEARCH LANDSCAPE

A number of academic research groups are developing Future Food Sources technologies. Tackling some of the global challenges, such as food security and sustainable agricultural production, has been at the heart of worldwide research in recent years. The past decade has been particularly interesting, with substantial progress in the field, especially in regards to developments in the cultured meat space. This is also consistent with a high level of patenting activity by universities and research institutes identified as top patent assignees in the patent analysis section of this white paper, discussed later.

Industry has repeatedly turned to academia for answers and will continue to do so. Consequently, analysis of academic research publication trends is useful, in that it can serve as a good indicator of where commercial market trends may be heading, as well as offering a snapshot of where technology stands now.

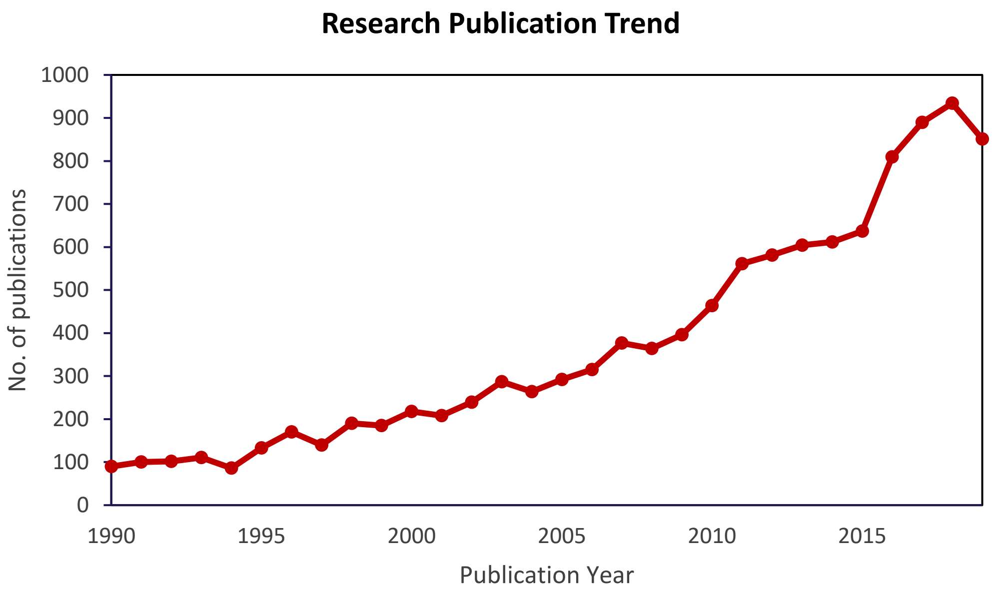
We have carried out title, abstract and keyword literature searches to provide an overview of the level of research currently taking place and the number of publications in the field of Future Food Sources. To generate a list of published papers that focus on the topics described in this white paper, databases were searched using the broad technology search terms and search operators shown in the table below. As discussed in more detail in our patent analysis, we found that the search terminology for alternative protein sources was sufficient to identify key plant-based food technologies discussed in the Animal Product Replacements sections above. Therefore, for the purposes of our academic literature search, a focused search was conducted exclusively for cultured meat and dairy technology.

Section	Search string	No. of publications
Alternative Protein Sources	TITLE-ABS-KEY((ALTERNATIVE OR VEGAN* OR VEGETARIAN* OR BACTERI?? OR INSECT OR CRICKET OR PLANT OR INVERTEBRATE OR ALGA+ OR MICROALGA+ OR CYANOBACTERIA OR SPIRULINA OR CHLORELLA) AND (((ANIMAL W/1 FEED) OR FOOD OR INGREDIENT OR DIET OR ALIMENT OR FOODSTUFF OR (HUMAN W/1 CONSUMPTION) OR NUTRITION*) W/5 (PROTEIN))) PUBYEAR > 1989 AND PUBYEAR < 2020	11,210
Future Farming Technologies	TITLE-ABS-KEY((AGRICULTURE OR FARMING OR (PLANT w/1 GROW*)) w/3 (VERTICAL OR PRECISION OR URBAN OR INDOOR OR ROOFTOP OR SOIL-LESS OR SOILLESS OR AEROPONIC OR HYDROPONIC OR AQUAPONIC OR (DEEP w/1 WATER w/1 CULTURE))) PUBYEAR > 1989 AND PUBYEAR < 2020	13,974
Cultured Animal Products	TITLE-ABS-KEY((((MEAT w/5 (CULTURE* OR CULTIVAT* OR GROW*)) AND ((‘IN’ W/1 VITRO) OR (‘EX’ W/1 VIVO) OR (MUSCLE W/1 (TISSUE OR CELL*)))) OR ((CULTURED OR ('IN' W/1 VITRO) OR ('EX' W/1 VIVO) OR SYNTHETIC) W/1 MEAT)) OR ((FOOD OR MEAT) w/5 (CULTURED w/1 MUSCLE)) OR ((TISSUE w/1 ENGINEER+) w/1 MEAT)) PUBYEAR > 1989 AND PUBYEAR < 2020	440

6.1 ALTERNATIVE PROTEIN SOURCES

6.1.1 PUBLICATIONS BY YEAR

Publications by year offer a snapshot of the activity trend in the Alternative Protein Sources research field over a given time period. The annual trend points to a consistent increase in the number of relevant publications over the last 30 years. Publications related to this particular field started increasing around 1995 onwards, reaching a peak of 934 publications in 2018. Data for 2019 are not yet complete, which accounts for the drop at the end of the trendline.

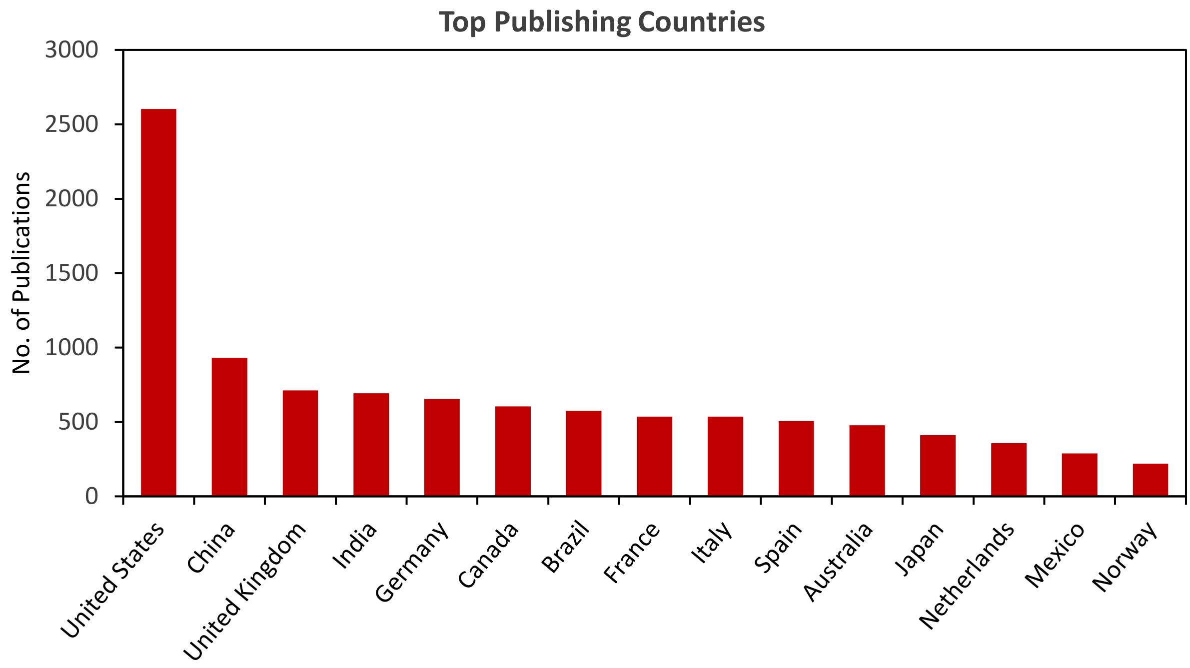


6.1.2 PUBLICATIONS BY AFFILIATION

Sorting the dataset by affiliation gives an indication of the top publishing organisations. The top 20 publishing institutions, which mostly have a strong agricultural focus, are shown below. Although collectively the United States displays the highest number of publications (6 out of the top 20 organisations listed below), **INRA (French National Institute for Agricultural Research)** has the highest number or relevant publications (241 publications). Besides INRA and a number of US-based research-focused organisations, the list also features a number of public research institutions across five continents.

6.1.3 PUBLICATIONS BY COUNTRY

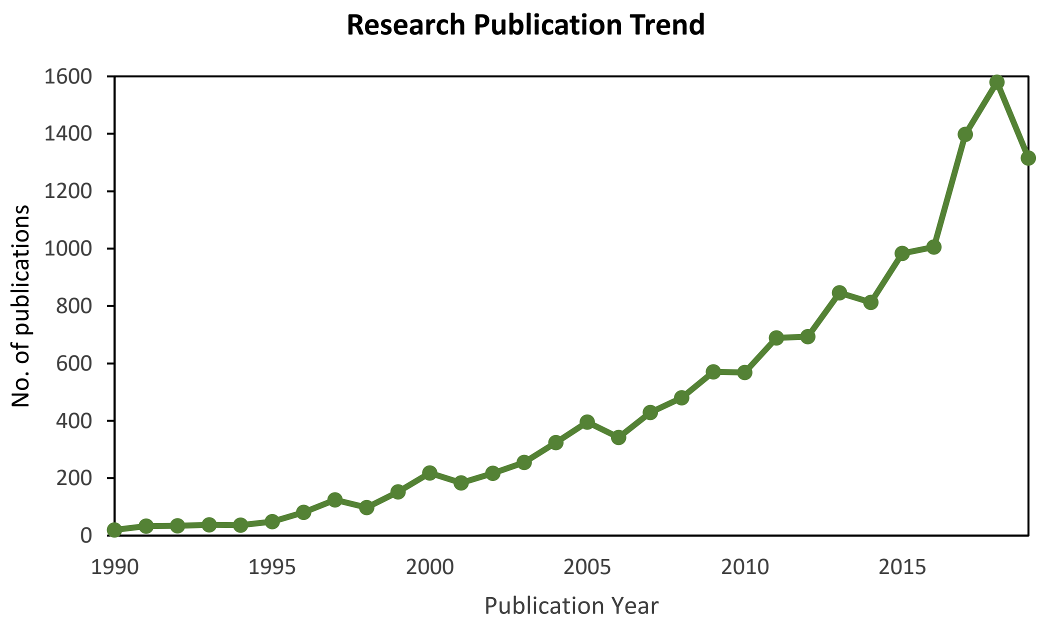
The top 15 countries by publishing territory are shown in the graph below. The US and Chinese institutions have the strongest representation. The position of the US as a clear leader in this field is unsurprising considering the location of the top publishing organisations identified in the section above. In addition, the fact that the most developed countries are leading the field and produce more publications was not unanticipated given the number of research institutes and the dollar amount of research funding in these countries. However, research centres from BRIC countries are also very active in this space, which aligns with our findings in the patent analysis section described later.



6.2 FUTURE FARMING TECHNOLOGIES

6.2.1 PUBLICATIONS BY YEAR

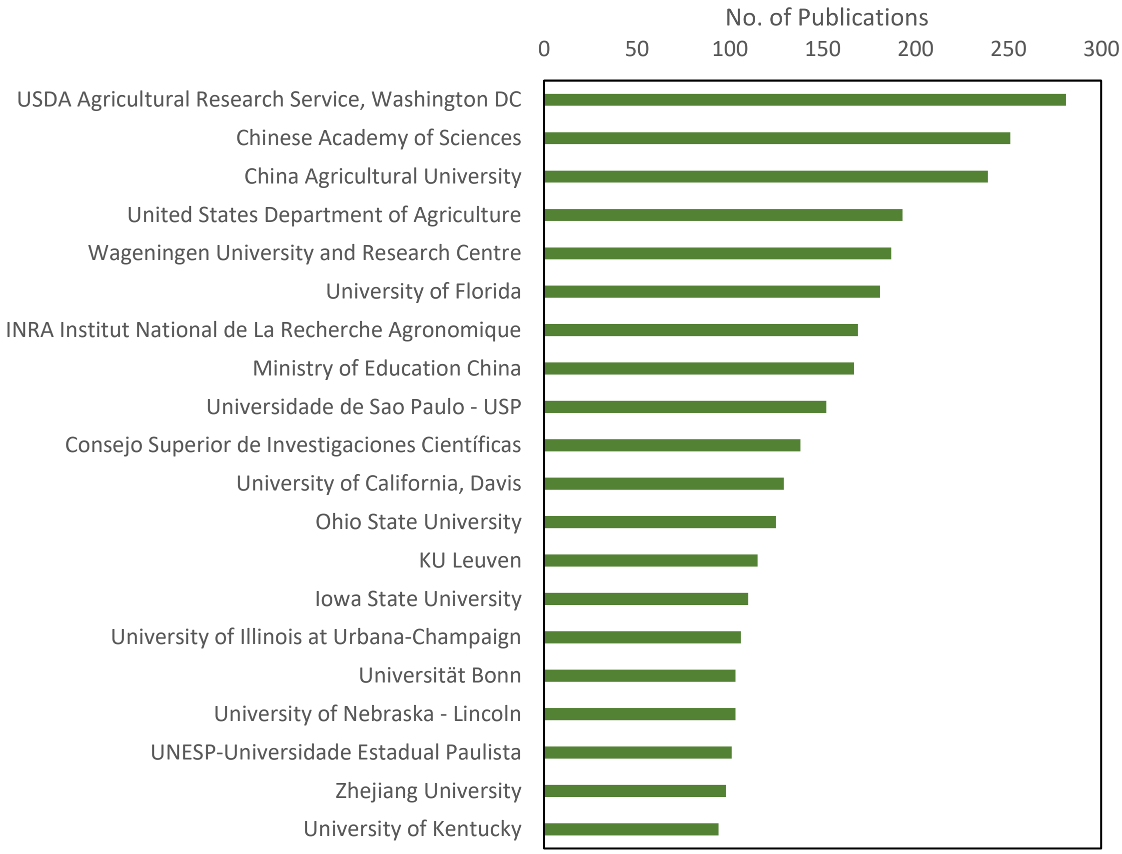
This research field has been experiencing continuous growth since the early 21st century, and in particular has been rising rapidly over the last two years.



6.2.2 PUBLICATIONS BY AFFILIATION

The top 20 most prolific publishing institutions, which are shown in the graph below, are from a geographically diverse mix of institutions and national research agencies, with a notable proportion research centres based in the US and China. All are public sector academic and/or research institutions and some are also key players for industry partnerships and licensing. This is exemplified by a recent partnership between USDA and Microsoft to pilot sensor-based solutions leveraging artificial intelligence (AI) to optimise food production.[162]

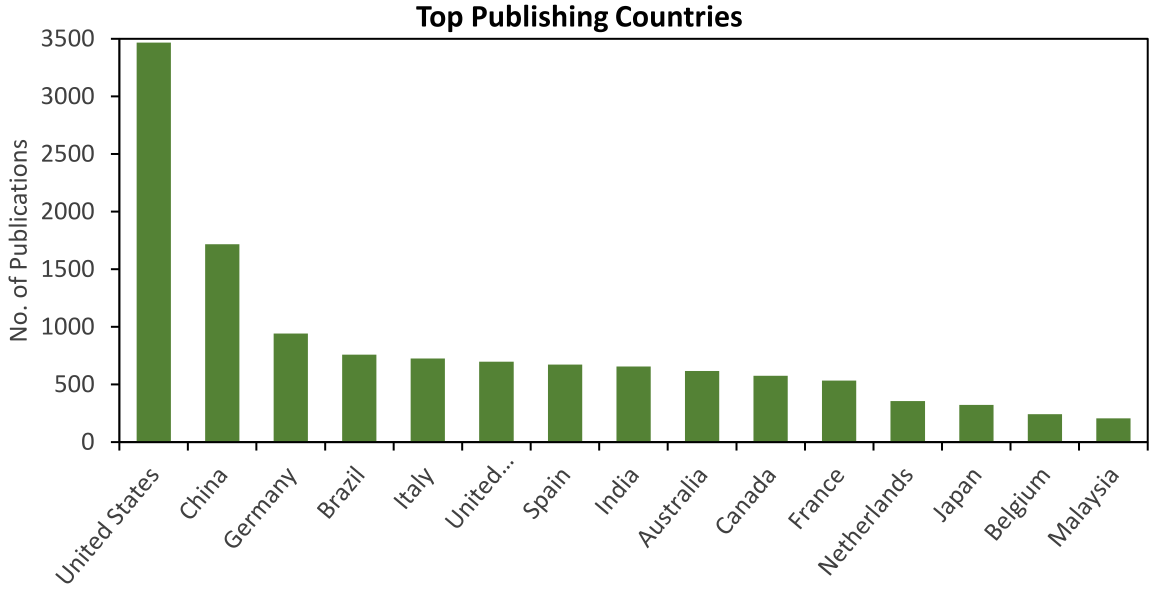
Top Patent Publishing Organisations



6.2.3 PUBLICATIONS BY COUNTRY

The most active countries in terms of frequency of publication are displayed in the graph below. Overall, US-based organisations again dominate the publication landscape in the Future Farming technologies sector. It is interesting to note the relative disparity between the US and China literature publishing trends, and the patenting trends discussed in the next section. Chinese research institutions dominate the number of patents filed for Future Farming Technologies by a huge margin. This suggests that Chinese researchers are patent-protecting a much higher percentage of their research findings, though these are mostly only protected in China itself, rather than internationally.

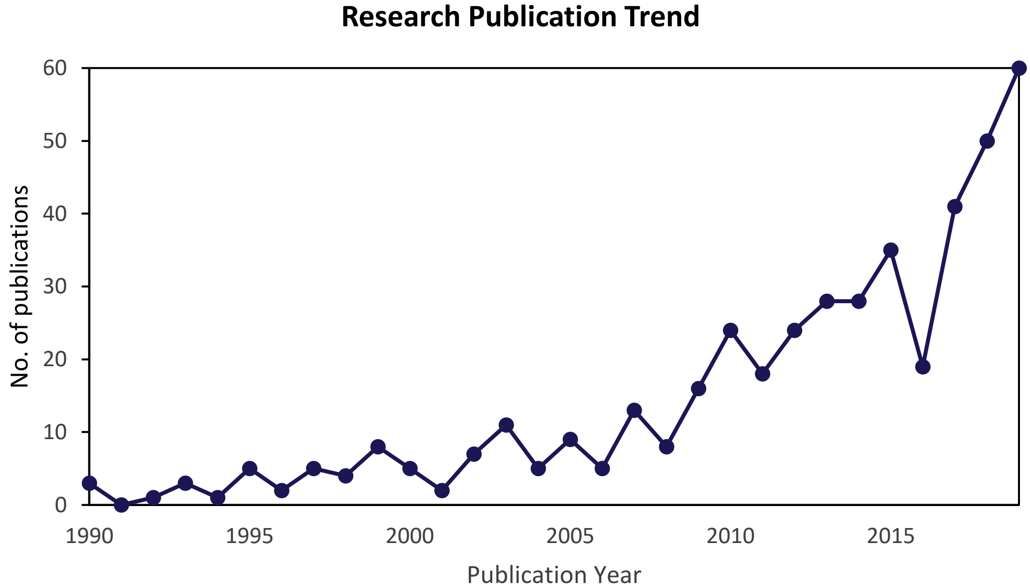
[162] https://www.technologyrecord.com/Article/microsoft-partners-with-usda-to-help-farmers-leverage-ai-87490



6.3 CULTURED MEAT

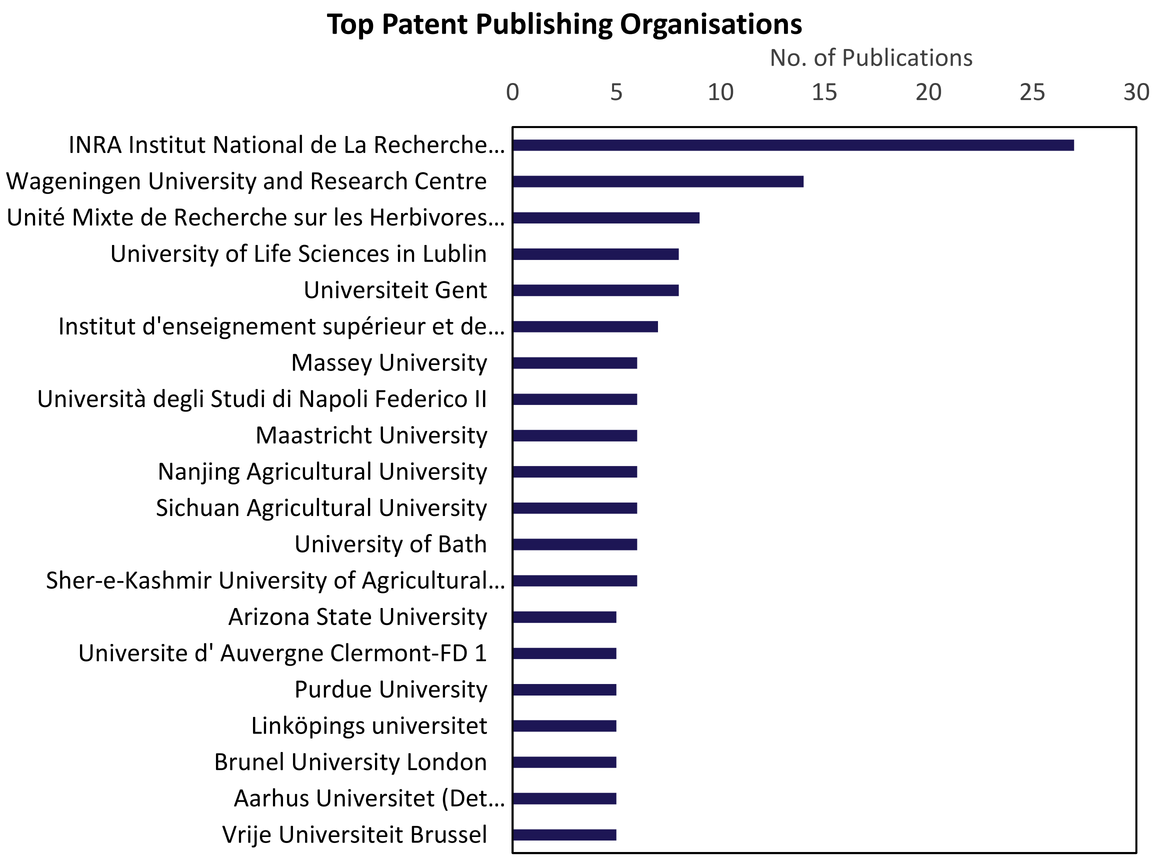
6.3.1 PUBLICATIONS BY YEAR

The level of publishing in cultured meat research was almost non-existent until around 2009. The number of academic publications has undergone rapid growth over the last three years, reaching a peak of 60 academic publications in 2019 (despite the fact that the data for this year are not yet complete).



6.3.2 PUBLICATIONS BY AFFILIATION

In the field of Cultured Meat research, **French National Institute for Agricultural Research (INRA)** has been identified as by far the most prolific publisher. This is somewhat surprising, since relatively few of the key companies in this field are based in France. Often, academic publishing trends and commercial activity in a country correlate relatively well. Regardless, INRA (and in particular Dr Jean-François Hocquette) is undoubtedly a key opinion leader and publicly visible player in this industry.[163] INRA was followed by **Wageningen University** (Netherlands). The third publisher on the list is **Unité Mixte de Recherche sur les Herbivores,** a joint research unit between INRA and the Institute of Higher Education and Research in Food, Animal Health, Agroscience and the Environment (VetAgro Sup). Apart from the Dutch and French institutes, there are also Polish, Belgian, New Zealand, Italian, Chinese, British and Indian research centres listed below. Although **Arizona State University** is listed below, the USA is surprisingly under-represented considering its usual academic dominance and the number of key synthetic meat companies based in the country.

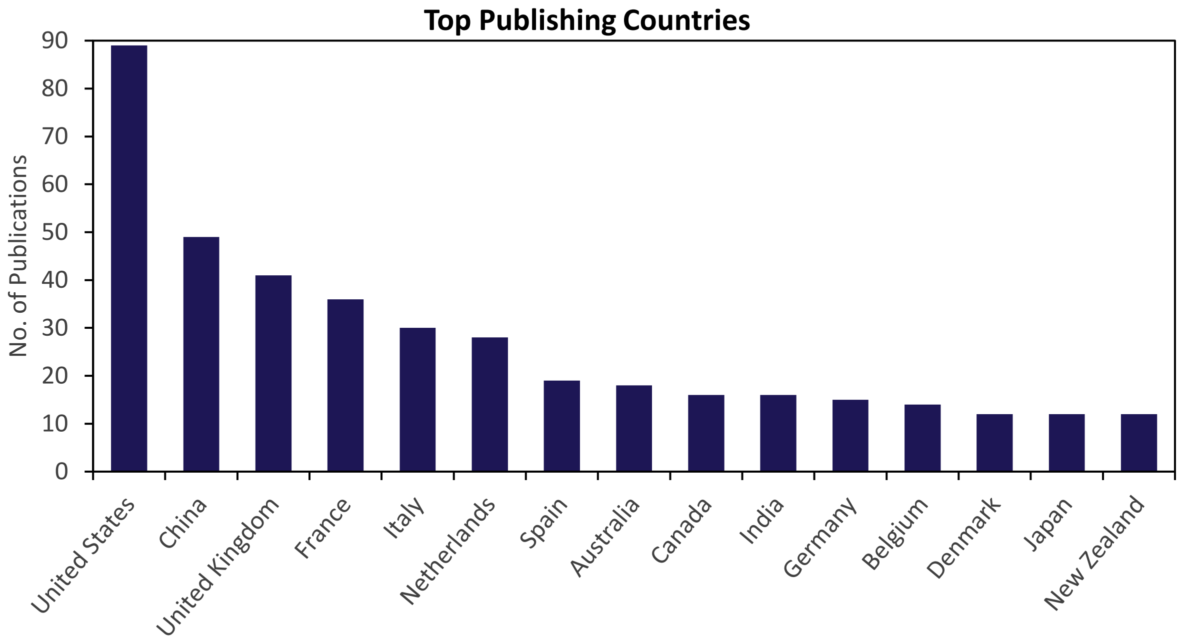


6.3.3 PUBLICATIONS BY COUNTRY

The top 15 countries by publishing territory, which are summarised in the figure below, are broadly similar in breakdown as observed for both Alternative Protein Sources as Future Farming Technologies sections. This further emphasises the cross-over between the research themes as the same countries are likely to be publishing across all three areas described in this white paper. While the chart above

[163] http://www.inra.fr/en/Scientists-Students/Agricultural-systems/All-reports/Where-s-the-beef-fake-meat-or-real-livestock-production/In-vitro-meat-to-beef-or-not-to-beef

might suggest that Europe is the leader in the research field, the analysis below shows that the US is the most prolific publisher. What this suggests is that US publications are spread over a number of institutions, while in European countries there is often one dominant academic player where most of the expertise is located. One further point of note is that, considering the number of Israeli companies focusing on clean meat production process, it may be somewhat surprising that Israel is not featured as one of the leaders in the ranking below. This may be a reflection that activity in the country is more focused commercially rather than academically, or perhaps there are processes that are being kept as trade secrets.



6.4 SUMMARY

All of the three segments of the Future Food Sources research have increased dramatically in recent 30 years, particularly over the past 5-10 years.

Organisations that have been repeatedly identified as top institutions across all three sectors are the French **Institut national de la recherche agronomique** (**INRA**) and **Wageningen University & Research**. Additionally, the top academic research organisations in the fields of both Alternative Protein Sources as well as Future Farming Technologies are institutes based in the US (**USDA Agricultural Research Service**, **University of California, Davis** and **University of Illinois** at Urbana-Champaign), Brazil (**Universidade de Sao Paulo**), China (**Chinese Academy of Sciences, Ministry of Education China**) and Spain (**Consejo Superior de Investigaciones Científicas**).

The top countries analyses further substantiate the conclusion that the majority of innovation comes from the United States and China. The remaining key counties where most of Future Food Sources research was conducted are located in Europe (UK, Germany, France, Italy, Netherlands, Spain and Belgium) as well as in Canada, Australia and Japan, Brazil and India.

Some of these findings are well aligned with our findings from the patent analysis section discussed below. On one hand, the presence of research institutes from BRIC countries (particularly China) as top countries is consistent with the location of top patent assignees. Conversely, the position of the

US as a clear leader in research publications could be considered as surprising given that there is comparatively little patenting by US academic organisations.

Finally, governments and industry alike are partnering with academic research institutions. Several initiatives are described throughout this report. In particular, some of the key commercial players, predominantly in the cultured meat field, are university spin-outs or have very strong links with the academic institutions, such as **Mosa Meat, Impossible Foods, Aleph Farms** and **Future Meat Technologies**.

7 MARKET DRIVERS AND TRENDS

Based on a high-profile report by the InterAcademy Partnership (IAP) in 2018, The Guardian newspaper reported that "the global food system is broken, leaving billions of people either underfed or overweight and driving the planet towards climate catastrophe, according to 130 national academies of science and medicine across the world".[164]

The global food system is responsible for a third of all greenhouse gas emissions. The resultant global warming effect is in turn damaging food production through extreme weather events such as floods and droughts. The food system also fails to properly nourish billions of people. More than 820 million people went hungry in 2017, according to the UN Food and Agriculture Organisation, while a third of all people did not get enough vitamins. On top of this, more than 1bn tonnes of food are wasted every year – a third of the total produced.

Whether considered from a human health, environmental or climate perspective, the world's food system is currently unsustainable. The IAP report considers that, fundamentally, a radical, whole-scale, root-and-branch overhaul of farming and consumption, with less meat intake, is needed to avoid world hunger and climate catastrophe.

The report recommends many actions that could help deliver the transformation that is required. These include crops that are more resilient to climate change, smarter crop rotation, soil protection, better use of fertilisers and less use of pesticides. It also backs innovations such as laboratory-grown meat and insect-based foods.

With the world's governments, international agencies, businesses, media and public becoming increasingly aware of – and alarmed by – these problems, the big market drivers which underpin the Future Food Sources markets are essentially these same issues which appear in news headlines every day. More technology- and market-specific factors are discussed in more detail below.

7.1 ANIMAL PRODUCT REPLACEMENTS

Cultured and plant-based meat substitutes are currently a popular, rapidly growing market. This is due to the growing global disposable income, increasing demand for meat and desire among customers to enjoy the taste of meat, combined with a growing awareness for a healthier meat-free lifestyle, reduced carbon footprint and concern for animal welfare. Companies large and small, new and established, are responding by increasingly mimicking the taste and texture of meat down to the molecular level, giving the exact juicy and tender texture of meat, with the same protein density.[165]

From a technological perspective, advancements in cell culture have facilitated the production of cultured meat and are driving the global synthetic meat market. In particular, the advent of 3D cell culture technology has revolutionized the cell culture field and by extension the cultured meat industry.[11]

Beef is the most common meat that companies are trying to replace; it is the most resource intensive meat to produce and one of the biggest contributors to global warming.[49] Beef is also one of the priciest meats, selling at two to three times the price of pork and poultry, so a premium price can be justified. However, cultured and plant-based meat alternatives to almost all animal products are now

[164] https://www.theguardian.com/environment/2018/nov/28/global-food-system-is-broken-say-worlds-science-academies
[165] Frost & Sullivan (2017) *Innovations in Plant-based Alternatives for Animal Protein – Industrial Bioprocessing TechVision Opportunity Engine*

either on the market or in development, as outlined previously. All product categories are expected to see substantial growth over the next few years.

The rapid market expansion is being driven and shaped by numerous industry partnerships, with major players showing interest in launching cultured or plant-based meat products or investing in smaller companies. This trend only began in the last two years with a significant increase in the number of plant-based meat investment deals.[10]

The market is growing across the world, with North America unsurprisingly being the largest opportunity, as shown in the cultured meat market projection below. However, other territories are also key targets for growth for companies in the cultured and plant-based meat industry. In particular, in a reflection of the customer emotional/experiential component of the alternative meat market, the CEO of JUST has noted that China has a huge opportunity to lead the way in food technology since many senior government officials in China have experienced famine in their lives, and have a different respect for food scarcity.[10]

Global Market for Synthetic Meat, by Region, Through 2027 ($ Thousands)

Region	2021	2022	2027	CAGR % 2022–2027
North America	6,528	6,774	8,186	3.9
Europe	4,411	4,569	5,479	3.7
APAC	1,951	2,029	2,484	4.1
RoW	2,840	2,965	3,692	4.5
Total	15,730	16,337	19,841	4.0

A further notable market trend in this industry is that some companies do not consider others to be competitive threats. Though this may not be true of, say, **Impossible Foods** vs **Beyond Meat**, the co-founder of the Spanish company **Biotech Foods** has commented that many new cultured meat companies are appearing in Europe but consider themselves to be ambassadors for a new concept rather than traditional competitors.[49]

Given the market drivers discussed above, a curious and somewhat paradoxical point of note for the cultured meat market is that some key players and industry observers do not consider the adoption of this new technology to be a significant threat to the traditional livestock industry. The primary reason for this is that the cultured meat industry is still far from mass production. However, it has also been argued that grazing animals play an important role in maintaining the environment, and that re-wilding or re-foresting significant amounts of grazing land may not be a practical or a suitable approach to land management.[118]

7.2 ALTERNATIVE PROTEIN SOURCES

The main drivers and trends for the alternative protein market can be categorised into sustainability, cost, regulatory changes and consumer perception.

- **Sustainability** – A major driver of growth in the alternative protein market is the growing awareness of conventional agriculture's unsustainability and the role it plays in climate change. Consumers are increasingly looking for sustainable products which is being reflected in the growing interest in vegetarian and vegan lifestyles in industrialised countries. The promise of a sustainable circular economy in which zero waste is generated with all outputs being recycled, is driving the market growth of novel sources of protein. Novel sources of protein may be able to efficiently convert organic waste and by-products from other process into foodstuffs – something that neither plants, traditional livestock or cellular agriculture can offer to the same extent.

Unlike plants, cellular agriculture and livestock, several alternative protein sources are amenable to urban farming due to their low land use and relatively simple technical requirements. Several companies are selling kits or offering advice to the budding insect farmer to allow people to grow their own protein and provide for their communities. Local farms result in reduced transport thereby further reducing the carbon footprint of food. It is also possible to build smaller farms near waste centres to improve efficiency.

- **Costs** – Whilst major steps are being made in the area of cellular agriculture, it remains very expensive to produce and is not yet commercially available. The industry may also find it difficult to scale production to the degree needed to completely satisfy the growing population's demands for protein. Therefore, other alternatives will likely play an important role in meeting this high demand, complementing the offerings from cellular agriculture with less technical solutions that will likely be easier to scale and cheaper to produce. Novel protein sources, such as insects and single cell protein from microalgae, bacteria and fungi, will help to fill this protein gap by providing cost effective solutions and high-quality protein that cannot always be found in plants.

- **Regulation** – To keep up with an increasing demand for alternative protein sources, new regulations have been introduced across the world indicating the growing market and allowing innovators in this area to bring authorised products to market. New regulations in the EU for novel foods is set to make the process clearer, simpler and easier for new products to reach the market and to be safely traded across the single market.

  Feed conversion ratios and costs of production will be important factors for dictating which new generation protein source will dominate. Insects have a high feed conversion rate, yet production has yet to be scaled up to a point where cost is low enough.

- **Consumer perception** – The market is also being driven by the many options available to using such alternative protein sources. One route that many innovators in this field are taking is to use the novel protein sources for animal feed rather than directly for human consumption. This route improves the sustainability of meat by reducing the land required for livestock feed whilst encountering fewer regulatory issues and benefiting from consumers' acceptance. The largest funding rounds raised in the edible insect market have been by companies focusing on using insects for animal feed.

  For those pursuing the human food market, a promising option for novel protein sources is their use in extending or improving foods stuffs. This introduces consumers to alternative sources without the neophobia that is often encountered. For example, finely milled powder can be used to supplement pasta and snacks amongst others to create foodstuffs with improved nutritional profiles and mostly unchanged flavours.

  Collaborations with food product specialists and innovative products will improve the flavour, aesthetics and texture of alternative sources of protein improving uptake by consumers.

7.3 FUTURE FARMING TECHNOLOGIES

A range of innovations and developments are driving market growth in this space. The most prevalent market drivers can be summarised into the following:

- **Rapidly escalating population levels** - A growing population is the biggest threat to conventional agriculture, and so low cost, high yielding alternatives such as urban farming have become increasingly attractive.

- **Urbanisation** – An estimated 30% of global population will live in urban areas by 2023, posing a threat to food supply access.[166] Furthermore, this will be most noticeable in emerging economies; meaning that urban produce will help mitigate the threat to access of food supplies that this conveys. In addition, more farmers may be wishing to move into cities too. Development of smart cities and industrial corridors is one solution, but this will depend on sufficient and timely access to food supplies.

- **Technology development** – Emergence of automation, digitalisation and novel growth mechanisms based on hydroponics and aeroponics, as well as new LED lights, the IoT, robotics and Big Data will offer greater control to indoor farmers resulting in higher yields, cost reduction and ultimately higher return on investment (ROI).

- **Environmental conditions and climate change** – Changing weather patterns affect soil quality and crop yield and will directly impact agriculture. This in turn will push farmers to opt for alternative and innovative farming techniques that are less exposed to the variation of environmental conditions and can ensure a more consistent harvest year-round.

Other market drivers are sector-specific, such as:

- A scarcity of arable land along with an increasing demand for higher agricultural yields. In the next few years, increasing soil erosion is predicted to boost the vertical farming market.

- For hydroponics, the main market drivers are its perception as an environmentally-friendly and profitable technology, and promotion by government programs and non-governmental organisations due to its food security benefits.

The rapid growth of the market, as well as rapidly turning some companies into top global players, has also resulted in many of them failing. This market offers many opportunities for entry due to its relatively early age, but also poses a lot of competition. The high costs and rapid advances in technology make it difficult for certain companies to stay afloat as new ones appear with novel and more efficient technologies, whereas the older ones which are unable to update their toolsets to the newest version every time there is a new development, and might be left behind.

[166] Frost & Sullivan (2017) *Innovations in Urban Farming*

8 BARRIERS TO ENTRY

As many of the future food and farming technologies discussed in this white paper are mostly all in development or yet to make the transition to mass production/roll out, the barriers and challenges are many, and for all sectors/products the biggest hurdles relate to the myriad costs involved, from development to market launch. However, there are a number of other barriers related to perception, regulation and technology readiness, among other considerations. These are outlined in the Table below. For the Animal Product Replacements category, cellular agriculture and plant-based meat are considered separately, because a number of issues are unique to one or the other.

Barrier	Description	Relevant Industry Sector			
		Cellular ag.	Plant-based meat	Future farming	Alt. protein
Underpinning technology development	Further research and development and technology optimisation required. For cultured meat, for instance, this is in cell lines, cell culture media and scaffolds.	✓		✓	
	Contrary to what is often portrayed in news media coverage, very little scientific attention is being given to the research and development of cellular agriculture.	✓			
	Achievable product range is still limited. E.g. in cellular agriculture, it is not possible to produce large pieces of meat like steak, and in vertical farming, only a small range of crops can be grown.	✓		✓	
	Shortage of skilled labour for R&D as well as scale-up	✓	✓	✓	✓
Scale-up/ manufacture	Technology for scaled up manufacture is not available. For instance, currently, no large-scale bioreactors exist that would accommodate commercial scaling for cultured meat.	✓			
	Requires a fundamental shift in the way production is organised, which faces several practical as well as neophobic and perceptional barriers			✓	
	Space, cost and technological limitations impede scaling up of facilities. This is particularly true in urban or container farming.			✓	
	Lack of innovation in plant-based meat production, with the industry using the same technology and equipment it has been using for decades.[61]		✓		
Costs	Production on a large scale is still too expensive to facilitate mass market roll-out. For example, cell culture technology was originally designed for medical applications, where price is not as big an issue.	✓		✓	✓
	While water and land use are lower than for conventional methods/products, energy use and costs are high.	✓		✓	✓
	Initial capital cost is hindering the establishment of new companies in the sector	✓		✓	✓

Barrier	Description	Relevant Industry Sector			
		Cellular ag.	Plant-based meat	Future farming	Alt. protein
Sustainability	Unknown effects of 'burden-shifting'. For example, the heat used for insect farming or the water usage for algae growth could have unintended production consequences.	✓		✓	✓
Price	Product prices are still significantly higher than existing products/methods. Though a minority of consumers will be willing to pay a high premium, the price to the consumer will need to come down if the technology is to penetrate the market.	✓	✓	✓	✓
Research & funding	There are as yet no scientific disciplines, departments or institutes devoted entirely to the research and development of the technology as distinct areas of study. Ongoing initiatives with promising long-term strategies are currently held back by a lack of research funding.	✓	✓		✓
	The technological know-how/expertise may limit application to wealthy nations	✓		✓	✓
	Yet to explore the extent of insect species that are edible to determine which are truly best for large scale, commercial applications in addition to palatability.				✓
	Large-scale farming still being developed and so there is currently a lack of knowledge. Even for smaller-scale operations, knowledge is concentrated in certain areas of the world only.			✓	✓
Regulation	The regulatory landscape and frameworks in different territories are still unclear for foods containing novel sources.	✓			✓
	Use of genetic modification will add extra complexity and will also involve rigorous transparency and openness to public inquiry.	✓		✓	✓
	Legislation required for using waste, such as human organic waste, as a feed source for insects				✓
Intellectual property	Product mimicry has already become widespread as more companies enter the market, posing challenges to new entrants		✓		
Public perception/ acceptance	Consumers may be sceptical of the new technology/company, which may require the adoption of a new mindset to switch from a lifetime of existing foods and production methods. Requires education of the market. 'Ick factor' particularly large barrier for insect protein.	✓	✓	✓	✓
	Nomenclature may cause confusion	✓		✓	
Existing players	The market in cultured and plant-based meat is becoming crowded with a number of large, well-funded companies. New companies may	✓	✓		

Barrier	Description	Relevant Industry Sector			
		Cellular ag.	Plant-based meat	Future farming	Alt. protein
	find it difficult to gain market share without backing from big food companies/investors.				
	The past few years have been about captivating audiences with anticipation of these products, but in the next few years, it will be all about getting to market – new entrants will rely on large retailers to reach consumers.	✓	✓		✓
	New technologies may encounter deep resistance from farmers and other players, e.g. the meat industry, whose livelihoods are threatened	✓	✓	✓	✓
Policy	International policy changes will be required (e.g. through subsidies for food biotech research) to facilitate large-scale roll-out. This in itself may be hindered by resistance on account of the impact of new technologies' impact on the currently heavily-subsidised agricultural industry.	✓	✓	✓	✓
Health claims	The veracity of some claims of health benefits compared to animal products are yet to be properly tested.[167]	✓	✓		✓
Safety	The safety of some product elements has not been fully determined for human consumption (e.g. foetal calf serum can harbour communicable diseases)	✓	✓		✓
	There have been several reported cases of allergy to insects with the mechanism and exact cause still unknown. It is thought that there may be a link to allergies to shellfish and dust mites. Workers in insect farms can develop allergic reactions to the insects over time.				✓
	Real vs perceived safety issues. Insects can carry certain pathogens. But consumers particularly see insects as 'unclean' and unsafe.	✓			✓
Ethical issues	Though animals are not slaughtered, stem cells used in the technique are sourced from animal muscle that may be by-products of an animal's slaughter. Furthermore, using serum from cow foetuses as the growth medium raises ethical concerns	✓			✓

[167] https://www.nbcnews.com/think/opinion/impossible-burger-or-beyond-meat-aren-t-healthy-fast-food-ncna1050911

9 PATENT ANALYSIS

9.1 SEARCH STRATEGY

In order to understand the intellectual property landscape in the field of future food sources, an assessment of the registered industrial patent rights was carried out using Orbit Intelligence, a global comprehensive patent database. We ran three separate searches corresponding to the market segments described in the previous sections of this white paper. We found, generally speaking, that patent wording related to cultured meat in particular can be opaque, with patents difficult to find. Therefore, the patent searches are structured slightly differently to the previous sections, with broad searches conducted to look at alternative protein and future farming technologies, followed by a more focused search to identify cultured meat patents. We found that the search terminology for alternative protein sources was sufficient to identify the key plant-based foods discussed in the Animal Product Replacements sections above. The number of patent families returned by each search string is provided in the table below.

Section	No. of patent families
Broad search: Alternative Protein Sources	864
Broad search: Future Farming Technologies	1188
Focused search: Cultured meat and dairy	107

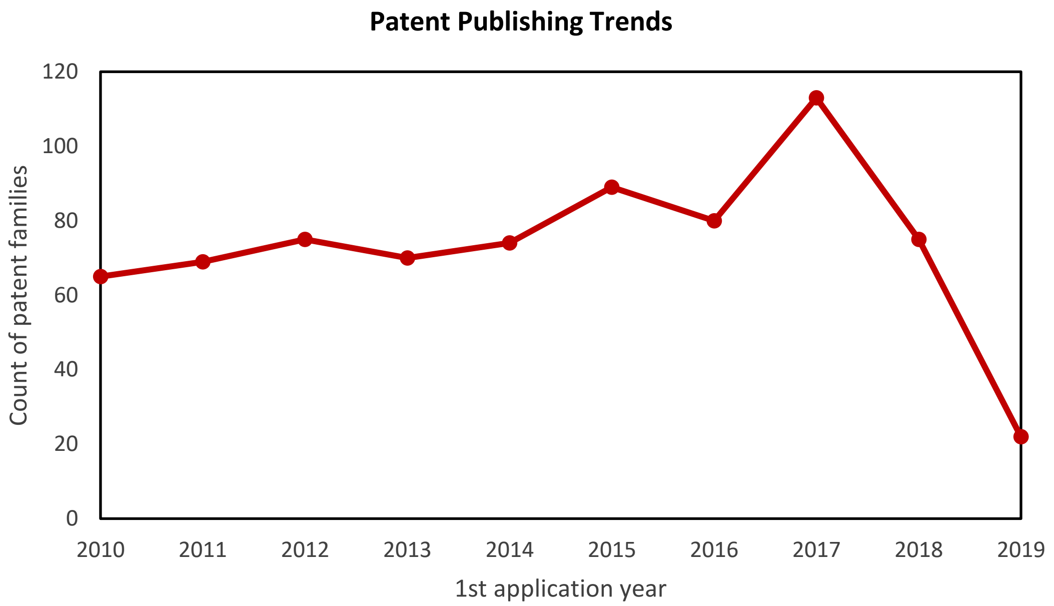
Specific search terminology and further details of the patent search strategy are discussed in **Appendix 2.**

9.2 ALTERNATIVE PROTEIN SOURCES

9.2.1 PATENT PUBLISHING TRENDS

Patent publishing trends offer a snapshot of the level of activity in a technology space over the given period. This filing data gives an indication of the number of new inventions published in the field of Alternative Protein Sources over the course of the past 10 years. Orbit Intelligence uses the publication number to include both published application numbers and granted patent numbers.

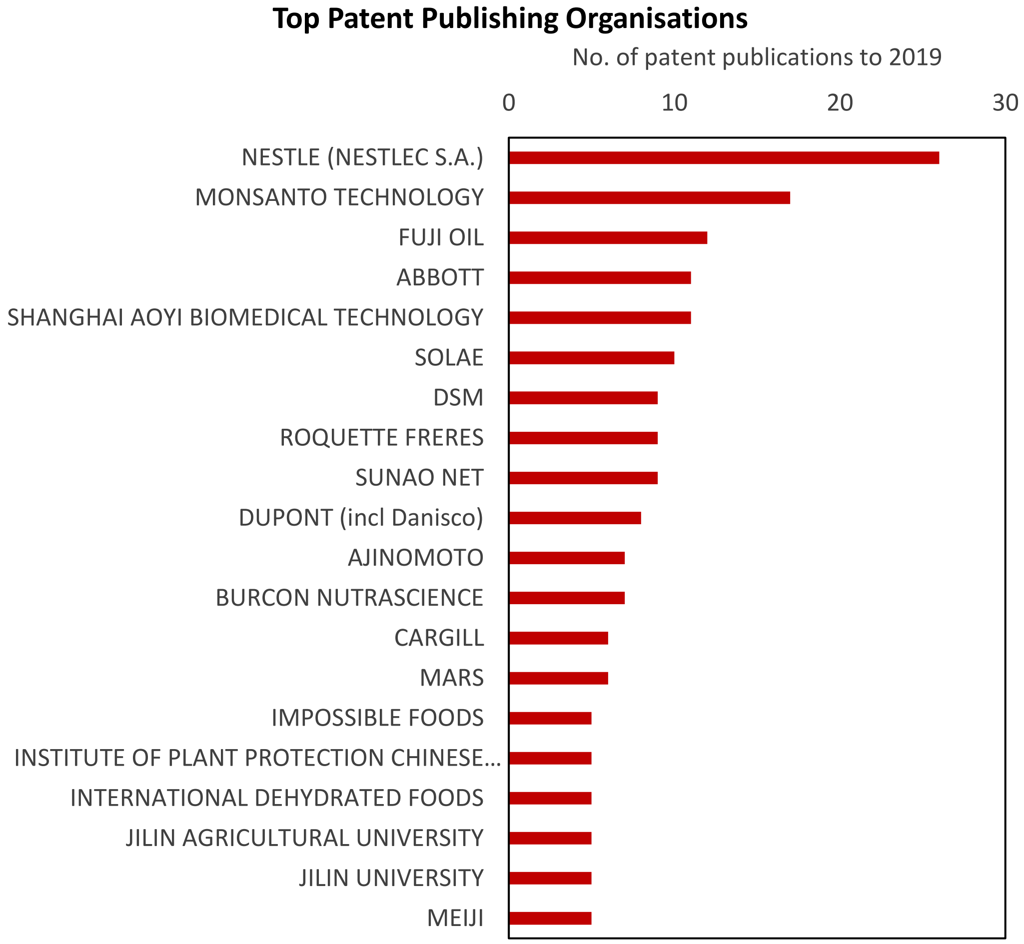
The number of published patent families has remained relatively stable over the last decade. Note that the drop in 2019 is reflective of the point at which the search was conducted (September 2019). The patenting activity tends to indicate some general market trends and a stable profile could be a sign of sector maturity. This is unsurprising due to the continuous advancements in utilising proteins from various sources in the production of various food products for human and animal consumption. As such, the broad concept of using Alternative Protein Sources is not novel and some alternative protein technologies are deemed mainstream, however, there is still a scope for innovation in the field emphasised by the steady number of new patent applications each year.



9.2.2 KEY ENTITIES

Focusing on the top organisations filing in the sector identifies those organisations carrying out R&D in the area and the comparative level of activity in the space.

The data illustrate a fragmented market with a number of multinationals (including food companies and conglomerates), small biotech/nutrition companies and academic institutions. **Nestlé** (via its R&D subsidiary, **Nestéc** S.A) is by far the most prolific patent filing organisation. The remaining top assignees consist of **Monsanto**, which was acquired by **Bayer** in 2018), followed by a couple of large companies with a similar level of patenting activity, **Fuji Oil** and **Abbott Laboratories**. There are also a number of academic institutions predominantly based in China. The following chart summarises the top players by patenting activity with further details discussed in the sections that follow.



Cluster by Entity Type: Commercial Vs. Academic

The top patent publishing organisations were divided into commercial companies and academic research institutions. The table below summarises the top commercial organisations in order of patenting activity and a corresponding industry sector as well as location of company's headquarters are also provided. Food & drink/nutrition companies dominate the list, indicating that this market sector is propelling innovation within the space of Alternative Protein Sources. **Nestlé** and **Fuji Oil** came first and third in the ranking, respectively. The list also features a number of companies specialising in agriculture technology, with **Monsanto Technology** (owned by Bayer since 2018) being the top agriculture-focused organisation in the field, followed by **DuPont** (incl. Danisco) and **Dow**. These two companies merged together in 2017 and then subsequently split into three businesses: DuPont, Dow Inc. and Corteva Agriscience. While the main focus of **Abbott Laboratories** is production of generic branded pharmaceuticals and medical devices, the company also offers nutritional products, which explains its high position on the list of top assignees.

Impossible Foods, an American company behind the plant-based Impossible Burger described in previous sections is also one of the top assignees in the field with their patents related to formulation of animal-free food products. Other companies described in the previous sections include food and biochemicals multinationals, such as: **Nestlé**, which is already manufacturing the meatless patty for McDonald's; **Cargill**, which is heavily investing in alternative meat products; **Corbion**, which acquired algae-based food company **TerraVia** (previously known Solazyme) in 2017 and a plant-based ingredients company **Roquette Frères**. The search also identified companies focused on reducing the extent of animal-based agriculture, such as **Modern Meadow**, a US-based company manufacturing material made out of biologically-produced collagen protein without using animals.

As a whole, in the space of Alternative Protein Sources, commercial players dominate the innovation landscape. The key companies in the field consist of a mix of large food/nutrition multinationals, materials and agriculture corporations as well as small biotechnology companies. Apart from a high proportion of US-based companies identified as key commercial entities in the field, the headquarters of remaining companies listed below were located in various countries around the globe.

Commercial Assignee/Applicant	No. of patent publications, 2009-2019	Sector/Category	Headquarters Location
NESTLE (NESTLEC S.A.)	26	Food & Drink	Switzerland
MONSANTO TECHNOLOGY	17	Biotechnology, Agriculture	USA
FUJI OIL	12	Food chemistry	Japan
ABBOTT	11	Pharmaceuticals, Nutrition	USA
SHANGHAI AOYI BIOMEDICAL TECHNOLOGY	11	*Food chemistry, Pharmaceuticals	China
SOLAE	10	Food chemistry	USA
DSM	9	Nutrition, Organic chemistry	Netherlands
ROQUETTE FRERES	9	Nutrition, Organic chemistry	France
SUNAO NET	9	*Food chemistry	Japan
DUPONT (incl. Danisco)	8	Food chemistry, Agriculture	USA
AJINOMOTO	7	Food chemistry, Biotechnology	Japan
BURCON NUTRASCIENCE	7	Food chemistry	Canada
CARGILL	6	Food & Drink	USA
MARS	6	Food chemistry	USA
IMPOSSIBLE FOODS	5	Food and Nutrition	USA
INTERNATIONAL DEHYDRATED FOODS	5	Nutrition	USA
MEIJI	5	Food & Drink (dairy), Pharmaceuticals	Japan
NUTRICIA NV (part of DANONE)	5	Nutrition	Netherlands
YILI GROUP	5	Nutrition (dairy)	China
ARLA FOODS	4	Nutrition (dairy)	Denmark
AXIOM FOODS	4	Food chemistry	USA
CORBION BIOTECH	4	Food chemistry, Biotechnology	Netherlands
DOW	4	Agrochemical producer, Organic chemistry	USA
KANEKA	4	Chemical producer	Japan
CONAGRA FOODS	3	Food & Drink	USA
FONTERRA	3	Nutrition	New Zealand
FUJIAN TIANMA SCIENCE & TECHNOLOGY	3	*Food chemistry	China
GUANGDONG SHUANGJUN BIOLOGICAL TECHNOLOGY	3	*Biotechnology, Pharmaceuticals	China
HENAN SHUANGCHENG BIOLOGICAL SCIENCE & TECHNOLOGY CO	3	*Food chemistry	China
HILLS PET NUTRITION (part of COLGATE-PALMOLIVE COMPANY)	3	Food chemistry - pet food, Consumer Products	USA

Commercial Assignee/Applicant	No. of patent publications, 2009-2019	Sector/Category	Headquarters Location
JIASHI RUIKANG PHARMACEUTICAL	3	*Food chemistry, Pharmaceuticals	China
KIBOW BIOTECH	3	Nutrition	USA
LI RUI GUEST INFORMATION TECHNOLOGY	3	*Food chemistry	China
LIUZHOU LIKE TECHNOLOGY	3	*Food chemistry	China
MEAD JOHNSON NUTRITION (division of Reckitt Benckiser)	3	Nutrition	USA
MODERN MEADOW	3	Biotechnology	USA
NEXT PROTEINS	3	Food chemistry	USA
NIPPON SUISAN KAISHA	3	Food (marine products)	Japan

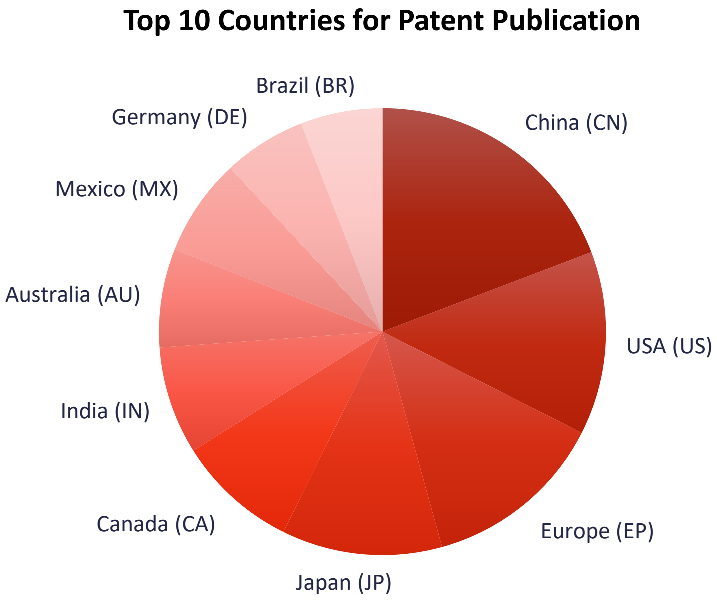
* Due to the limited information on the organisation available online, the sector was completed based on the organisation's patent portfolio.

The table below summarises academic organisations in this field. The vast majority of the academic players are based in China, indicating that Chinese research institutes have been patenting heavily in the field of Alternative Protein Sources. The research centres listed below are spread geographically across the entire country indicating no particular "hub" of activity. A similar trend also emerged in the Future Farming patent section discussed later.

Research Institution Assignee/Applicant	No. of patent publications, 2009-2019	Location
INSTITUTE OF PLANT PROTECTION CHINESE ACADEMY OF AGRICULTURAL SCIENCES	5	China
JILIN AGRICULTURAL UNIVERSITY	5	China
JILIN UNIVERSITY	5	China
BEIJING TECHNOLOGY AND BUSINESS UNIVERSITY	3	China
BEIJING UNIVERSITY OF TECHNOLOGY	3	China
CHINA AGRICULTURAL UNIVERSITY	3	China
RUSSIAN ACADEMY OF AGRICULTURAL SCIENCES (RAAS) *('GOSUDARSTVENNOE NAUCHNOE UCHREZHDENIE VSEROSSIJSKIJ NAUCHNO ISSLEDOVATEL SKIJ INSTITUT SOI ROSSIJSKOJ AKADEMII SKOKHOZJAJSTVENNYKH NAUK')*	3	Russia
HENAN AGRICULTURAL UNIVERSITY	3	China
HUAZHONG AGRICULTURAL UNIVERSITY	3	China
INSTITUTE OF BIOTECHNOLOGY THE ACADEMY OF MILITARY MEDICAL SCIENCES CHINA	3	China
INSTITUTE OF MICROBIOLOGY & EPIDEMIOLOGY ACADEMY OF MILITARY MEDICAL SCIENCES PR CHINA	3	China
JIANGNAN UNIVERSITY	3	China

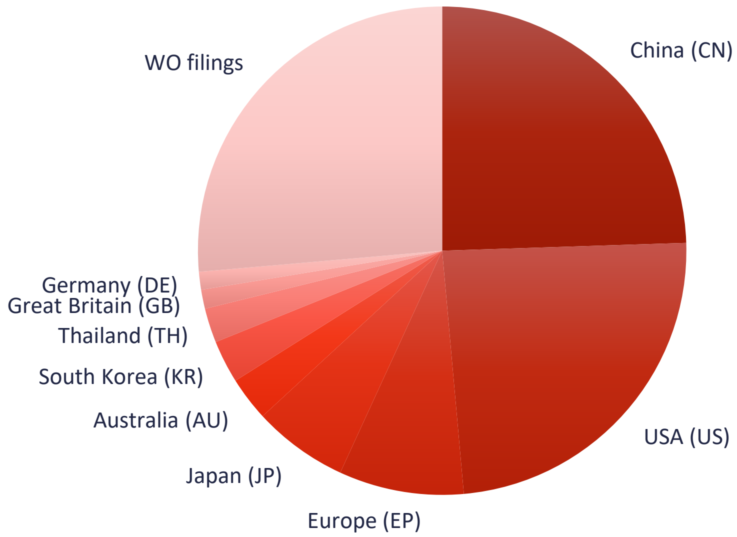
9.2.3 GEOGRAPHICAL ANALYSIS

The top countries for patent publications gives an indication of the territories in which patent protection is sought, and is therefore an indication of those countries considered to be most important territories for commercialisation. Organisations will choose to publish the patent in those countries where the industry sector is likely to be most commercially viable, to secure patent exclusivity rights in those markets. Protection for technologies related to Alternative Protein Sources is sought in China (19.2%), the US (13.3%) and Europe (13.2%), which, to some extent, is consistent with the location of key patent assignees listed in the previous section. Other individual countries which are likely to be important markets are shown below. This country breakdown is fairly evenly split across all territories, indicating a global customer base



Priority countries (where patents are initially filed) give an indication of where most innovative research is taking place, as patents are commonly filed in the home territory of the inventing company or organisation. Over a quarter of all patents were initially filled as the Patent Cooperation Treaty (PCT) applications (26.4%), which indicates a tendency for applicants to achieve a broad geographical scope of protection for new technologies in the field. China and the US appear to be in a close competition with 24.5% and 24.1% of priority filings, respectively. Other important territories for innovation include Europe (indicated by the European patent applications - 8.3%), Great Britain (1.3%) and Germany (1.2%). Apart from China, a number of other markets from the Asia-Pacific region were also featured as top countries for priority filing: Japan (6.3%), Australia (2.9%), South Korea (2.8%) and Thailand (2.3%).

Top Priority Countries



9.2.4 TECHNOLOGY AREAS

The patent dataset was analysed further to identify the top International Patent Classification (IPC) codes within the specified IPC categories used to conduct the initial patent search. The international classification system provides a hierarchical system of language-independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. Therefore, these give an indication of the most important specific technology sub-areas for the Alternative Protein Sources patent landscape. Some of this can be gleaned from the top assignees as described above, which operate in key sectors such as Food & Drink, Nutrition, Pharma/Biotech and Agriculture. However, the IPC code is the formal structure in which technologies described within a patent are classified, and so provide additional information. Below is a table displaying the top 10 IPC codes in order of commonality along with their respective description.

IPC Code	Document Count	Description
A23L-033/00	31	A23 - Human Necessities / Foods or foodstuffs; their treatment, not covered by other classes L - foods, foodstuffs, or non-alcoholic beverages, not covered by subclasses A21D OR A23B-A23J; their preparation or treatment, e.g. cooking, modification of nutritive qualities, physical treatment; preservation of foods or foodstuffs, in general 033/00 - Modifying nutritive qualities of foods; Dietetic products; Preparation or treatment thereof
A23J-001/14	22	A23 - As above J - protein compositions for foodstuffs; working-up proteins for foodstuffs; phosphatide compositions for foodstuffs 001/14 - Obtaining protein compositions for foodstuffs; Bulk opening of eggs and separation of yolks from whites / from leguminous or other vegetable seeds; from press-cake or oil-bearing seeds

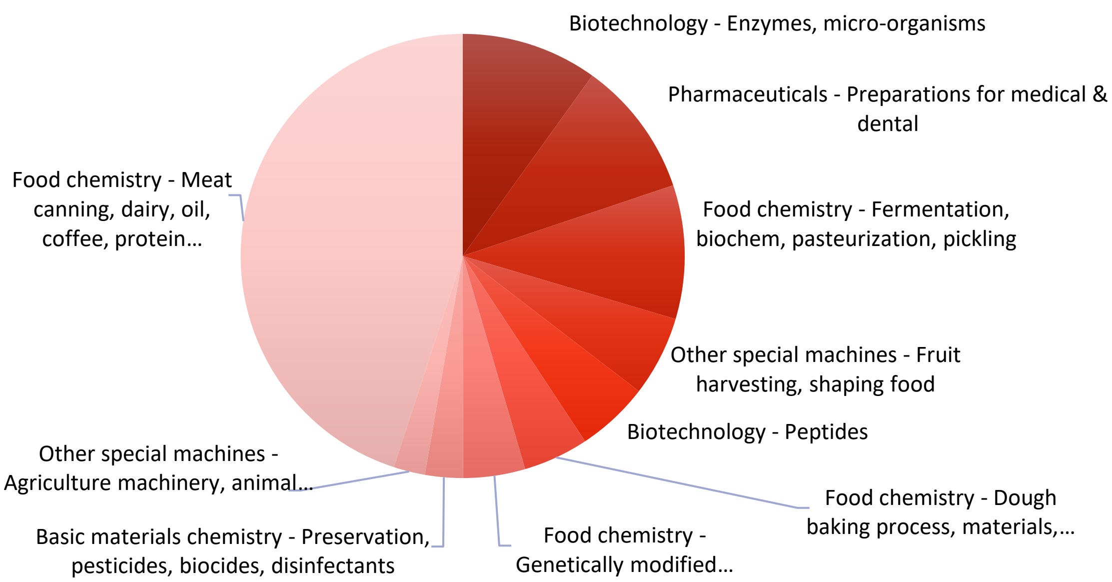
IPC Code	Document Count	Description
A23K-001/18	13	A23 - As above K - feeding-stuffs specially adapted for animals; methods specially adapted for production thereof 'A23K 1/18' group has been now re-classified to the following subgroups: 'A23K 50/00 - 50/90', which correspond to 'Feeding-stuffs specially adapted for particular animals'
A23L-033/17	12	A23L – As above 033/17 - Modifying nutritive qualities of foods; Dietetic products; Preparation or treatment thereof / Amino acids, peptides or proteins
C12N-015/82	12	C12N - Chemistry; metallurgy / biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation or genetic engineering / microorganisms or enzymes; compositions thereof; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media 015/82 - Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, e.g. plasmids, or their isolation, preparation or purification; Use of hosts therefor / for plant cells
A23L-005/00	11	A23L – As above 005/00 - Preparation or treatment of foods or foodstuffs, in general; Food or foodstuffs obtained thereby; Materials therefor
A23C-011/10	10	A23 - As above C - planting; sowing; fertilising 011/10 - Milk substitutes, e.g. coffee whitener compositions / containing or not lactose but no other milk components as source of fats, carbohydrates or proteins, e.g. soy milk
A23J-001/00	10	A23J – As above 001/00 - Obtaining protein compositions for foodstuffs; Bulk opening of eggs and separation of yolks from whites
A23J-003/00	10	A23J – As above 003/00 - Working-up of proteins for foodstuffs
A23J-003/16	10	A23J – As above 003/16 - Working-up of proteins for foodstuffs / from soybean

Nine out ten IPC codes start with prefix '**A23**' corresponding to '**Human Necessities** / **Foods or foodstuffs; their treatment, not covered by other classes**'. This group can be further stratified into subclasses corresponding to modifying nutritive qualities of foods (A23L-033/00), in particular 'Amino acids, peptides or proteins' (A23L-033/17) as well as food or foodstuffs obtained as part of treatment process (A23L-005/00). The IPC subclass A23J was also common in the data set, primarily the subgroups corresponding to obtaining protein compositions for foodstuffs (001/00), particularly from leguminous or other vegetable seeds; from press-cake or oil-bearing seeds (001/14) as well as working-up of proteins for foodstuffs (003/00), particularly from soybean (003/16). The subclasses A23K and A23C were related mainly to animal feed and milk substitutes, respectively. Finally, the subclass falling outside the 'Human Necessities' group was labelled with C12N-015/82 code related to the preparation and use of genetically modified plant cells, which is consistent with the use of GMO in agriculture and microorganisms to express proteins for various uses e.g. human consumption.

In parallel, we used the classifications describing the main technology areas identified by Orbit Intelligence, which are given in the figure and table below. The most common categories are 'Food chemistry - Meat canning, dairy, oil, coffee, protein supplements' followed by 'Biotechnology - Enzymes, micro-organisms' which is unsurprising given the data presented above. In addition, the third most common technology class identified by the Orbit algorithm was 'Pharmaceuticals -

Preparations for medical & dental' that covered patents related for example to algae-based nutrition products, baby food products containing allergenic proteins, pea protein isolate etc. In comparison to concepts related to food chemistry, there appears to be relatively little patenting activity around biotechnology and agriculture technology, even considering the fact that the patent search was restricted by the technology classes in the first instance.

Patent Count by Technology Classification



9.2.5 PATENT LANDSCAPING

Using the patent landscaping tool developed by **Questel's Orbit Intelligence**, we mapped the patent search described in the section above. The tool visualises the relationship between patents in the field by using several algorithms to cluster documents based on shared language – in this case the English Title, Claims and Abstracts of individual patents. The text from one record is compared with the text from all other patent records within the search collection. The map then uses vectors to give each patent record a proximity score to all of its peers. The outcome of this analysis is a visualisation of the patent space with each patent (dot) represented once in the map according to their semantic proximity i.e. patents in close proximity share more phraseology than those located apart. The patents are grouped into map 'contours' to show areas of high and low patenting activity organised into common themes. The illustration shows these contour lines, with the 'mountain peaks' representing a concentration of patents. Each peak is labelled with the key terminology concepts contained in the patents within the cluster. Although the landscaping is not an entirely precise tool, it is possible to identify clusters of technology areas on the map which can be useful for analysing trends within the dataset. The map was generated using the same search query as in the broad search, and the resulting graph is shown on the following page. The topics identified by the algorithm are labelled on the map and each peak is annotated with the key terminology concepts contained in the patents within the cluster.

The patent landscape shown here reinforces the key technology areas of focus identified from initial patent searching around the Alternative Protein Sources (i.e. nutritional products, the use of algae, protein ingredients etc.). While there is some degree of crossover between these areas, the map also illustrates that the patenting field comprises technology areas from various clusters, which might seem unrelated at first.

Unsurprisingly, one of the emerging themes are nutritional products. A number of plants and microorganisms were also identified as the commonly used terms, some of which included primarily functional plants, such as *Salvia hispanica* (chia), bamboo as well as *Stevia rebaudiana* (mentioned later in the key patent section), which could indicate that these plants are gaining popularity due to their unique properties. In addition, *Bacillus subtilis*, an aerobic bacterium, is also included on the map. This bacterial species can be found in soil and is also said to perform a crucial function in the human gastrointestinal tract.[168] Algae are also featured on the map – as an algae flour and in the context of reduction of heavy metal content, which is consistent with the absorption and sequestration capacity to remove heavy metals by several microalgae species with some examples described by Shanab *et al.* (2012) and Jahan *et al.* (2004).[169,170]

A few terms related to chemical processing can also be found on the map. Specifically, chemical compound 'flavone', which is the basis for some plant pigments, has been returned by the search, highlighting its potentially important application in preparation of food products. Additionally, the terms related to 'chloroform methanol mixed solvent' are likely to be related to the methods used for extracting and separating lipids from microorganisms and biological tissues, known as Bligh and Dyer or Folch procedures.[171]

Moreover, there were a few key terms associated with gene editing pointing towards more advanced biotechnological techniques. The peak titled 'gene encoding/recombinant vector/fusion protein' contains patents covering GMOs used in agriculture that already shape the current state of the industry (e.g. patents WO2018/130828 'Methods of increasing seed yield' or WO2019/079135 'Production of heme-containing proteins in cyanobacteria').

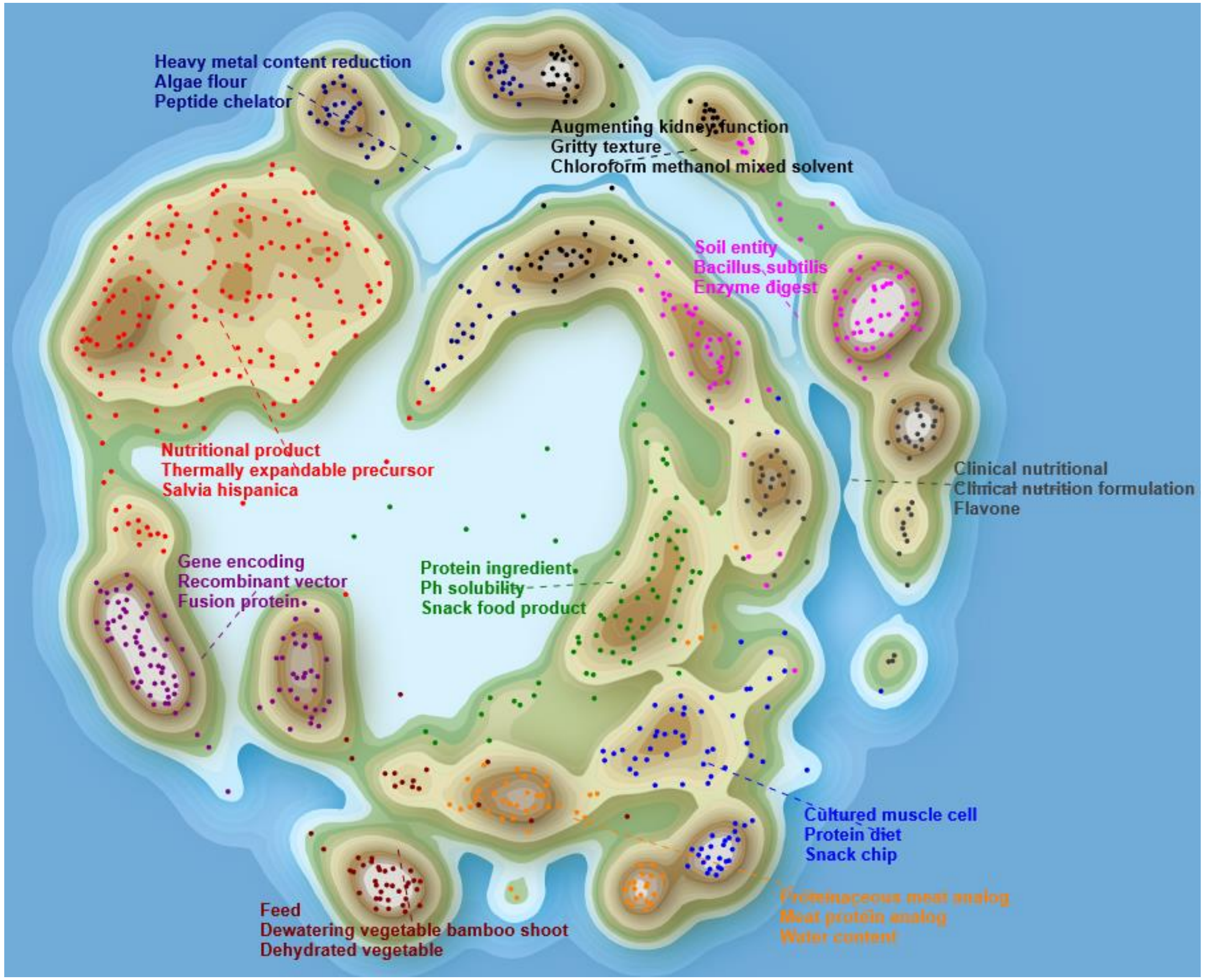
Finally, there is also a subsection of the map representing patents that relate to 'proteinaceous meat analog' and 'cultured muscle cell', some of which correspond to inventions that are fundamental to several of the top players described above in the Animal Product Replacements section. The patents pertaining to these classes are discussed in further detail below in the Focused Search: Cultured Meat section.

[168] Williams (2007) *Bacillus subtilis: a shocking message from a probiotic*. Cell Host Microbe., **14**, 248-9.

[169] Shanab *et. al.* (2012) *Bioremoval capacity of three heavy metals by some microalgae species (Egyptian Isolates)*. Plant Signal Behav., **7**(3), 392–399.

[170] Jahan *et. al.* (2004) *Metal uptake by algae*.

[171] Folch (1956) *A simple method for the isolation and purification of total lipides from animal tissues*. J Biol Chem., 226, 497-509



Landscape by technology clusters: The landscape summarises the broad technology fields related to the Alternative Protein Sources patenting field from the search of 864 patent families. The coloured dots refer to patents with keywords shown next to the cluster. Here some common themes include nutritional products, a few of them using specific organisms, such as algae, bamboo, chia etc. There is also a proportion of patents that relate to meat analogues/cultured muscle cell as well as a proportion of the map occupied by technologies based on gene editing techniques (Source: Questel Orbit Intelligence).

9.2.6 KEY PATENTS

A patent citation analysis identifies key patents and patent applications and their corresponding assignees, within a patent dataset. Citations link documents together based on the citing of one document in another. For patents this means the document has related content. In patent literature citations will either mean that the applicant has disclosed the former patent as prior art, or the examiner from the patent office identified the former patent during the search. A forward citation is commonly used in patent analytics and refers to the citing documents. The number of forward citations refer to citations received by a particular patent by subsequent patents. The frequency may be an indicator of key inventions or patents with high value.[172] The table below summarises the top 10 patent publications with the highest number of forward citations. The Title and Abstract fields are included for each publication. The more recent the application date, the more likely it is that the given publication is a key invention in the field. Please note that only non-self forward citations were included in the analysis of most cited patent families.

While a few of the patents listed below appear to be related to pest control and food processing techniques, there are also a variety of patents covering innovative food products such as sucralose-based sweetener, 'Infant nutritional compositions for preventing obesity' that consist of linoleic acid and alpha-linolenic acid, 'Carbonated protein drink' etc. Please note that while patents ranked 2 and 3 on the list below appear to be related to the same invention, they are still listed in the database as separate records.

Some patents are assigned to organisations identified as key players in the sector throughout this white paper e.g. **Solazyme** (later known as **TerraVia Holdings,** and subsequently acquired by **Corbion**) and a number of companies mentioned as key entities in this patenting field, such as **Nutricia** (part of **Danone**), **Monsanto Technology** (now owned by Bayer) and **Abbott Laboratories**. Examples of other patent assignees listed below include: **DevGen**, a large multinational agricultural company and a number of small to medium size biotechnology companies including **ZeaChem** (now known as Zea2), a chemical company focused on biorefining, **Sanei General FFI**, a Japan-based food ingredients company and **Next Proteins**, a US-based organisation developing soft drinks with high protein content.

<table>
<tr><th></th><th>Count of non-self forward citations</th><th>Publication Number</th><th>Assignee</th><th>1st Application Date</th><th>Latest Publication Date</th></tr>
<tr><td rowspan="3">1</td><td>297</td><td>EP1813590</td><td>ZEACHEM, ZEACHEM INTELLECTUAL PROPERTIES</td><td>2000-03-10</td><td>2013-04-25</td></tr>
<tr><td colspan="5">Title: Process for recovering an ester</td></tr>
<tr><td colspan="5">Abstract: A process for producing ethanol including a combination of biochemical and synthetic conversions results in high yield ethanol production with concurrent production of high value coproducts. An acetic acid intermediate is produced from carbohydrates, such as com, using enzymatic milling and fermentation steps, followed by conversion of the acetic acid into ethanol using esterification and hydrogenation reactions. Coproducts can include corn oil, and high protein animal feed containing the biomass produced in the fermentation.</td></tr>
<tr><td rowspan="2">2</td><td>185</td><td>EP1929020</td><td>DEB JEN, DEVGEN NV, MONSANTO TECHNOLOGY</td><td>2006-09-15</td><td>2019-07-10</td></tr>
<tr><td colspan="5">Title: Dsrna as insect control agent</td></tr>
</table>

[172] Abrams *et al.* (2013). *Patent Value and Citations: Creative Destruction or Strategic Disruption? National Bureau of Economic Research*; NBER Working Paper No. 19647

	Count of non-self forward citations	Publication Number	Assignee	1st Application Date	Latest Publication Date
	Abstract: The present invention relates to methods for controlling pest infestation using double stranded RNA molecules. The invention provides methods for making transgenic plants that express the double stranded RNA molecules, as well as pesticidal agents and commodity products produced by the inventive plants.				
3	162	EP1971687	DEVGEN NV, DEVGEN NU	2007-01-12	2019-02-12
	Title: Dsrna as insect control agent				
	Abstract: The present invention relates to methods for controlling pest infestation using double stranded RNA molecules. The invention provides methods for making transgenic plants that express the double stranded RNA molecules, as well as pesticidal agents and commodity products produced by the inventive plants.				
4	155	EP1210880	SANEI GENERAL FFI	1998-11-17	2018-08-09
	Title: Compositions containing sucralose and application thereof				
	Abstract: Novel utilization of sucralose which is a high intense sweetener. Compositions containing sucralose including: sweetening compositions having excellent sweetness qualities based on the characteristics of sucralose; foods with a masked unpleasant smell and unpleasant taste; performance food compositions (viscous food compositions, gel food compositions, emulsified food compositions); foods with improved flavors; preservatives and foods with improved quality of taste; and flavor compositions with improved flavors. Novel utilization of sucralose as a sweetness improver, a masking agent for unpleasant smell/unpleasant taste, a flavor improver, a function improver (viscosity, gelling properties, emulsification properties), a taste characteristic improver, and a flavor improver/enhancer.				
5	117	EP1962617	NUTRICIA	2005-12-23	2019-09-11
	Title: Infant nutritional compositions for preventing obesity				
	Abstract: The present invention relates to a method for preventing obesity later in life by administering a certain nutritional composition to an infant with the age between 0 and 36 months. The composition comprises linoleic acid and alpha-linolenic acid.				
6	107	EP1809127	NEXT PROTEINS	2005-08-30	2019-02-19
	Title: Carbonated protein drink and method of making				
	Abstract: An improved carbonated protein beverage/drink composition which provides a relatively high protein content, ranging from about 2 % by weight to about 15 % by weight, while simultaneously employing a carbonation concentration between about 0.1 volumes of carbonation (per volume of liquid drink solution or liquid drink suspension) to about 4 volumes of carbonation. Preferably the protein is whey protein. The carbonated protein beverage has been heat treated to inactivate microbes in the presence of the carbonation which is used to provide taste and mouth feel for the drink. Typically, the treatment for microbe inactivation is carried out in the individual package used for storage and handling of the carbonated protein drink.				
7	98	EP1802929	ASURINYU AIPI HOLDINGS LIABILITY EARTHRENEW, EARTHRENEW IP HOLDINGS, EARTHRENEW ORGANICS	2004-07-19	2013-04-02
	Title: Process and system for drying and heat treating materials				
	Abstract: This invention discloses systems and methods for conversion of high moisture waste materials to dry or low moisture products for recycle or reuse. The equipment systems comprise a gas turbine generator unit (preferred heat source), a dryer vessel and a processing unit, wherein the connection between the gas turbine and the dryer vessel directs substantially all the gas turbine exhaust into the dryer vessel and substantially precludes the introduction of air into the dryer vessel and wherein the processing unit forms the dried material from the dryer vessel into granules, pellets or other desired form for the final product. Optionally, the systems and methods further provide for processing ventilation air from manufacturing facilities to reduce emissions therefrom.				
8	91	EP2339925	CORBION BIOTECH, SOLAZYME, TERRAVIA HOLDINGS	2009-10-14	2019-09-10
	Title: Food compositions of microalgal biomass				

	Count of non-self forward citations	Publication Number	Assignee	1st Application Date	Latest Publication Date
	Abstract: The invention provides algal biomass, algal oil, food compositions comprising microalgal biomass, whole microalgal cells, and/or microalgal oil in combination with one or more other edible ingredients, and methods of making such compositions by combining algal biomass or algal oil with other edible ingredients. In preferred embodiments, the microalgal components are derived from microalgal cultures grown and propagated heterotrophically in which the algal cells comprise at least 10% algal oil by dry weight.				
9	74	EP1809124	SGF HOLDINGS, SWEET ALOHA FARMS, SWEET GREEN FIELDS INTERNATIONAL, SWEET GREEN FIELDS ELSEY	2005-10-17	2019-01-17
	Title: High yield method of producing pure rebaudioside a				
	Abstract: The invention provides a high throughput, high purity, high yield system and method of isolating and purifying rebaudioside A ("Reb")h acceptable water solubility for all commercial uses, from commercially available Stevia rebaudiana starting material. The invention also provides a means of maximizing yields of 99+% purity Reb A based on the attributes of a given batch of Stevia starting material. The Reb A produced by the invention is water soluble, devoid of bitterness heretofore associated with rebaudioside sweeteners, non-caloric, and suitable for use as a reagent and as an ingredient in orally consumed products, e.g., as a sweetener, flavor enhancer, and flavor modifier.				
10	58	EP1039892	ABBOTT LABORATORIES, UNIVERSITY OF TENNESSEE RESEARCH CORPORATION, UNIVERSITY OF TENNESSEE RESEARCH FOUNDATION	1997-10-03	2011-11-16
	Title: Use of polyunsaturated fatty acids for reducing the incidence of necrotizing enterocolitis				
	Abstract: Enteral formulas that contain long-chain polyunsaturated fatty acids (PUFAs), e.g. arachidonic acid (AA) and docosahexaenoic acid (DHA) essentially free of cholesterol, and a process for making such enteral compositions are described. More particularly, the invention relates to methods for reducing the incidence of necrotizing enterocolitis by administering compositions which provide n-6 and n-3 long chain PUFAs; phospholipids and/or choline. Compositions from egg yolk lipids are presently preferred as they contain n-6 and n-3 long chain PUFAs and are predominantly in a phosphtidylcholine form. This is believed to provide a synergistic effect. Also disclosed is a process of making such a composition that provides improved organoleptic and stability properties.				

In addition to the patent application EP2339925 listed above, **Solazyme/TerraVia Holdings** (now owned by **Corbion**) is the patent assignee of a number of patent filings in the field. Another example includes the patent application EP3160264 - *High-protein food products made using high-protein microalgae*. Thus, it is possible, that the company initially aimed to build of a network of similar, highly overlapping patents, which could be described as a 'patent thicket'.[173]

Moreover, apart from the patents in the table of most cited patent families, there are several noteworthy patents in relation to Alternative Protein Sources for production of food and animal feed, which we identified by manually reviewing the hits returned by the broad search. Although the patents listed below are not aimed to form an exhaustive overview of the inventions in the patenting field, they can provide useful examples of the inventions in the field for which their inventors are seeking patent protection.

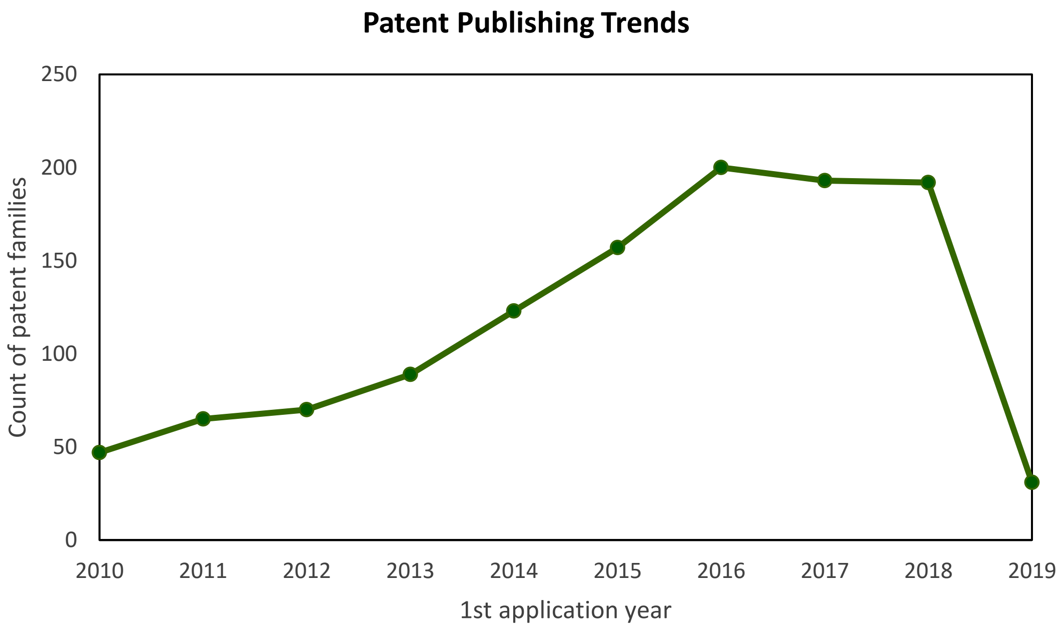
[173] Shapiro (2000) *Navigating the Patent Thicket: Cross Licenses, Patent Pools, and Standard Setting*. Innovation Policy and the Economy, **1**, 119-150

Publication Number	Assignee	1st Application Date	Latest Publication Date
EP2885980	KRAMERBRAEU SAATEN & OELE KRAMERBRÄU SAATEN & ÖLE	2013-12-19	2017-03-28
Title: Method and system for extraction of vegetable protein, in particular as protein-rich foodstuff or animal feed, and protein-rich human and animal food			
Abstract: To any method and the vegetable Protein and the food rich in Protein and by a, creating peeled sunflower a, a pressing step upstream preheating device are provided, in which the dehulled sunflower cores on a defined are heated. The preheated sunflower seeds are pressed so pressing stage having an oil press a at least one, that, besides the squashed oil, a protein-rich sunflower core press cake is produced, the residual fat content greater than or equal to 5 -% by weight -% by weight of 9 to less and a protein content of greater than or equal to 40%, based on the dry matter, thereto. A method and a unit is disclosed, the partially peeled sunflower kernel is compressed, that of the sunflower core filtercake a residual fat content greater than or equal to 8 -% by weight - by weight or less relative to 18 30%% and a content of greater than or equal 45% or less by weight, based on the dry weight, have. The feed or food rich in protein produced according to a body claimed.			
EP2294930	REAR VENT BIOSCIENCE VENTRIA BIO SCIENCE	2002-02-14	2014-06-12
Title: Expression of human milk proteins in transgenic plants			
Abstract: The invention is directed to food and food additive compositions comprising one or more human milk proteins produced in the seeds of a trangenic plant and methods of making the same. The invention is further directed to improved infant formula comprising such food supplement composition.			

9.3 FUTURE FARMING TECHNOLOGIES

9.3.1 PATENT PUBLISHING TRENDS

There has been a steady increase in patent filings for new Farming Technologies over the last decade. The patenting activity in the field corresponds to the number of new inventions in a particular research area or industry sector and could indicate some general market trends. On one hand, a growing number of patents may point towards a high-growth sector and notable investment in R&D programmes related to the field. On the other hand, the plateau in the most recent years could be a sign of a stable publishing profile, which is consistent with sector maturity.



9.3.2 KEY ENTITIES

Although the number of patents returned by the broad patent search in the field of novel Farming Technologies was higher than the number of Alternative Protein Sources patents analysed in the previous section, the patents in the space of Future Farming Technologies are spread out over a larger number of assignees. This is exemplified by the fact that, for the Future Farming Technologies, only 5% of total patents generated by the broad search are owned by top 10 players, compared to 14% of all patent owned by top 10 players in the Alternative Protein Sources sector. This, together with the data presented in the chart below, shows that the market is fragmented, even to a greater extent than the Alternative Protein Sources market.

The following chart revealed that the top patent assignees are **the Ministry of Agriculture of the Russian Federation** and **ClearAg, Inc.** (a subsidiary of **Iteris Inc.**), followed by four research institutions based in China: the **Chinese Academy of Fishery Sciences, Nanjing Agricultural University, the Shanghai University** and **Sichuan Agricultural University**. The top players leading the field are characterised by a similar level of patenting activity in this research area.

Cluster by Entity Type: Commercial Vs. Academic

The table below summarises the top commercial organisations in order of patenting activity and a corresponding industry sector as well as location of company's headquarters are also provided. The tables below highlighted a strong presence of academic and research institutions, particularly from BRIC countries, in this patenting field. As a result, the number of large companies focused on agriculture and small biotech companies identified as key patent assignees in the field is relatively small.

In terms of the commercial players, agriculture companies occupied the strongest position in this patenting field, particularly those with headquarters located in China and the USA. The leader in the field was **ClearAg** (part of Iteris), which is a data analytics company providing a farming platform for crop analytics. ClearAg was followed by CNH Industrial, a multinational manufacturer of agricultural and construction equipment, **Sichuan Huigu Agricultural Technology**, a subsidiary of **Sichuan Guoguang Agrochemical**, a Chinese chemical producer, and **Blue River Technology**, a US-based company offering novel farming equipment used for spraying crops. Also, the company **Just Greens** is now owned by **Dream Holdings**, which is also the parent company of **AeroFarms**, previously mentioned in this white paper as a key player in the vertical farming sector. Also, it is worth noting that a couple of patents currently assigned to MJNN (part of Fortune Brands Home & Security) were previously held by **Bright Agrotech**, which was later acquired by **Plenty** in 2017, another key vertical farming company.

Overall, the top commercial patent assignees operate in a range of sectors spanning from manufacturers of agriculture/automotive equipment (**CNH Industrial, Blue River Technology**), through aquaculture and food companies (**Dantu District Jiangxinzhou Fengze Fishery Park, Xinjiang Zhongkehai Aquatic Technology**) to a Japanese distillery (**Yamazaki**).

Commercial Assignee/Applicant	No. of patent publications, 2009-2019	Sector/Category	Headquarters Location
CLEARAG (part of Iteris)	9	Data analytics in agriculture	USA
CNH INDUSTRIAL	5	Agriculture, Automotive	Netherlands
SICHUAN HUIGU AGRICULTURAL TECHNOLOGY	5	Agriculture	China
BLUE RIVER TECHNOLOGY	4	Agriculture	USA
DANTU DISTRICT JIANGXINZHOU FENGZE FISHERY PARK	4	*Food chemistry, Aquaculture	China
JIANGYIN BAIXIN AGRICULTURAL TECHNOLOGY	4	*Agriculture	China
SHENZHEN CAIBOSHI URBAN AGRICULTURE	4	*Agriculture	China
SICHUAN GOIL BIOTECHNOLOGY	4	*Agriculture, Biotechnology	China
XINJIANG ZHONGKEHAI AQUATIC TECHNOLOGY	4	Aquaculture	China
YAMAZAKI	4	Distillery	Japan
HUAXING GLOBAL AGRICULTURE	3	*Agriculture	China
JUEZI TECHNOLOGY	3	*Agriculture	China
JUST GREENS	3	Agriculture	USA
MJNN (part of Fortune Brands Home & Security)	3	Agriculture	USA
QUANZHOU SUNSHINE HORTICULTURE	3	Agriculture	China
SHANGHAI LANMU CHEMICAL	3	Chemical producer	China
SHENGZHOU MOSANG HIGH TECHNOLOGY	3	*Agriculture, Aquaculture	China
XIANYU WISDOM AGRICULTURAL TECHNOLOGY	3	*Agriculture	China
ZHEJIANG FUKANG BIOTECHNOLOGY	3	Chemical producer, Biotechnology	China
4EN INCORPORATION	2	*Agriculture	South Korea
AESSENSE TECHNOLOGY HONG KONG (part of AEssense Corp)	2	*Agriculture	Hong Kong (HQ in USA)

* Due to the limited information on the organisation available online, the sector was completed based on the organisation's patent portfolio.

The academic field is strongly dominated by Chinese research institutes that have been patenting heavily in the recent years. While **the Ministry of Agriculture of the Russian Federation** was identified as the leader in the patenting field with the highest number of relevant patents, it was followed by four research institutions located in China: **Chinese Academy of Fishery Sciences, Nanjing Agricultural University, Shanghai University** and **Sichuan Agricultural University**. Similar to the Alternative Protein Sources Patent Analysis section, Chinese research centres highlighted in the table below are not restricted geographically to one area within the country, which shows that the research interest in the Future Farming Technologies is shared on a national level. In addition, there are two Brazilian universities featured on the list, emphasising strong interest in the field expressed by BRIC countries.

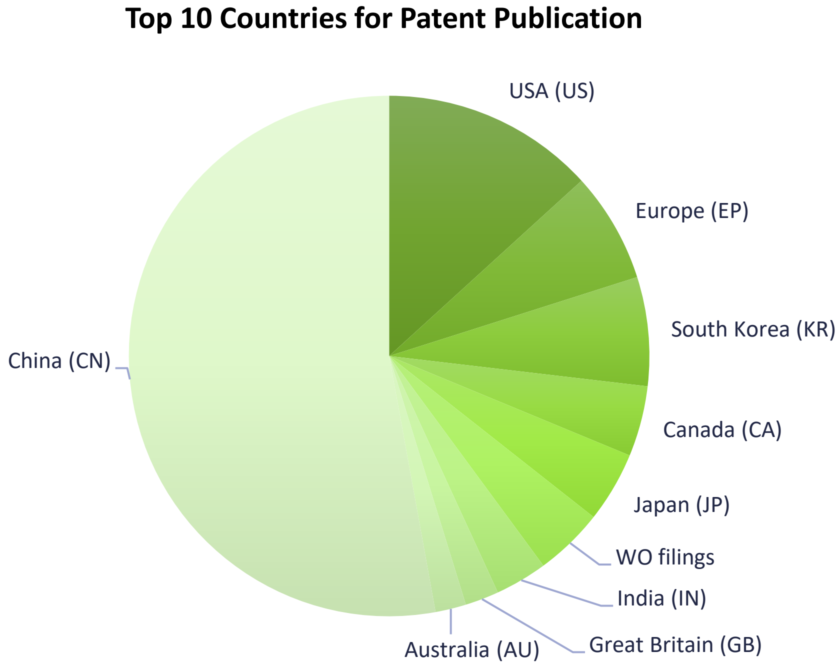
There are also several patents held by assignees based in South Korea, which has been classified a 'developed market' since 2009.[174] The full list of top academic patent assignees is included below:

Research Institution Assignee/Applicant	No. of patent publications, 2009-2019	Location
MINISTRY OF AGRICULTURE OF THE RUSSIAN FEDERATION	10	Russia
CHINESE ACADEMY OF FISHERY SCIENCES	8	China
NANJING AGRICULTURAL UNIVERSITY	8	China
SHANGHAI UNIVERSITY	6	China
SICHUAN AGRICULTURAL UNIVERSITY	6	China
CHINA AGRICULTURAL UNIVERSITY	5	China
FUJIAN AGRICULTURE & FORESTRY UNIVERSITY	5	China
JIANGSU UNIVERSITY	5	China
SOUTH CHINA AGRICULTURAL UNIVERSITY	5	China
YELLOW SEA FISHERIES RESEARCH INSTITUTE CHINESE ACADEMY OF FISHERY SCIENCES	5	China
ZHEJIANG A & F UNIVERSITY	5	China
GUANGXI UNIVERSITY	4	China
HUAZHONG AGRICULTURAL UNIVERSITY	4	China
INSTITUTE OF PLANT PROTECTION OF FUJIAN ACADEMY OF AGRICULTURE	4	China
LIAN YUNGANG MARINE FISHERIES RESEARCH INSTITUTE	4	China
SHANGHAI FISHERIES RESEARCH INSTITUTE	4	China
REPUBLIC OF KOREA	4	South Korea
AGRICULTURAL UNIVERSITY OF HEBEI	3	China
BEIJING UNIVERSITY OF AGRICULTURE	3	China
GUANGDONG OCEAN UNIVERSITY	3	China
INSTITUTE OF PLANT PROTECTION CHINESE ACADEMY OF AGRICULTURAL SCIENCES	3	China
NORTH WEST AGRICULTURE & FORESTRY UNIVERSITY	3	China
SHANDONG AGRICULTURAL UNIVERSITY	3	China
SHANDONG MARINE FISHERIES RESEARCH INSTITUTE	3	China
UNIVERSIDADE ESTADUAL PAULISTA JULIO DE MESQUITA FILHO – UNESP	3	Brazil
UNIVERSIDADE FEDERAL DE SAO CARLOS UFSCAR	3	Brazil
YANGTZE UNIVERSITY	3	China
ZHEJIANG OCEAN UNIVERSITY	3	China

9.3.3 GEOGRAPHICAL ANALYSIS

The geographical spread of the top patent assignees is exemplified using top publication (i.e. protection) countries analysis below. China is the most popular territory where patent protection is sought, demonstrated by over a half of all patents in the field (52.9%). Protection for technologies related to Novel Farming Technologies is also sought in the US (13.2%), Europe (6.9%), Canada (4.4%) and Great Britain (2.1%). Countries from the Asia-Pacific region other than China are also important territories for protection, particularly South Korea (6.8%), Japan (4.4%) India (3.2%) and Australia (1.9%).

[174] Woods (2013) *Classifying South Korea As A Developed Market*. White Paper Report FTSE Publications.



A very similar spread of results is observed for the countries where patents are initially filed, since the vast majority of the research is taking place in China, and inventors are generally only seeking protection in China. Multinational US/European companies, by contrast, will generally file a patent in their home territory but seek protection in a variety of territories.

Overall, this analysis, together with the location of key patent assignees listed in the previous sections, demonstrates China's strong position in the patenting field, which appears to be fuelled primarily by the activities of the academic research institutions in this country.

9.3.4 TECHNOLOGY AREAS

To narrow down the patent database analysed in this section, the patent search conducted was already restricted to IPC subclasses with codes starting '**A01**', which stands for technologies classified as '**Human Necessities / Agriculture; forestry; animal husbandry; hunting; trapping; fishing**'. Nonetheless, since the IPC code is the formal structure in which technologies described within a patent are classified, it can provide an indication of the most important specific technology sub-areas for the Future Farming Technologies patent landscape. The table below provides further classification of the records identified by the broad search.

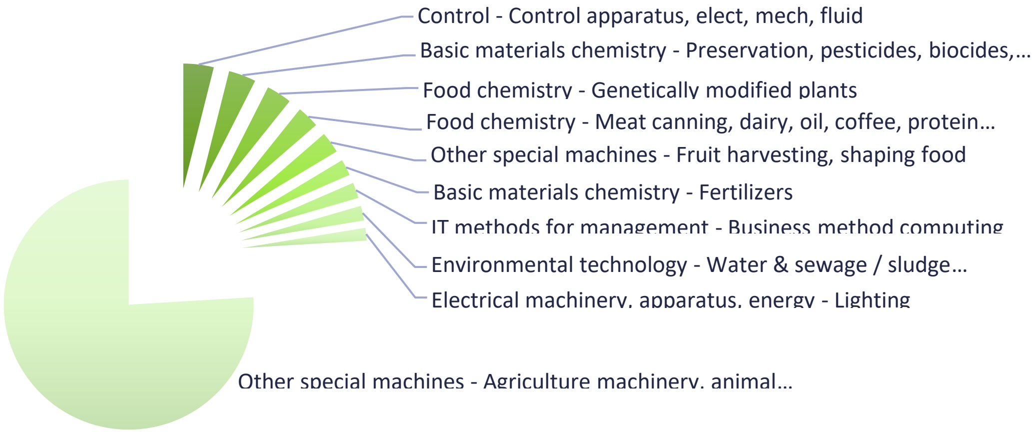
IPC Code	Document Count	Description
A01G-031/02	181	G - Horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops or seaweed; forestry; watering 031/02 - Soilless cultivation, e.g. hydroponics / Special apparatus therefor
A01G-009/02	97	G - As above 009/02 - Cultivation in receptacles, forcing-frames or greenhouses; Edging for beds, lawn or the like / Receptacles, e.g. flower-pots or boxes; Glasses for cultivating flowers
A01G-031/06	68	G - As above 031/06 - Soilless cultivation, e.g. hydroponics / Hydroponic culture on racks or in stacked containers
A01K-067/033	56	K - Animal husbandry; care of birds, fishes, insects; fishing; rearing or breeding animals, not otherwise provided for; new breeds of animals 067/033 - Rearing or breeding animals, not otherwise provided for; New breeds of animals / Rearing or breeding invertebrates; New breeds of invertebrates
A01G-031/00	53	G - As above 031/00 - Soilless cultivation, e.g. hydroponics
A01K-061/00	52	K - As above 061/00 - Culture of aquatic animals
A01G-001/00	46	G - As above 001/00 - (transferred to A01G 2/00-A01G 2/20, A01G 9/033, A01G 20/00-A01G 22/05, A01G 22/15-A01G 22/20, A01G 22/25-A01G 22/67, A01G 24/00-A01G 24/60)
A01K-063/00	41	K - As above 063/00 - Receptacles for live fish, e.g. aquaria
A01G-009/24	26	G - As above 009/24 - Cultivation in receptacles, forcing-frames or greenhouses; Edging for beds, lawn or the like / Devices for heating, ventilating, regulating temperature, or watering, in greenhouses, forcing-frames, or the like
A01G-009/14	21	G - As above 009/14 - Cultivation in receptacles, forcing-frames or greenhouses; Edging for beds, lawn or the like / Greenhouses

A large proportion of the patents from the broad search were classified under the class A01G-031 which corresponds to the methods and devices used for soilless cultivation, e.g. hydroponics. This is unsurprising considering the search criteria used. Also, the classes related to breeding animals (codes starting with 'A01K'), such as culture of aquatic animals (061/00), receptacles for live fish, e.g. aquaria (063/00) could include inventions around aquaponics systems where aquatic animals are farmed together with plants (pp. 132-134). Additionally, the records classified under the class containing patents related to breeding invertebrates (A01K-067/033) include several patents related to farming systems for various insects such as cochineal, an insect used for production of a natural food dye. Finally, several top IPC class codes start with 'A01G-009', which stands for 'cultivation in receptacles, forcing-frames or greenhouses; edging for beds, lawn or the like', further classified by the equipment type: receptacles, i.e. flower-pots or boxes; glasses for cultivating flowers (-02), greenhouses (-21) and devices for heating, ventilating, regulating temperature, or watering, in greenhouses, forcing-frames etc. (-24).

The parallel technology classification provided by Questel's Orbit Intelligence is shown in the figure and table below. Considering the criteria used to conduct the broad patent search i.e. the restriction of the search output to the IPC codes that begin with A01, it is unsurprising that the vast majority of the records returned by this search pertain to the same category, namely 'Other special machines –

Agriculture machinery, animal husbandry'. However, this analysis also revealed that the patent dataset included patents associated with a range of different technology areas, such as food and materials chemistry as well as machinery (specifically: control apparatus and special machines for e.g. fruit harvesting).

Patent Count by Technology Classification



9.3.5 PATENT LANDSCAPING

Technologies relating to Future Farming Technologies, such as methods, compounds and devices have been mapped using the patent landscaping tool provided by Orbit Intelligence. The description of how the map is constructed using various algorithms is outlined in the Alternative Protein Sources Patent Landscaping section above.

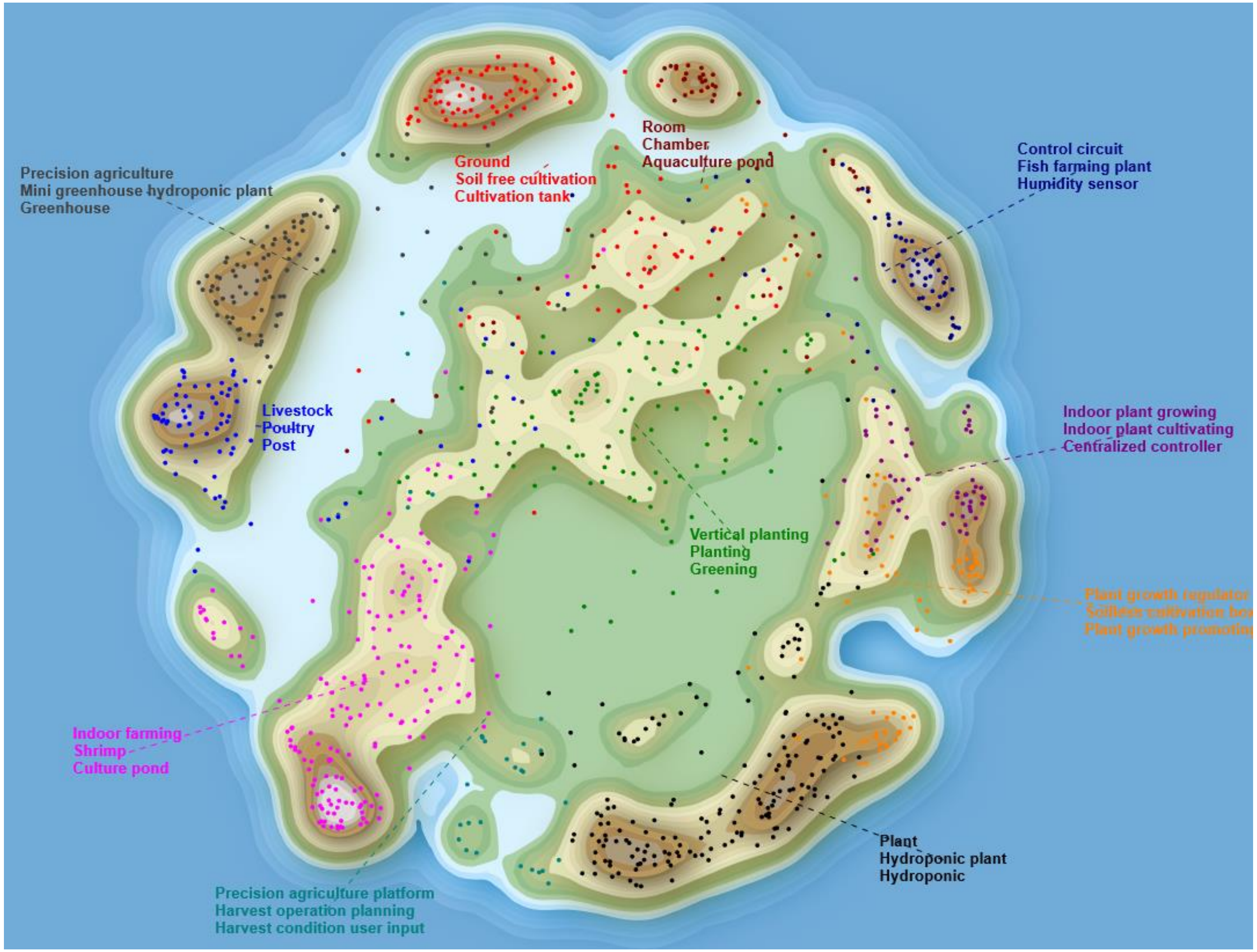
The main technology clusters revealed by the map emphasise the focus of the broad patent search around the Future Farming Technologies, which was designed to identify patents covering innovations in the space of vertical indoor farming, precision agriculture as well as aeroponic, hydroponic, and aquaponic systems. One of the recurrent themes emerging from the landscape is that the peaks described as 'soil free cultivation', 'soilless cultivation box', 'hydroponic plant' or 'mini greenhouse hydroponic plant' are interspersed with a number of different technology clusters, such as 'plant growth regulator', highlighting the fact that the inventions related to soilless plant cultivation might play an instrumental role for development of a range of innovative agriculture solutions.

The term 'precision agriculture' is mentioned twice on the map below and the technologies that appear to be closely related to this theme (based on their close proximity on the patent landscape) include 'greenhouses', 'mini greenhouse hydroponic plant', 'harvest condition user input' and 'harvest operation planning'. This not only reiterates the broad applicability of precision agriculture methods to the wider field, but it also illustrates the importance of machine-aided planning techniques/programmes.

As shown, patents relating to livestock, poultry, shrimp and fish farming are also scattered throughout the landscape, potentially reinforcing the position of conventional animal husbandry. This could emphasise a tendency that conventional animal-derived meat products will continue to play an important role in the agriculture industry over the next decades despite of the potential availability of the cultured animal products on the market and the consequent paradigm shift in the public's attitude towards meat consumption described in previous sections of this white paper.

Additionally, patents falling under the theme related to vertical planting occupy a central position in the landscape, with a number of different technology areas clustered around it. This reflects the high degree of crossover between research fields and the relevance of these technologies to a range of other inventions. There are also many additional technology areas within the landscape which may become increasingly important and more prevalent in future.

Overall, the thematic map below provides a broad overview of the landscape and emphasises the diverse character of the patents in the field of Future Farming Technologies. While there is some degree of crossover between these areas, the map also demonstrates that the patenting field comprises technology areas from various clusters highlighting a range of different aspects associated with the continual innovation in the agriculture industry.



Landscape by technology clusters: The map aims to select the broad technology fields related to the Future Farming patenting field from the search of 1188 patent families. The coloured dots refer to patents with keywords shown next to the cluster. Here some common themes include indoor and vertical farming interspersed with a number of different technology clusters. Soilless cultivation and hydroponic systems appear to be a recurrent theme within the landscape demonstrating wide applicability of these inventions to a broad research area of innovative agriculture and Future Farming Technologies (Source: Questel Orbit Intelligence).

9.3.6 KEY PATENTS

The table below summarises the top 10 patent publications with the highest number of forward citations. The Title and Abstract fields are included for each publication. The more recent the application date, the more likely it is that the given publication is a key invention in the field. Please note that only non-self forward citations were included in the analysis of most cited patent families.

The first two patents listed below cover technologies around pest control methods, which could indicate that the innovations in this space are highly influential. The remaining top records are related to construction of various agriculture systems and machinery e.g. automation robots, lighting fixtures, shipping containers to be used as portable farms hydroponic shipping container farms as well as sprayer systems and a device receiving sensor data for precision agriculture. This information could indicate the inventions which might most influence the farming industry in the future.

Only three highly cited patents in the field were assigned to organisations focused predominantly on agriculture, such as **Concentric Ag** (formerly known as Inocucor), a company offering soil and plant boosters using combinations of beneficial bacteria and yeasts, **Freight Farms**, a manufacturer of hydroponic shipping container farms, **Great Veggies** and **Just Greens**. The last two companies merged to form **AeroFarms**, which was described in previous sections of the white paper (pp. 67-68). The remaining companies identified as holders of the patents listed below consist of organisations from various sectors, including:

- Two chemical companies, namely **DuPont** and Japan-based **Sumitomo Chemical Co**. The former company merged with Dow in 2017 before the merged companies split up into three businesses: DuPont, Dow Inc. and Corteva Agriscience.
- A pharmaceutical company **Meiji Seika Pharma Co**., subsidiary of Meiji holdings, which is also the parent company of Meiji, a Japan-based dairy producer identified as one of the top patent assignees in the Alternative Protein Sources patent analysis section.
- Academic research organisations: **Dalhousie University, The Nova Scotia Agricultural College** and **University of Florida Research Foundation**
- Others: **Bee Robotics**, an UK-based company specialising in the automation equipment for laboratories, the large consulting firm **Accenture** as well as an US-based construction company **Huston General Contracting (HGCI).**

	Count of non-self forward citations	Publication Number	Assignee	1st Application Date	Latest Publication Date
1	187	EP1622879	SUMITOMO CHEMICAL	2004-05-04	2012-03-06
	Title: Pyrimidine compounds and pests controlling compositions containing the same				
	Abstract: The present invention relates to a pyrimidine compound of the formula (I):wherein R¿1< represents a hydrogen atom, halogen atom or C1-C4 alkyl; R¿2? represents C3-C7 alkynyloxy; R¿3? represents a hydrogen atom, halogen atom or C1-C3 alkyl; X represents C4-C7 polymethylene, in which a CH?2#191-CH?2#191 may be replaced with a CH=CH, optionally substituted with at least one substituent selected from the group consisting of halogen atoms, trifluoromethyl and C1-C4 alkyls. This pyrimidine compound has an excellent activity of controlling pests.				
2	187	EP2628389	MAI CHI SAIKAR PHARMACLTD MEIJI, MEIJI SEIKA PHARMA MEIJI SEKA PHARMACOLTIDA	2011-08-26	2019-05-31
	Title: Noxious organism control agent				
	Abstract: Specific amine derivatives have been found to possess excellent activities as pest control agents.				
3	120	EP2978665	BEE ROBOTICS	2014-03-20	2017-12-26
	Title: Aerial farm robot system for crop dusting, planting, fertilizing and other field jobs				
	Abstract: Modern farming is currently being done by powerful ground equipment or aircraft that weigh several tons and treat uniformly tens of hectares per hour. Automated farming can use small, agile, lightweight, energy-efficient automated robotic equipment that flies to do the same job, even able to farm on a plant-by-plant basis, allowing for new ways of farming. Automated farming uses unmanned aerial vehicles (UAVs) that are equipped with detachable implements and reservoirs and that we call "aerial farm robots." Automated farming uses high-precision GPS and other precision positioning and vision technology to autonomously and precisely perform crop dusting, planting, fertilizing and other field related farming or husbandry tasks. The subsystems for the control, refill, recharge and communication subsystems of the aerial farm robots are part of the overall automated farming system, and can autonomously handle most of the husbandry tasks on a farm.				
4	42	EP2989386	HGCI, IP HOLDINGS	2013-07-18	2019-09-17
	Title: Air cooled horticulture lighting fixture for a double ended high pressure sodium lamp				
	Abstract: An air cooled double ended high pressure sodium lamp fixture for growing plants in confined indoor spaces. The fixture seals the lamp and heat generated by the same to a reflector interior. Flow disruptors create turbulence in a cooling chamber thereby enhancing thermal transfer into a cooling air stream that flows over and around the reflector's exterior side thereby convectively cooling the lamp using the reflector as a heat sink. The lamp is effectively maintained at operational temperatures and the fixture housing is insulated from the hotter reflector by a gap of moving cooling air, allowing use of the double ended HPS lamp in confined indoor growing spaces.				
5	29	EP3046066	ACCENTURE GLOBAL SERVICES	2015-03-20	2019-08-29
	Title: Precision agriculture system				
	Abstract: A device may receive sensor data from a sensor device located on a particular farm. The device may identify an alert, associated with the particular farm, based on the sensor data and using a model. The model may be created based on imagery data and numeric data relating to a group of farms. The device may determine, using the model, a recommended course of action to address the alert, and provide, to a user device associated with the particular farm, the recommended course of action.				
6	28	EP2866551	FREIGHT FARMS	2013-07-01	2019-08-22
	Title: Insulated shipping containers modified for high-yield plant production capable in any environment				
	Abstract: A system and method for generating high-yield plant production in any environment is disclosed. The system includes a container, a growing station, and a monitoring system. The growing station includes vertical racks, a lighting system, an irrigation system, a climate control system, and a ventilation system. The monitoring system monitors all of the systems in the growing station, as well as the environment within the container, to provide real-time data and alerts to a user.				

	Count of non-self forward citations	Publication Number	Assignee	1st Application Date	Latest Publication Date
7	27	EP1899806	DU PONT DE NEMOURS, DUPONT PIONEER	2006-06-12	2016-05-03
	Title: Method for use of environmental classification in product selection				
	Abstract: Methods and software for selecting seed products or other agricultural inputs for planting within an associated land base include classifying the land base with an environmental classification, determining at least one seed product to plant within the land base based on the environmental classification, and providing an output comprising identification of the at least one seed product to plant within the land base. The methods can incorporate precision farming data or other geo-spatially referenced data. Financial incentives for making particular selections for seed products or other agricultural inputs may also be provided.				
8	27	US20120195496	DALHOUSIE UNIVERSITY, HER MAJESTY THE QUEEN RIGHT OF THE PROVINCE OF NOVA SCOTIA REPRESENTED BY THE NOVA SCOTIA AGRICULTURAL COLLEGE, UNIVERSITY OF FLORIDA RESEARCH FOUNDATION	2011-01-31	2014-07-08
	Title: Variable rate sprayer system and method of variably applying agrochemicals				
	Abstract: Systems, methods and computer-readable media are provided for controlling a variable-rate sprayer for precision agriculture. Highly efficient digital image processing enables rapid and reliable control of the variable rate sprayer. In one embodiment, image processing uses only a subset of luminance, hue, saturation and intensity textural features to provide rapid image recognition. In another embodiment, an image is decomposed into RGB components and a G is ratio determined. For example, the textural method is useful in growing season where color differentiation is difficult. The G ratio method is useful in early spring and late fall where color differentiation is possible. These rapid computationally light methods enable a mobile sprayer system to identify crop or field conditions in real-time and to dispense an appropriate amount of agrochemical in a specific section of the sprayer boom where the target has been detected as the mobile sprayer advances.				
9	21	US20060053691	GREAT VEGGIES, JUST GREENS	2005-09-12	2014-07-22
	Title: Method and apparatus for aeroponic farming				
	Abstract: A system and method of aeroponic farming includes depositing seeds in a flat containing micro-fleece cloth and placing the flat within a growth chamber. The upper side of the flat is subjected to light of the proper frequencies to promote growth in plants. A nutrient solution is sprayed onto the micro-fleece cloth and the developing root mass of the plants, while controlling temperature, humidity, and carbon dioxide within the growth chamber. The plants are harvested resulting from the seeds at a desired stage of growth. The growth chambers can be stacked on each other and/or located side by side to save space within a facility, and to permit sharing the subsystems which control the nutrient solution, temperature, humidity, and carbon dioxide for the growth chambers.				
10	18	EP2663635	CONCENTRIC, INOCUCOR TECHNOLOGIES	2012-01-12	2019-09-10
	Title: Microbial compositions and methods				
	Abstract: The present invention comprises biological compositions, methods and articles. The disclosed composition, method of bioremediation of a site, method of affecting plant growth, method of treating a surface, method of treating a fluid, method of making an article, article made by a method of marking an article, method of making a food supplement and a method for food supplementation comprise an isolated bacteria, at least one isolated yeast, and at least one isolated micorrhyzal fungus, wherein the bacteria comprise at least a lactobacillus and at least a bacillus, wherein the bacteria were selected based on enzyme profiles so that the bacteria are complementary. The claimed invention further comprises a method for making a mixed culture encompassing measuring one or more enzyme activities of a group of microorganisms to form an enzyme profile for each microorganism and selecting microorganisms such that the enzyme profile of each selected microorganism is not identical to the enzyme profile of another microorganism.				

Additionally, by manually reviewing the records returned by the broad patent search, we also identified two noteworthy patents in the field, which are listed in the table below.

Publication Number	Assignee	1st Application Date	Latest Publication Date
EP3400791	AGRICOOL	2017-05-09	2018-11-14
Title: Aeroponic facility, system and cargo container			
Abstract: An aeroponic plant growth installation includes: a vertical support including a side capable of defining an inside of the vertical support extending from an upper end to a lower end of the vertical support, the at least one side including receiving openings each adapted to receive a cultivation container; a plurality of cultivation containers each including: a wall having a cross section defining an interior space, and first and second ends open, the cultivation containers being capable of being received in a receiving opening such that the second end of the cultivation container is inside the vertical support, and a material which is deformable so as to allow the growth of a plant, the material being disposed in the interior space of the cultivation containers; and a misting system capable of spraying a nutrient liquid onto the roots of the plant at the upper end of the vertical support.			
EP2491784	CUBE FARM	2009-10-19	2013-12-25
Title: Energy-saving system for vertically moving plant growing box, energy-saving method for vertically moving plant growing box, and household energy-saving device for growing plant			
Abstract: A plant-growing technique wherein growing boxes are provided in a vertically multistage manner attains reduction in power consumption and safely carries out implanting work, harvesting work, etc. of plants. This energy-saving system for vertically moving plant growing boxes is composed of the growing boxes (2) provided in the vertically multistage manner, a device (1) for vertically moving and connecting the growing boxes; and growing light source (20) wherein lighting can be controlled in a height direction corresponding to the vertical movement of the growing boxes. The intervals between upper and lower growing boxes can be increased and reduced by the device for vertically moving and connecting the growing boxes, and the growing box can be detached stage by stage.			

9.4 FOCUSED SEARCH: CULTURED MEAT

9.4.1 SEARCH OVERVIEW

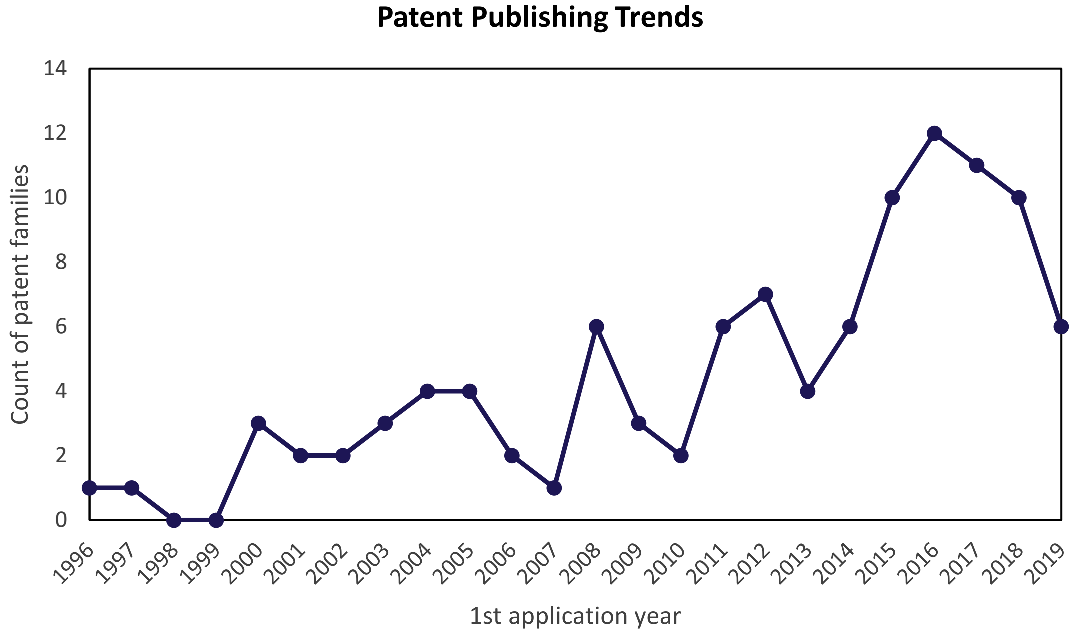
We carried out a separate search for patents focused on technologies relating to production of cultured meat and other cultured products conventionally obtained from animals. We aimed to identify patents that would cover technologies linked to tissue engineering methods (mainly muscle tissue), used specifically in the context of cultured meat production. As such, the search we conducted was not intended to cover a broad concept of 'meat-free' meat, which would also include plant-based meat alternatives. A range of vegetarian meat substitutes are already widely available on supermarket's shelves and the patents describing inventions in that space were already covered in the Alternative Protein Sources patent analysis section.

The use of purposefully ambiguous language in patent applications is not an uncommon practice in the majority of industries, making it somewhat difficult to easily identify relevant patents in the field. Further discussion of our patent search strategy is provided in the Appendix.

9.4.2 PATENT PUBLISHING TRENDS

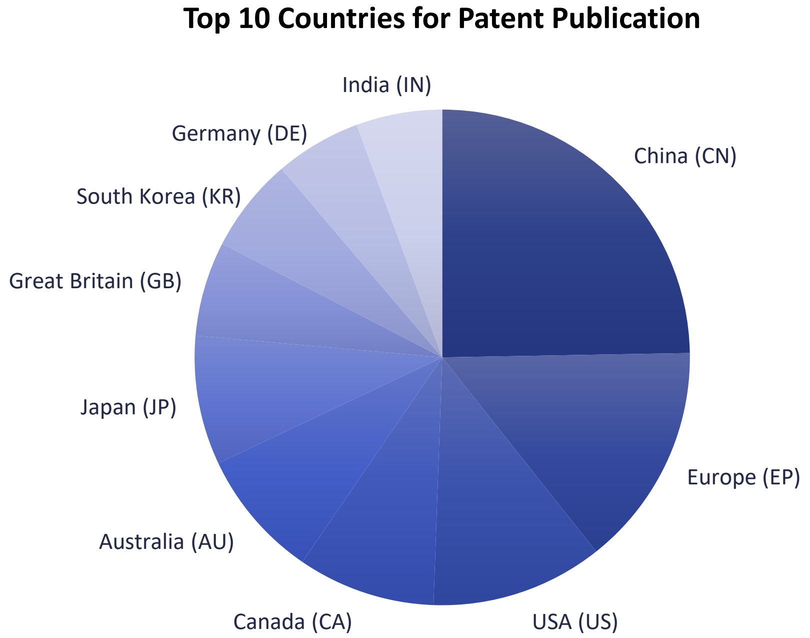
One of the first relevant patents filed in 1997 under the name *'Industrial production of meat from in vitro cell cultures'* (Publication number EP1037966) predates the first-ever cultured burger by 14 years.

Between years 2000 and 2014, the number of new patent applications did not exceed 7 records per year. An increase in patent applications in recent years is consistent with the developments in the lab-grown animal products research space and the respective market growth, primarily driven by the fierce competition of the cultured meat companies racing to launch their products on a large scale to gain competitive advantage by being first to market.



9.4.3 GEOGRAPHICAL ANALYSIS

The dataset generated by the focused search was also analysed in terms of territories where protection was sought. When the top 10 territories were analysed, China emerged as top territory for patent protection with a quarter of all relevant patents, which is consistent with our findings in the broad search analyses described in the two previous sections. China was followed by Europe and the US, together making up another quarter of all patents, with the remaining countries considered important for patent protection being Canada (9.0%), Australia (8.4%), Japan (8.4%), Great Britain (6.2%), South Korea (6.2%), Germany (5.6%) and India (5.6%). Similar to the previous broad search analyses, the position of the APAC region in this patenting field was particularly strong. The results of this analysis are presented below. A similar spread of results is observed for the countries where patents are initially filed, with 20% of all patents being initially filled as the Patent Cooperation Treaty (PCT) applications.



9.4.4 KEY PATENT ASSIGNEES

The table below summarises the patent publishing organisations holding at least 2 patent families. Reviewing the list of the top patent assignees can assist in identifying those organisations carrying out R&D in the area and the comparative level of activity in the space. Most of the key players are small biotechnology companies. Although these organisations are based in multiple locations; the US, particularly California, appeared to be the hub for innovative companies patenting in the field of cultured animal products.

Assignee/Applicant	No. of patent publications, 1994-2019	Location
JUST	5	CA, US
MEMPHIS MEATS	4	CA, US
MODERN MEADOW	3	NJ, US
CHONGQING XUXINYUE NC MACHINERY (CHONGQING JINFENG MACHINERY)	2	China
HUAZHONG AGRICULTURAL UNIVERSITY	2	China
IPSEN PHARMA	2	France
ITOHAM FOODS	2	Japan
PERFECT DAY	2	CA, US
PHENOLICS	2	NE, US
SUCCESS STORY	2	S Korea
UNIVERSITY OF MISSOURI	2	MO, US

However, the results shown in the table above should be considered with caution because, firstly, the search criteria specifically included identification of patents assigned to companies such as Memphis Meats or Perfect Day. Secondly, we speculate that a range of relevant technologies used by the key cultured meat companies are not reflected in the results set (due to the opaqueness in much of the language in patent documents) or may be protected by patents which are licensed from the external organisations such as universities, and thus are not owned by the companies themselves.

This is the case in relation to a patent assigned to an Israeli academic institute - **Yissum Research Development Company** of the **Hebrew University of Jerusalem**. Professor Yaakov Nahmias is the inventor named on patent application EP3481191 (*Systems and methods for growing cells in vitro*), which has been exclusively licensed from the university to **Future Meat Technologies**, a spin-out company founded by Yaakov.[175]

Although we were unable to track information in relation to the potential licence, we determined that **Aleph Farms** does not hold any patents itself, however it is possible that it uses the IP covered by the patents assigned to other parties, specifically to the **Technion – Israel Institute of Technology** (WO2019/016795 - *Cultured meat compositions*), as one of the named inventors of the technology is Prof. Shulamit Levenberg, who is now CSO of Aleph Farms. Additionally, Dr Neta Lavon, now VP R&D at Aleph Farms, is the named inventor of a patent assigned to **Kadimastem**, a biotechnology company focused on stem cell applications in biopharmaceuticals, where she previously acted as COO (WO2015/008275 – *Methods for large scale generation of stem cells*). While the patents assigned to Kadimastem were not returned by the search focused around cultured meat products for human consumption, the methods described by this patent family cover methods for growing cell cultures, which could play an instrumental role in the production process of 'clean' meat.

Finally, a Japan-based biotechnology company focused on production of cultured meat, **IntegriCulture**, was successfully granted its Japanese patent in 2017 (JP06111510B1 – *Growth induction system, growth induction control device, growth induction control method, and growth induction control program* – corresponding to the record WO2017/191691 in **Appendix 2**).

Through manually reviewing the patent dataset returned by the focused search we identified a number of noteworthy patents that may be important in the current processes for the production of lab-grown animal products and they may become increasingly important in future. These documents are listed in **Appendix 2**, and feature a mix of established key player such as **JUST, Memphis Meats and Modern Meadow,** as well as small companies, academic organisations other individual inventors.

9.5 SUMMARY AND COMMENTARY ON GRANTING OF PATENTS

China has been repeatedly identified as the leading territory for patent protection in the patent analysis sections above. This is consistent with the location of top patent assignees, especially academic entities publishing patents in the research areas linked to Alternative Protein Sources and Future Farming Technologies. A strong presence of research institutes located in BRIC countries, particularly China, in the two of the patenting fields from the broad searches may be indicative that research centres in industrially and economically developed markets are slowly moving away from R&D in the fields of 'conventional' farming techniques and alternative protein sources.

Despite China emerging as a leading country for patent protection across all three searches analysed above, these patent landscapes remain very diverse. A large proportion of patents are filed by commercial players with headquarters that are spread globally, particularly in the Alternative Protein Sources section where large food/nutrition and agriculture multinationals were the most prolific patent filing organisations, and which, from a commercial standpoint, continue to dominate the key markets in the USA and Europe.

[175] http://yissum.co.il/technologies/investment-opportunities/4638

Traditionally, obtaining patent protection has been perceived as ‘too slow’ or too expensive for the food and drink market, particularly for the fast moving consumer goods sector, with some industry players opting for trade mark protection and confidential know-how instead. However, patents in the Future Food Sources field are still considered to bring significant value to the companies operating in the industry. From the analysis of broad and focused patent searches in previous sections, we could observe that all three sectors are characterised by continuous developments. This is demonstrated by the fact that all three sectors have attracted notable attention over recent years, and crucial innovations have emerged that will undoubtedly shape the farming and food industries in the future.

In relation to the Future Farming Technologies space**, Bright Agrotech** is a patent assignee on two patents related to indoor farming systems (publication numbers: WO2018/017451 and WO2017/087644). The two filings cover lighting systems integrated with water cooling systems. Before the grant of US patents for both inventions (US10234125 B2, US10047943 B2) and Chinese Utility Model Patent for the latter PCT filing (CN209180700 U), the company was acquired by **Plenty** in 2017. Although Plenty has been identified in this white paper as a key market player in the vertical farming space (p. 67), the two patents have been re-assigned to company **MJNN** (part of Fortune Brands Home & Security), suggesting that **Plenty** might have sold the **Bright Agrotech’s** patents following the acquisition.

In May 2019, **Agricool** was also issued its French patent for an aeroponic plant growth system using vertical support packaged in a shipping container (FR3066069 B1). The technology is designed to be 120 times more productive than open-field agriculture and deliver high quality produce by avoiding transportation and pesticide use. The patent focused around urban indoor agriculture held by **Infarm** has been already been issued in a number of key territories countries including Austria, Australia, Canada, Switzerland, Germany, Denmark, Great Britain, Ireland, Japan, Netherlands and Sweden. This filing broadly covers a high efficiency plant growing system (PCT publication number: WO2016/020272 A1).

In September 2019, **AgJunction** Inc. announced the granting of three new European and US patents around precision agriculture (focused on position sensors that determine the location of farming equipment in a field, a steering wheel actuator mechanism also in the context of farm machinery and in-device thermal stabilization to minimise measurement errors in inertial measurement unit).[176] In its previous press release, the company indicated that it aims to address the need for more effective guidance and vehicle controls required to achieve greater autonomy of vehicles and allow cooperation of multiple machines in agriculture.[177] Altogether, this could point towards certain trends in the patenting field, which ultimately, will influence how farming will look like in the future.

In regards to patenting in the Alternative Protein Sources field, an algae-based food company **Solazyme**, which was later known as **TerraVia Holdings**, was successful in getting its patents granted in a number of territories including countries from Europe, APAC region and Mexico. The filings are related to oils and high-protein food products prepared from microalga biomass. The company faced opposition from **Roquette Frères** in December 2015 in relation to its Australian patent (AU2009303354). However, the opposition was subsequently withdrawn in in June 2018 following **Corbion**’s acquisition of Terravia in September 2017.

[176] https://www.globenewswire.com/NEWS-RELEASE/2019/09/05/1911502/0/EN/AGJUNCTION-SECURES-THREE-MORE-PRECISION-AGRICULTURE-PATENTS.HTML

[177] https://www.prnewswire.com/news-releases/agjunction-secures-patent-for-integrated-multi-sensor-vehicle-control-300881172.html

Patenting within the food & drink industry can difficult, especially with regards to demonstrating the novelty of the invention, or a food recipe/composition. However, the method of production should still be patentable as long as it is innovative and non-obvious. One particular area of development in the wider food industry is the production of meat substitutes without using animal products. While large food manufacturers have been interested in chemicals and methods of making products that resemble animal meat for a long time now, most of the commercially available products are plant-based food products designed to mimic the 'real meat taste'. The technology behind the production of **Quorn** mycoprotein (developed by Marlow Foods) was one of the first commercially successful inventions in the space.

Although the concept of cultured meat has appeared in the realms of science fiction over the last 50 years, the beginnings of the activity in this patenting field can be dated back to the end of the 20th century. Some early patents around cultured meat for human consumption related to growing muscle cells in growth media. The most important early patents in the field were assigned to individuals including Jon Vein (publication numbers: US20050084958, EP1789063) as well as Wiete Westerhof, Willem van Eelen and Willem van Kooten (EP1037966). The latter patent application dates back to 1997, considerably earlier than the first-ever synthetic burger was demonstrated to the public in 2013.

A number of patents comprising a portfolio relating to the 'clean' meat production process was acquired by **Hampton Creek** in 2017 (the company was later rebranded as **JUST**). Apart from **JUST** emerging as a leader holding a number of relevant patents granted internationally, **Modern Meadow** was also granted its US patent in 2017 (US9752122 - *Edible and animal-product-free microcarriers for engineered meat*) and Australian patent in 2018 (AU2015214092 - *Dried food products formed from cultured muscle cells*). Also in 2017, Japan-based **IntegriCulture** was issued its Japanese patent for a growth induction system/device/control method (JP06111510B1), which is based around the use of cytokines to promote cellular growth.

Overall, considering the number of the cultured meat companies that have been established in recent years and notable market interest generated by this research space, it is somewhat surprising to see only a small number of publicly available patents that cover methods related to cultured meat production processes. Some might perceive this as a warning sign that the cell-based meat companies are still at a very early stage of technology development, and consequently, are still lacking the expertise to produce cultured meat at large scale in a cost-effective way in the near future. Conversely, it might simply indicate that cultured meat organisations are opting to keep their inventions as trade secrets, a strategy that is not uncommon in the wide food & drink industry. There is also an 18-month delay between filing of a patent and its publication, which means that there may be other relevant applications which are not yet publicly available. Nevertheless, with a third of all patent families identified by the focused search as being successfully granted in a number of different territories, the patenting field is projected to follow strong growth in coming years.

10 APPENDIX 1: MARKET ANALYSIS

10.1 ALTERNATIVE PROTEIN SOURCES

10.1.1 PLANTS

Plant-based sources of protein are the most common alternative protein source accounting for 84% of the alternative protein market in 2018.[70]

Soy protein accounted for approximately 80% of revenue share in 2016 globally and is predicted to remain the major product type.[178] However, pea protein is predicted to grow significantly over the forecasted period of 2018-2024 with a CAGR of 12% according to Graphical Research.[179] Other popular plant-based sources include rice, rapeseed and nuts with high-protein, next generation plant-based alternatives such as hempseed and flaxseed gaining popularity over recent years despite currently accounting for a small market share.

Plant-based alternatives can be placed on a spectrum from unprocessed to processed meat-like textured substitutes. Lentils and other pulses are often used unprocessed whereas soybeans and wheat are both often processed into tofu and seitan, respectively. On the far end of the processed plant spectrum are the 'bleeding' burgers using cutting edge biotechnology to transform plants into realistic meat substitutes which are discussed further in the Future Food Technologies section.

10.1.2 INSECTS

Production

Mass production

Most farmed insects can be easily raised in small ventilated plastic containers at high ambient temperatures (up to 30 °C) and relative humidity (up to 70%) and are fed organic wastes and cereals. They have low technical requirements, high production densities, and do not require sunlight during some life stages. This allows for easy automation of farming using robotics and vertical farming.

Data analysis and automation will be key to the mass production of insects with many insect farming companies developing ways to use robotics and machine learning to optimize their processes. **Aspire Food Group** uses precision farming in their insect farms by deploying sensor technology, the internet of things and complex modelling to scale up their farming of crickets and weevil larvae whilst producing zero waste. **Ÿnsect** plan to use their record-breaking Series C funding to build the largest automated insect farm in the wold.

Insect species suited to mass production should possess certain characteristics, including a high intrinsic rate of increase; a short development cycle; high survival at immature stageand high egg laying rate; a high potential weight gain per day; a high feed conversion rate; the ability to live in high densities; and low vulnerability to disease.

Good candidates are considered to be the black soldier fly for feed and the yellow mealworm for both food and feed. However, because of the vulnerability of production systems, heavy reliance on a single species is discouraged. The insect-rearing company **Kreca** lost 50 percent of their crickets in 2000,

[178] https://www.credenceresearch.com/press/global-alternative-proteins-market
[179] https://www.graphicalresearch.com/request/1059/sample

possibly caused by an adenovirus infection. Kreca now rears three cricket species: *A. domesticus*, *Gryllus bimaculatus* and *Gryllodus sigillatus*.

The table below lists the most commonly mass-farmed species of insects for both human and animal consumption.

Human consumption	Animal feed
House crickets (*Acheta domesticus*)	Black soldier fly larvae (*Hermetia illucens*)
Banded crickets (*Gryllodes sigillatus*)	Housefly larvae (*Musca domestica*)
Field crickets (*Gryllus bimaculatus*)	Silkworms (*Bombyx mori*)
Migratory locusts (*Locusta migratoria*)	Yellow mealworms (*Tenebrio molitor*)
Yellow mealworms (*Tenebrio molitor*)	Grasshoppers
Lesser mealworms (*Alphitobius diaperinus*)	Termites

Household/small-scale production

As the demand for insects grows, their production, shipping and storage will increase leading to greater energy consumption and use of land. However, insect farming can easily be carried out in small, portable containers which makes them amenable to urban farming and home growing.

Several companies such as **Tiny Farms** (California, US) and **Livin Farms** (Hong Kong) sell kits for home-use that use locally obtained feed such as organic waste sources or food leftovers. These kits allow anyone to set up their own small insect farms to feed their household or even their community without the need for extensive transport or storage of insects.

Insect feed

Insects can typically consume a wider variety of feed than most traditional livestock, thereby reducing volatility in feed prices and availability towards a more sustainable and reliable food source.

While some insect farmers formulate their own feeds, there are already several animal feed companies offering commercially available cricket and mealworm feeds which are specially formulated for those species. Companies selling specialised insect feed include **Purina**, **Coyote Creek Farm** and **Homestead Organics**. It is very interesting to see the feed companies already well prepared to meet the coming demand for the potentially massive, specialized human consumption insect farms, even before the industry has reached mainstream scale.

A particularly interesting area of research is using waste or by-products from existing processes as insect feed. Some of the most promising will likely be waste from the food and agriculture industry. Some popular examples among these include: yeast and spent grains from alcohol production or ethanol production operations, by-products from food manufacturing, preconsumer waste produce ("ugly fruit/vegetables" that are not aesthetically pleasing or suitable for processing), the unused parts of crop plants (e.g. leaves and stalks). Finally, the feedstock needs to be inexpensive, locally available, of consistent quality and supply, and above all free of pesticides and antibiotics.

By using waste streams and by-products from other processes, insect farming can become an important way to achieve a circular economy in which zero waste is generated. Companies like **Entocycle** and **EntoFood** are using black soldier fly larvae to convert organic waste into feed for livestock towards this aim.

However, insects intended for human consumption need to be fed feed-grade or food-grade food if the insects are not to be degutted. Additionally, the type of feedstock used for the insects may impact their flavour which is a very important consideration especially when so many consumers are already neophobic. Therefore, waste streams might not be a viable option for insects intended for human consumption; this area requires further research.

Safety and welfare

Disease management strategies and rearing system designs are critical for minimizing risks of disease. Automation will also prevent certain health and safety issues associated with human involvement such as the carrying of diseases that can contaminate insect populations, and reducing allergies amongst personnel.

Animal welfare is considered to be high for mass insect production compared to traditional livestock farming, as many insect species naturally live in large groups with small amounts of space. Further, the most commonly used method for harvesting insect species is by chilling them to freezing temperatures. This process causes the insects to enter a state of sleep as their body temperature lowers. After an extended period of being frozen the insects die without regaining consciousness resulting in a high-welfare, humane process.

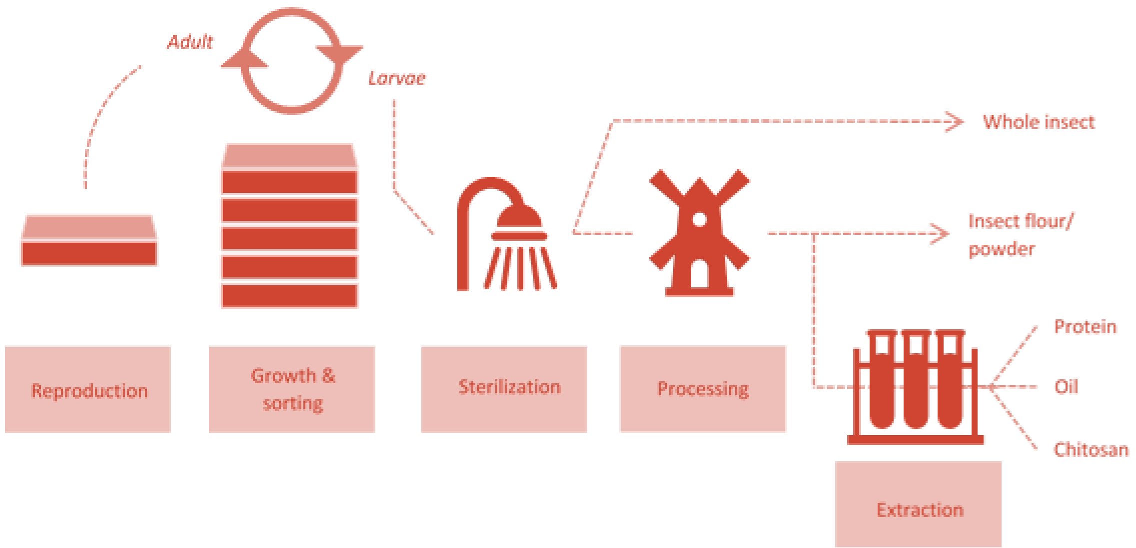
Processing

As mentioned previously, insects are generally killed by freeze-drying. They can then be processed in one of three ways: as whole insects; in powder or paste form; or as a high-value extract of protein, fat or chitin. Whole insects are consumed mostly in countries where entomophagy has been practised for a long time whilst the more processed products can be incorporated into other foods are often more acceptable to those new to insect eating.

Drying and grinding the insects creates a flour which is versatile and has been used in many consumer products such as **Eat Grub**'s energy bars, **Jimini's** pasta and **Eat Chirp's** crisps, which is a preferable form for consumers not accustomed to insect eating. Flours of different degrees of fineness can be created to suit the needs and textures of various consumer product

In some cases, isolating and extracting components of the insect is desirable. For example, extracting insect protein can be used to create a protein powder for supplementing foods or for high protein beverages. Extracted proteins can be separated based on solubility or by chromatographic processes. The cost of protein extraction is often high and so resulting products will have a higher value than whole insect flour.

Oil is often removed in the processing of insects to reduce the moistness of resulting products. The extracted fat can be used for other purposes such as frying.



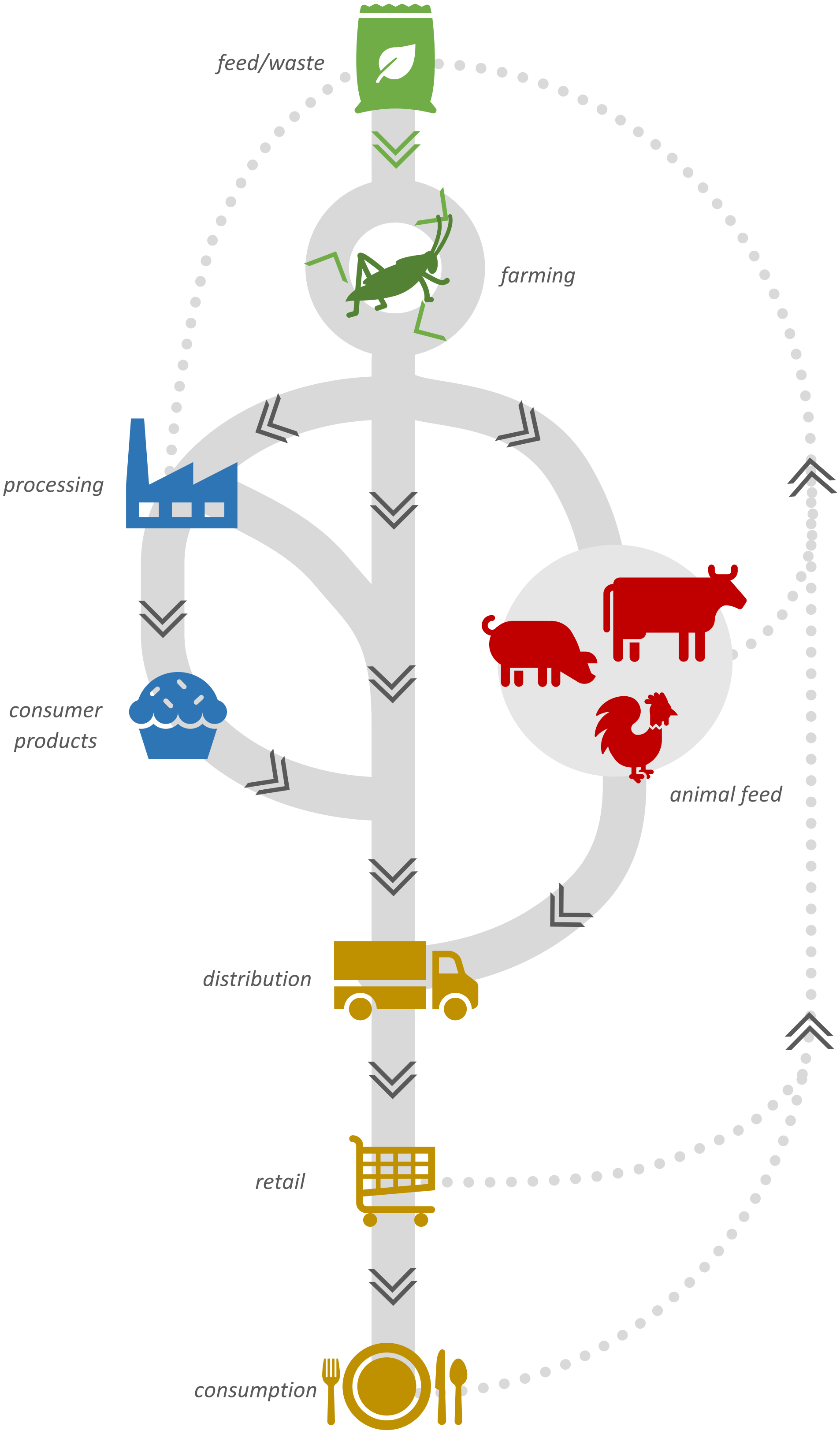
Summary of edible insect farming and processing

The final major component of insects is the chitin that makes up the exoskeleton. If the insect has been finely milled then chitin content should not affect the texture but will add a significant amount of fibre. However, the chitin in insects may be undesirable for some food products due to its indigestibility or by changing the texture of foods which cannot use finely group insect flour. Methods to reduce or remove chitin may therefore be desirable but will add further costs to processing.

Insects used for animal feed do not require the same degree of processing as for human consumption. For example, chickens would naturally eat whole insects so very little processing is required for poultry feed.

Circular economy

Waste products created by the processing of insects can be fed back into the value chain either by being incorporated into the insect's feed or by use as fertiliser for crops that will later provide organic waste for feed. Other streams of organic waste including those from agriculture, preconsumer and retail can be used as feed for the insects thereby closing the value chain and becoming a circular economy. It has been suggested that human and animal organic waste could also be used to feed insects but would likely be problematic for regulatory and safety reasons.



Edible insect value chain (solid lines) and demonstration of a possible circular economy (dashed lines) created by insect farming.

10.1.3 ALGAE

Production

The main cultivation systems for growing algae for food are open pond systems, fermenters and closed photobioreactors. Open ponds and race ponds have been well established since the 1950s because of lower investment requirements, operating costs and labour intensity. However, these open systems are at risk of contamination, low in efficiency and are heavily reliant on the climate.

Closed systems have therefore gained interest as they allow for greater control over cultivation systems, unlocking the potential of microalgae in temperate climates and allowing greater biomass productivity. Photobioreactors and fermenters allow for closed production with tighter regulation over conditions. Photobioreactors utilize a light source to cultivate photosynthetic algae and pump in CO_2, potentially from waste streams in industrial processes. Most photobioreactors are optimised to specific algae strains and try to balance exposure to light with high biomass densities. Generally closed systems are more expensive to buy and maintain than open systems.

Whilst microalgae are generally known for being photosynthetic (autotrophic), they can also be heterotrophic or even mixotrophic, that is, they have the ability to both perform photosynthesis and acquire external organic nutrients. Specialised fermenters can be used to balance the mixture of autotrophic and heterotrophic modes for maximum efficiency, growth rate and use of CO_2.

Cultivation mode	Carbon source	Advantages	Disadvantages
Autotrophic	CO_2	• Carbon capture • Low costs • High production of pigments	• Sensitive to weather conditions and temperature variations • Special bioreactors • Low growth rate
Heterotrophic	Organic	• Higher growth rate and cell density • Smaller surface to volume ratio • Use organic waste as input • Amenable to closed bioreactors	• Increased contamination susceptibility • High costs • Produces CO2 • Contamination issues
Mixotrophic	CO2 & organic	• Higher growth rate and cell density • Decreased production of CO2	• Higher costs • Sterilised to reduce contamination • Reduced energy conversion efficiency

Scaling up production through improved cultivation methods could help to bring the cost per kg of biomass down drastically. Companies such as **UniVerve, LGEM** and **EnerGaia** are developing new cultivation techniques with the goal of improving yields and reducing costs. **UniVerve** have developed their patent pending HAVP cultivation system using a suspended, modular and scalable triangular vessel which allows light to penetrate from all sides. **EnerGia** have created a system that allows for the production of *Spirulina* in all climes with a closed bioreactor system that can be installed on rooftops and uses industrial CO_2 emissions.

Other companies including **Xanthella**, **Varicon Aqua**, **Photo Systems Instruments**, and **bbi biotech** sell a variety of photobioreactors for cultivating algae and for simplifying downstream processing by allowing higher biomass densities.

After cultivation, biomass is harvested and concentrated before further downstream processing takes place. The main methods of harvesting include filtration, flocculation and centrifugation to reduce the volume of algal suspension. Harvesting costs are generally reported to make up 20-30% of total production costs.[180] A two-step harvesting process initially utilising the low-cost technique flocculation followed up by the more energy consuming and equipment-requiring centrifugation or filtration can drastically improve cost-effectiveness downstream.[181]

The simplest way to process microalgae for food is to spray dry, drum dry, and freeze dry and to sell as dried whole cell algae. Such whole cell products make up the majority of the market share by volume with low prices resulting from minimal processing. A benefit of using whole cell products is the increase in fibre caused by indigestible cell wall components. The intact cell wall can also help in the use of whole dried algae as an ingredient as it improves product stability and prevents interaction with other ingredients.

Generally, seaweed and microalgae have poor protein accessibility and digestibility and so downstream processing is required to improve their bioavailability.

Further downstream processing and stepwise extraction raises the content of the main valuable compounds, for example, fatty acids, proteins, and polysaccharides as well as the high-value compounds, such as carotenoids, phycobilins, PUFAs, and sterols. For this, the tough cell walls must be disrupted through mechanical or nonmechanical methods. Cell wall disruption can also improve the bioavailability of protein.

Protein can be further isolated through a variety of techniques including centrifugation, ultrafiltration, precipitation, chromatography, or solvent extraction and fractionation via lyophilization.

Whilst microalgae represent a promising potential feedstock for food and feed, the technology for the production of microalgae is still somewhat immature. Becoming cost competitive is one of the major factors for microalgae to become a realistic source of protein. Ongoing research hopes to improve cultivation systems and processing to allow for scalable production at low costs. The exploration and development of new algal strains may also play an important part in optimising algae growth and reducing costs. **Triton Algae Innovations** are using new, non-GMO strains of the microalgae *Chlamydomonas reinhardtii* that produce high levels of heme to improve the taste and appearance of plant-based meat products.

Selecting the right strain for mass production is very important and is based on characteristics such as high growth rate and high conversion yield; different modes of cultivation; low-cost growth medium. A strain that results in simpler, cheap downstream processing would also be advantageous.

Regulation

Arthrospira, Chlorella, Dunaliella, Haematococcus, Schizochytrium, Porphyridium cruentum, and *Crypthecodinium cohnii* all have GRAS status.

- **EU**

  Market introduction of food products using the whole microalgae organisms (such as *Spirulina*, or *Chlorella*) or products that include the microalgae (such as pasta) are subject to food safety regulations that apply to all food products under European Community Regulation on Food Safety (EC 178/2002) published in 2002. Food safety is an important issue in algae-

[180] Uduman et. al. (2010) *Dewatering of microalgal cultures: A major bottleneck to algae-based fuels*. J. Renew. Sustain. Energy, **2**, 15

[181] Gonzalez-Fernandez and Ballesteros (2013) *Microalgae autoflocculation: An alternative to high-energy consuming harvesting methods*. J. Appl. Phycol. **25**, 991–999

technology and needs particular consideration when algae are produced in open-air systems, since they can be easily contaminated by other microorganisms. Food safety must be proven over a prolonged period of consumption.

For products new to the market with a history of safe use, the Regulation on Novel Foods and Novel Food Ingredients (EC 258/97) is required before they are authorised to be marketed. This Novel Food regulation applies for those foods and food ingredients that were not on the European market before May 15, 1997. This risk assessment process is usually time consuming and expensive and therefore companies argue with the regulators that these requirements are too strict.

A novel food or ingredient can also be marketed through a simplified procedure called "notification". This is done when the applicant considers its food or ingredient to be 'substantially equivalent' to a similar product already on the EU market.

- **US**

  In the USA, the regulatory status of algae products and additives is under the responsibility of the Food and Drug Administration (FDA), which can assign GRAS status (Generally Recognized as Safe) to a product.

  The FDA regulates the two laws that are applicable on microalgae-based food and feed products once they are sold on the consumer market:

  - the Federal Food, Drug and Cosmetic Act (FD&C) introduced in 1938, which regulates all foods and food additives
  - the Dietary Supplement Health and Education Act (DSHEA) introduced in 1994, which amended the FD&C Act to cover dietary ingredients and supplements.

  Domestic and foreign companies that manufacture, package, label or hold dietary supplements, including those involved with testing, quality control, and dietary supplement distribution in the USA, must comply with the Dietary Supplement Current Good Manufacturing Practices (cGMPS) for quality control.

- **Genetic modification (GM)**

  The issue of the biosafety of GM algae has two aspects: potential adverse environmental consequences and potential harm to human or animal health in case of food/ feed or pharmaceutical applications. In the USA the FDA, and in Europe the EFSA, are responsible for this biosafety evaluation. GM foods are generally not marketed in Europe but are elsewhere in the world, including the USA.

Genetic and mechanical containment, plus conditional matching of GM algal traits to unnatural cultivation conditions, would further reduce this risk.

10.2 FUTURE FARMING TECHNOLOGIES

10.2.1 PRECISION AGRICULTURE

The key technologies in the precision farming technology market are:

- Guidance systems
- Remote sensing technology
- Variable rate technology

Guidance systems help farmers guide their equipment while traversing fields, in order to maintain the desired path. They can be manual (those that need an operator in addition to GPS data), automated (self-driven), or intelligent (those that provide different steering patterns depending on the shape of the field).

Remote sensing technology involves the gathering of information through an aerial-based, satellite-based, or agricultural equipment-based sensing design. This data is analysed to obtain real-time information on crop and soil condition. This helps farmers make decisions in advance and take precautionary measures. In addition, data collected and stored over multiple seasons allows farmers to discover patterns and trends.

Variable rate technology allows producers to vary the rate of crop inputs by combining a variable rate control system with application equipment to apply inputs at desired times and locations. This helps farmers apply products in areas where they are needed only, increasing efficiency, production and quality.

Because guidance systems are amongst the oldest adopted technologies in precision agriculture, many key players are traditional agriculture providers. The attractiveness and growth rate of the market has allowed the entry of new players; as well as significant number of mergers, acquisitions, partnerships and joint ventures. More information on deal-making this is found in the Deals section, above.

One of the key developments in this sector was the introduction of smartphone applications. The MachineryGuide app, developed by **Afflield Ltd**., is an Android-based GPS guidance system. This app allows the smartphones to be turned into an agricultural navigation system, helping the farmer to save money when it comes to cultivation.[182]

BCC Research estimates the global market for precision farming technologies to grow to almost $6 billion by 2021. The robust 12.4% CAGR is high in a market already worth billions of dollars, indicating that the market is far from saturated and remains in a growth phase. Thus, it is likely for the stakeholder landscape to remain dynamic and for new technologies to arise, particularly in emerging regions, where prices of precision farming technologies are decreasing, and knowledge bases and government educational programs are growing.

Although the demand for novel technologies and machines is on the rise, these will be largely limited to large farms in economically advanced, industrialised countries. Less industrialised countries with smaller farms will continue to see limited to no use of autonomous machines.

[182] https://www.f6s.com/afflield

10.2.2 URBAN FARMING

In our current world, urban farming offers some advantages in comparison to traditional rural farming. During times of abundance, it may be cheaper to purchase, compared with produce that is transported over great distance, and during times of scarcity or emergency it can fill a void. Furthermore, locally produced food can avoid the energy required, and pollution emitted, by transportation from faraway farms into cities.

Despite their smaller size, urban farms often produce higher yields than rural ones. This can be due to several reasons: a smaller insect pressure; lack of predators (e.g. deer or hedgehogs); ability to carefully monitor crops due to the small size; and the possibility of planting more densely as farmers hand-cultivate and take care of soil, water and fertiliser more carefully.

In the US, **FarmedHere** is the largest player in controlled environment urban agriculture. It is located in the industrial outskirts of Chicago and consists of a 90 000 square foot warehouse. Without interference from weather or pests, it fulfils year-round contracts with local supermarkets, including nearly 50 Whole Foods Markets. Unlike outdoor farms, it has no call for pesticides and contributes no nitrogen to waterways, while producing yields that are 10 to 20 times higher than the same crop grown outdoors.

In the US, community gardens are the most common form of urban agriculture. They produce more food, in aggregate, than their commercial counterparts. As social enterprises, community gardens do not sustain themselves with sales, nor they have to pay employees – they rely on volunteer or cheap youth labour. In addition, they pay little or nothing in rent and solicit outside aid from government programs and foundations.

In 2017, the global urban farming market revenue was estimated to be worth $210 billion, of which community gardening is the largest segment, worth an extraordinary $136.1 billion.[183] Home gardens generated revenue worth $29.61 billion which is expected to rise over the coming years.

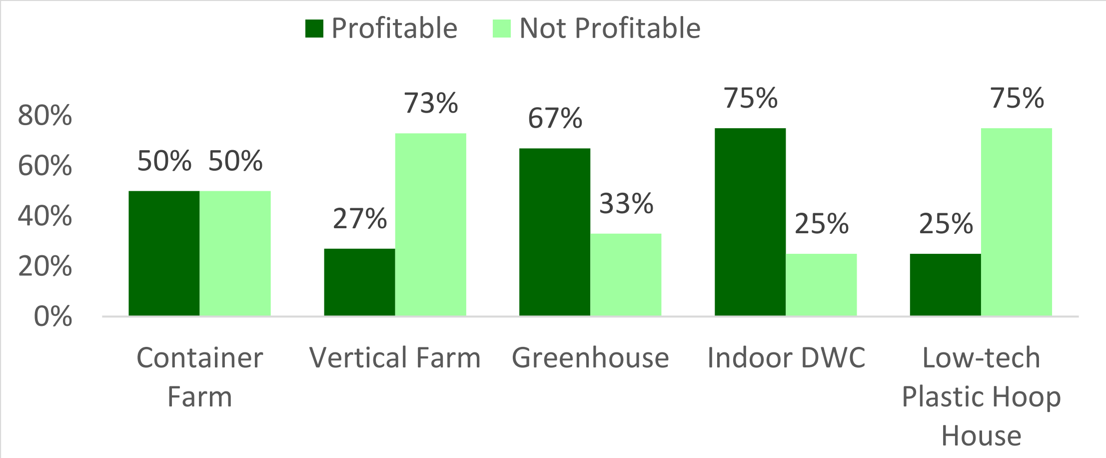
10.2.3 INDOOR AGRICULTURE

One of the big market constraints facing indoor farming is the high cost of operating facilities, which poses a great challenge for farmers. It takes about seven years for an indoor farm to be profitable, and operational costs are often underestimated. The challenges for reaching profitability in this industry is summarised by the profitability breakdown in the charts in Appendix 2. Out of all types of indoor agriculture, the most profitable are indoor deep-water culture systems.[109]

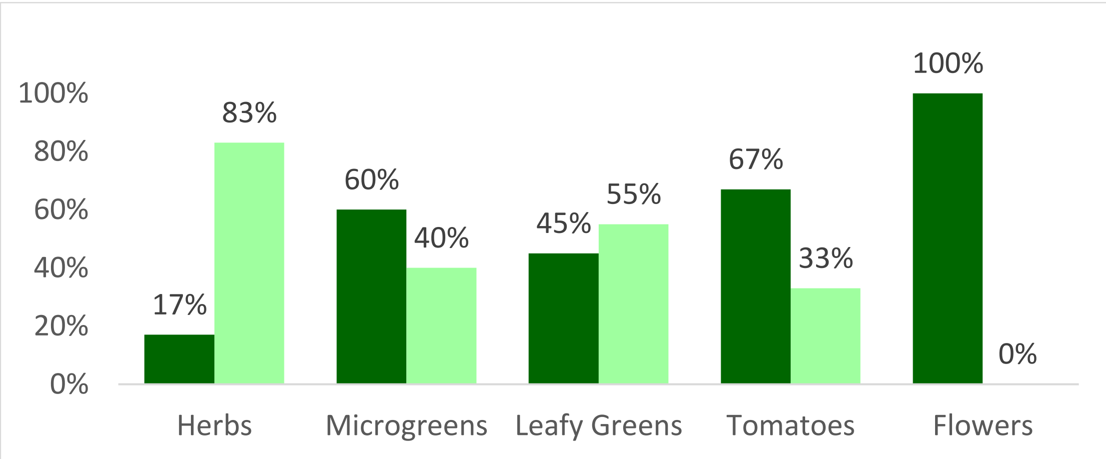
[183] https://www.industryarc.com/Report/15491/urban-farming-market.html

Farm Profitability by:

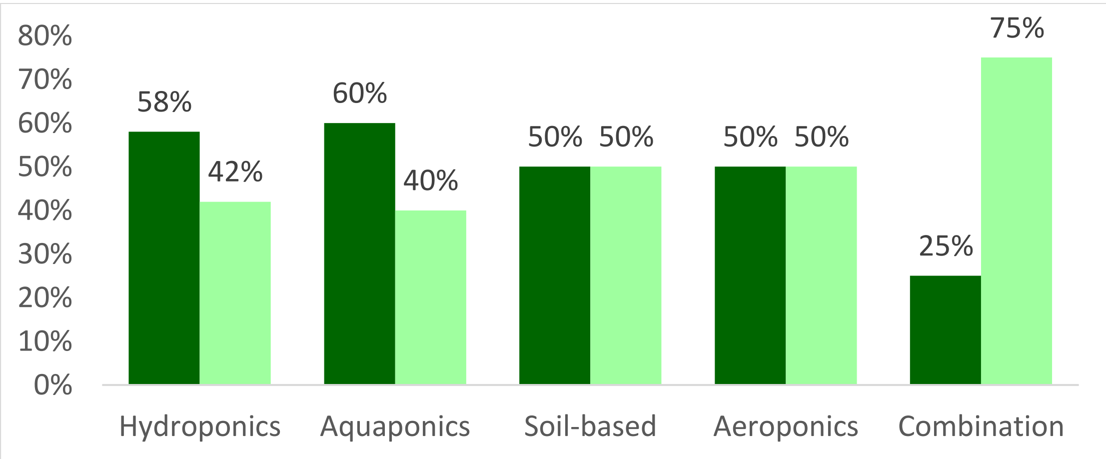
Farm Type



Crop Type



Farming System



Greenhouse agriculture

Greenhouse growing protects crops from adverse climatic conditions like drought, extreme heat, cold, wind, precipitation, and pests and diseases. In addition, by recreating the optimum growing conditions for certain crops, as well as being able to modify them during the life cycle of the crops as necessary; higher and more homogeneous yields can be achieved. A completely secluded greenhouse building ensures a micro-climate within the greenhouse, achieved with the use of equipment using lighting, heating, and cooling installations, all of which can be automated.

Among crop types, fruits and vegetables account for the largest market share. This is predicted to increase even further due to an increased population and rising demands for fresh fruits and vegetables. Other market drivers include higher yields compared to traditional agriculture and the possibility of growing crops in areas where traditional agriculture is not viable (particularly close to urban centres) e.g. with rooftop farming.

In the Netherlands, greenhouses now produce 35% of the country's vegetables despite occupying less than 1% of its farmland. The Netherland's **Wageningen University** has led much of the research on how to best grow crops indoors. As a reflection of where greenhouse agriculture sits in the future farming technologies landscape, according to Wageningen' Prof Leo Marcelis, the Dutch agricultural revolution needs to move beyond greenhouses, which still rely on some outside forces like sunlight.[184]

That being said, despite moves towards more advanced agricultural methods, conventional approaches like greenhouses are still growing strongly - the commercial greenhouse market is projected to grow at a CAGR of 8.8% until 2020, when it is expected to reach a value of almost $30 billion.[185]

Vertical farming

In vertical farming, plants are stacked in shelves vertically or in inclined surfaces above each other.[186] Because it requires less space, this approach can be utilised in places where space is limited, including urban and suburban environments; as well as where productivity rates are low and food availability is scarce. They can also be built inside old warehouses, thus making it an effective urban regeneration strategy.

Vertical agriculture has been deemed as one of the answers to providing high-quality produce sustainably – it uses up to 95% less water, fertilizer and nutritional supplements, and zero pesticides.

In 2017, the vertical farming market size was estimated to be worth over $2 billion, and is expected to grow at a remarkable CAGR of more than 25% through 2024.[187] The main market drivers are a scarcity of arable land along with an increasing demand for higher agricultural yields. In the next few years, increasing soil erosion is predicted to boost the vertical farming market.

The most commonly grown crops in vertical agriculture farms include fruits, vegetables and herbs; particularly strawberries, tomatoes, lettuce and leafy greens.

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[184] https://www.pbs.org/newshour/show/could-indoor-farming-help-address-food-shortages
[185] https://www.globenewswire.com/news-release/2016/03/01/815679/0/en/Commercial-Greenhouse-Market-Report-2016-Equipment-Type-Crop-Type-by-Region-Global-Trends-Forecasts-to-2020-for-the-29-Billion-Market.html
[186] Frost & Sullivan (2016) Emerging Technologies Stimulating the Future of Agriculture
[187] https://www.gminsights.com/industry-analysis/vertical-farming-market

Container farms

Container farms are standardised, portable, self-contained growing units that employ vertical farming and artificial lighting. In contrast to custom-designed warehouses, container farms strive for standardisation.

The concept of container farms is relatively new, with only three commercial container farm companies currently operating. This is still a small, niche market, but a handful of other companies are in the process of commercialising, so this sector is likely to grow within the next few years. An example of a container farm in the process of commercialising is **Local Roots Farm** (USA). Other companies in the sector include **Daiwa's agri-cube** (Japan), **Crop Box**, **Freight Farms** (USA), **Growtainers** (USA), and **PureGenius** (formerly **AquaHarvest;** USA).

Indoor-based container gardening can utilise discarded or new cargo containers, which can be easily automated to provide the optimal conditions for crop growth. A big benefit of container farming is that they are – as the name implies – easy to ship. Manufacturers can set up shop where it is cheap and then ship the containers directly to the farm site fully loaded and ready to grow.[188]

However, this benefit largely stays with the farmer – it is unlikely that a farmer will want to change the location of their farm often. The main farmer benefits include a reduction of weed growth and elimination of spread of soil-borne diseases to other plants, as the particular container can be treated easily without the spread of the disease to nearby containers. Furthermore, they are very inexpensive and readily available, making the setting of a farm cheap and fast.

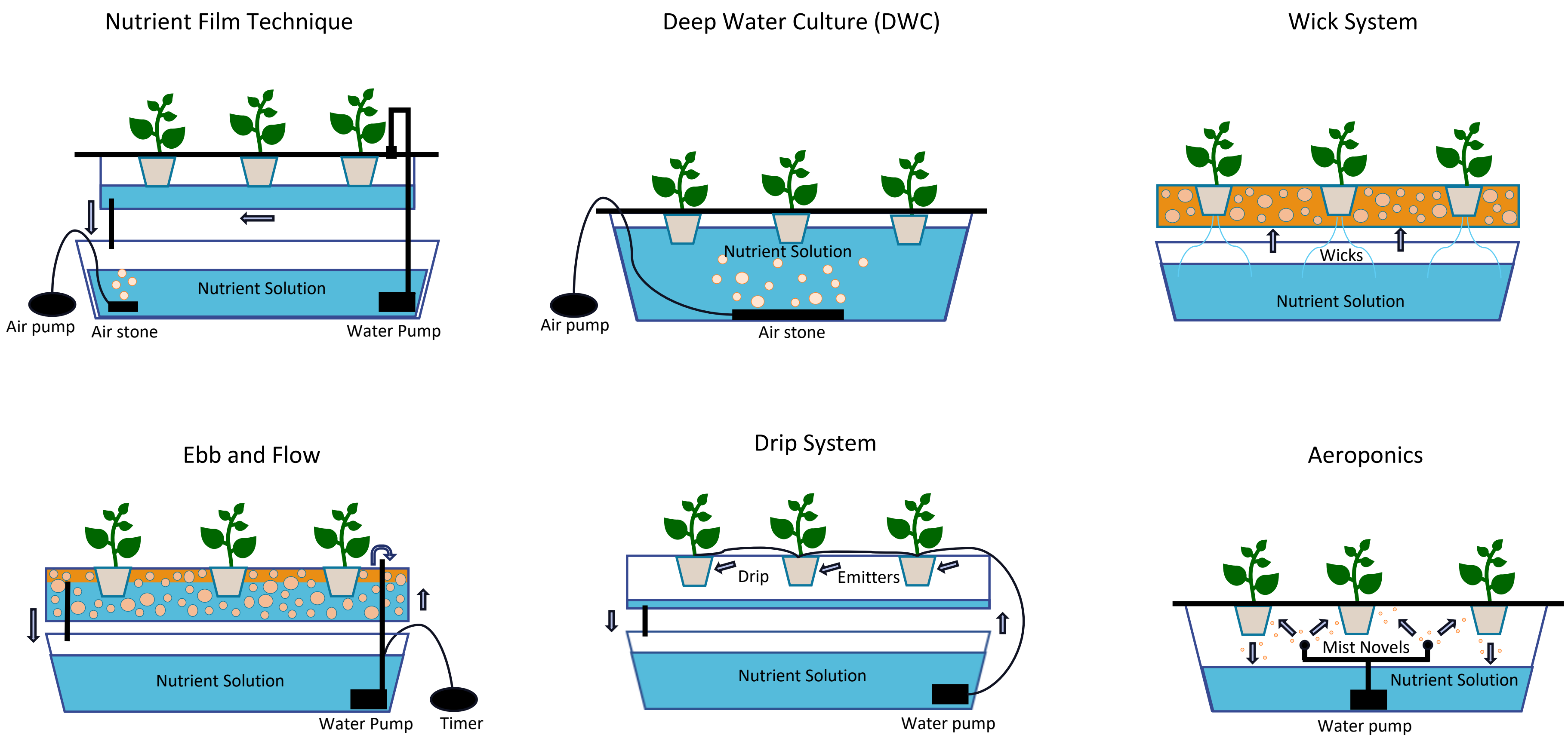
A big market driver for container farming will be smaller-scale production. Being able to 'park' a farm anywhere food is needed can offer huge opportunities for independent grocery shops and restaurants – it could be dropped off behind a restaurant or in a school parking lot.

Hydroponics

Hydroponics is a soil-less method of crop growing, with an inert, water-based growing medium being used instead.[189] In this system, plant trays are placed above a water tank with an air reservoir separating the plants from the water. A submersible pump moves nutrients from the reservoir to the grow tray.

There are several types of hydroponic system, the basics of which are displayed in the diagram below:

[188] https://medium.com/bright-agrotech/the-good-the-bad-and-the-ugly-of-container-farms-d32f4f13f31b
[189] https://www.greenandvibrant.com/hydroponic-systems



Overview of hydroponic farming systems

The global hydroponics market was valued at $26 billion in 2019 and is expected to register a CAGR of 6.8% from 2019 to 2024.[190] In 2018, Europe had the largest market share, accounting for 47.3% of the market although the fastest-growing segment is Africa.

The main market drivers are the perception of hydroponics as an environmentally-friendly and profitable technology, and promotion by government programs and non-governmental organisations due to its food security benefits. The key players are **HortiMax**, **Green Spirit Farms**, **Sky** and **Argus**. However, high-costs, particularly in R&D, are holding back the market. To mitigate this, a lot of R&D activity is being carried out globally to reduce the cost involved in technology.

In the future, poor land management and availability of sufficient water is likely to increase popularity of hydroponics. This will trigger further technological advances including:

- High intensity lighting systems
- Microgreens cultivation
- Solar powered-based hydroponics
- Pollen-based biofertilisers

Sundrop, an Australian-based company, has become a key player in the sector through the development of a hydroponic seawater technology that combines solar, desalination, and agriculture to grow vegetables in any region. This sustainable system does not rely on fossil fuels and does not require land.

Aeroponics

Aeroponic cultivation involves the growth of crops in a misty environment, without the use of any aggregated medium.[191] It is a technological leap forward from hydroponics – it uses both water and air to produce high-quality crops.

Plants are suspended by small baskets or closed foam plugs that compress around the plant stems, leaving the roots to hang in mid-air. Mister heads spray the roots with nutrient solution periodically, keeping them moist and providing the necessary nutrients for plant growth. The system containing the mister heads and roots is enclosed in a sterile chamber to avoid infection or growth of bacteria.[192]

The aeroponics market, although still quite small and fragmented, is growing rapidly. In North America, it is predicted to rise at a huge CAGR of 25.5% between 2018 and 2025, reaching a total of $759.4 million by 2025.[193]

AeroFarms is arguably the biggest player in the aeroponics market to date. Named one of the World's Most Innovative Companies by Fast Company magazine, they have produced a patented, award-winning aeroponic technology that can be applied to vertical farming to increase precision and productivity and with low environmental impact and virtually zero risk.

[190] https://www.mordorintelligence.com/industry-reports/hydroponics-market
[191] http://www.homehydrosystems.com/hydroponic-systems/aeroponics_systems.html
[192] https://newatlas.com/aerofarms-urban-agriculture/15371/
[193] https://www.alliedmarketresearch.com/north-america-aeroponics-farming-marke

Their retail brand Dream Greens provides locally grown, pesticide-free produce all year round.[194]

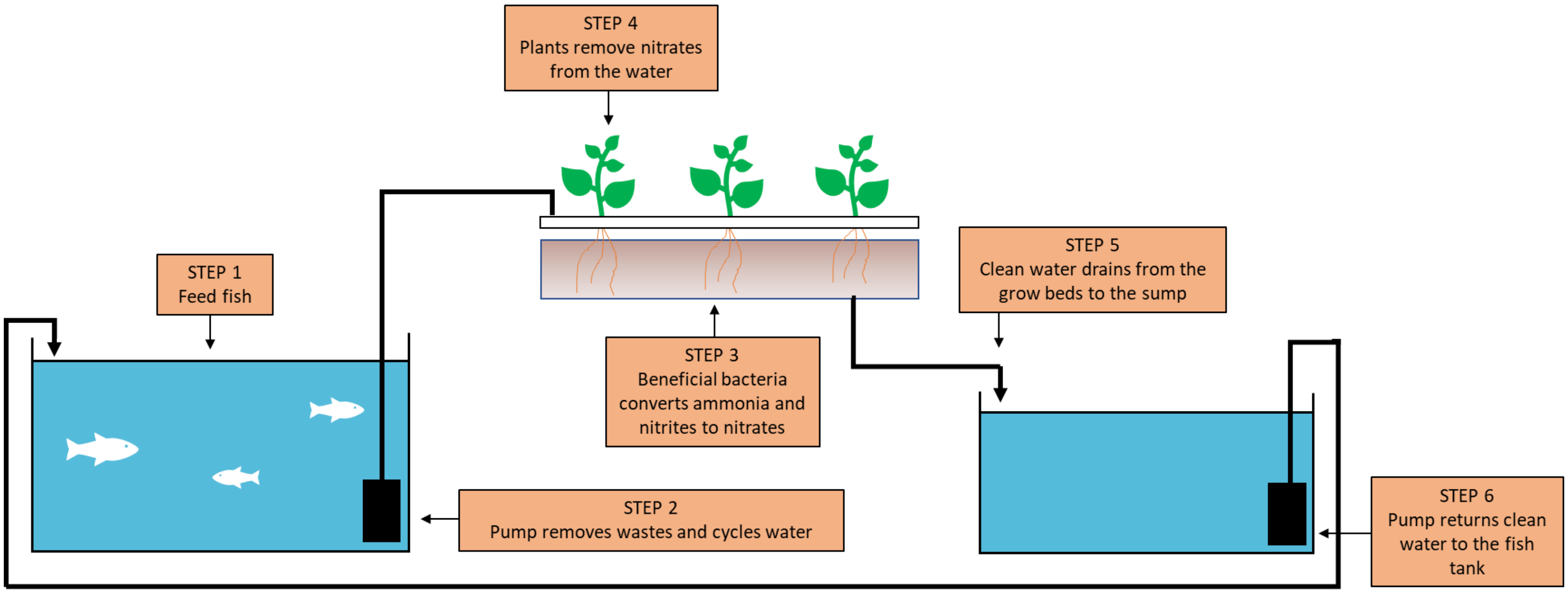
Other key players include **CombaGroup** (Switzerland) and **Neofarms** (Germany). CombaGroup sells fresh salads and herbs that come from mobile, hi-tech aeroponic systems. Since its establishment in 2011, it has won prices such as the Adenova Price for Innovation (Prix Adenova) and become one of the largest global players in the sector. NeoFarms supplies small, in-home aeroponic systems that can be custom-made to fit buyers' needs.

Future technologies in aeroponics will use fewer natural resources while producing higher yields due to increased efficiency. Digitalisation and automation will also increase productivity of aeroponic systems.

Aquaponics

Aquaponic systems are another soil-less farming method. It involves the simultaneous cultivation of fish and plants in a re-circulating closed system (a water tank) – it is a combination of hydroponics and aquaculture.

[194] https://aerofarms.com/



Aquaponic farming system cartoon (adapted from Jena *et. al*)[195]

[195] Jena *et. al.* (2017) *Advanced farming systems in aquaculture: strategies to enhance the production*. Innovative Farming, 2455-6521. 2. 84-89.

An aquaponic system relies on the creation of a natural ecosystem in the water tank, which represents a closed loop system with minimum impact on the environment. It requires no fertiliser, no herbicide, and minimum water use; as water is only added to replace loss from plant absorption, evaporation or removal of biomass from the system.

The size and type of food grown in an aquaponic system vary as compared to hydroponic and aeroponic. It is most suitable for the cultivation of fruits and vegetables, and aquatic animals can be raised at the same time.

Benefits of aquaponics include: lack of requirement of external supplements; the possibility of generating two sources of income (fish and vegetables); the possibility of installing them in old warehouses or retrofitted existing systems; an increased crop density; and cost reduction in comparison to aeroponics as no sterile environment needs to be set up.

Commercially, aquaponics is at a very early stage at the moment. Although the number of aquaponic operators is quite limited, there is a strong and growing interest in this method of intensive food production.

There have been initiatives such as the EU Aquaponics Hub; a four-year COST Action which brought together a multidisciplinary group of 28 Member Countries and Cooperating States in order to promote innovation and capacity building by a network of researchers and commercial aquaponics companies.[196]

Key companies in this field include **GrowUp Urban Farms** (UK), **Nelson & Pade Aquaponics** (USA), **Future Foods Farms** (USA), and **Midas Aquaponics** (Thailand).

Future technologies developed based on aquaponics in urban agriculture will be crucial for solving challenges including water shortages, as well as improvements in crop quality. To maximise adoption of the system, future technologies must focus on reducing capital expenditure associated with installing aquaponic systems. Integrated systems can help achieve this.

10.2.4 SUPPORTING AND EMERGING TECHNOLOGIES

Crop sensors and livestock biometrics

Crop sensors are one of the most established novel technologies in the agricultural landscape. They have applications in yield prediction, irrigation, soil mapping, nitrogen mapping and drop disease, between many others. In addition, they can be combined with GPS data in order to generate soil field maps. Sensors enable responsive agriculture as they can allow farmers to adapt the products and product quantity (e.g. fertiliser or water) they add to smaller patches of land. It does also reduce wastage by ensuring that products are only added where and when needed.

Livestock biometrics involves identifying and tracking animals, much like the traditional form of marking them with tattoos or toe clipping. However, it works by recognising animals based on physical characteristics or behavioural signs instead of physical marking.[197] Most biometric devices track aspects such as nose-prints, iris or retinal patterns, facial recognition, bite marks,

[196] https://euaquaponicshub.com/
[197] https://norecopa.no/media/6304/biometric-methods.doc

saliva sampling and movement patterns. This increases accuracy and reduces human error when tracking farm animals, as well as automating the process for the farmer.

The global market for agriculture sensors was estimated at $1.1 billion in 2018 and is expected to be worth $2.75 billion by 2024.[198]

Drone technology and satellite data

Drone technology and satellite data have been around for quite a long time now, however, their inclusion in agriculture programs and farms is still very novel. This technology is predicted to be particularly useful in big farms where it is more difficult for farmers to visualise their fields. It reduces human labour (and the cost associated with it) and increases efficiency and productivity through less disruption of crops, as opposed to having workers walk through the field. They tend to be coupled with sensors and algorithms to provide data on aspects such as soil moisture and pest concentration.

There are six main uses of drones in agriculture:

- Field and soil analysis: Precise 3D maps for pre-seeding
- Planting: drone-planting systems that shoot pods with seeds and nutrients into the soil, reducing planting costs by up to 85%.
- Crop spraying: drones can scan the ground and spray for even coverage, with speeds up to five times faster than with traditional machinery.
- Crop monitoring: time-series animations to show crop development and highlight problems or inefficacies.
- Irrigation: drones with the ability to identify arid patches of land.
- Health assessment: crop scan with drones with visible and/or near-infra-red light.

The agricultural drone market size was estimated at over $300 million in 2016, and is expected to grow at over a 13% CAGR through 2024.[199]

Nanotechnology and enhanced efficiency fertilisers

Nanotechnology has the potential to lead the precision agriculture revolution by allowing substances to be delivered to plants via nanoparticles. These nanoparticles can serve as 'magic bullets' containing herbicides and chemicals which target the particular plant parts to release their content.[200] The use of target-specific nanoparticles can reduce the damage to non-target plant tissues and the amount of chemicals released to the environment.[201]

The key companies operating in the agriculture nanotechnology landscape include **Nanosys Inc** (US), **ASML Holding** (Netherlands)**, Zyvex Labs** (USA), **Oxford Instruments Plc** (UK), **Nanoco Group Plc** (UK), **and ThalesNano Inc** (Hungary).

Although nanotechnology offers great potential in precision agriculture, it is expected that widespread commercial use will be delayed due to high costs associated with R&D – so far the

[198] https://www.credenceresearch.com/report/agriculture-sensors-market
[199] https://www.gminsights.com/industry-analysis/agricultural-drones-market
[200] https://www.isaaa.org/resources/publications/pocketk/39/default.asp
[201] https://www.nanowerk.com/spotlight/spotid=37064.php

costs of development are being compensated by higher returns in the medical or pharmaceutical fields, but practically no returns are being generated in the agricultural sector. Furthermore, the EU's definition of nanomaterials poses challenges for companies as it offers the possibility that non-active substances already used for many decades (such as silica or pigments) will fall within the nano definition. The need for labelling of products that are already on the market for decades can result in a stigmatisation of the technology, preventing further and innovative applications in agriculture.

The internet of things

Internet of Things (IoT) is a network of physical objects embedded with electronics, sensors, connectivity, and software. It enables remote sensing controlling, with the aim of collecting but also analysing data. This enables farmers to make smarter decisions by providing an array of detailed information in space (across the field) and time (both in the short term such as over days, weeks or months; or in the long term, such as over one or several growing seasons).

It has applications in practically every aspect of agriculture, including management of plant profile, climate, light, nutrients and irrigation protocols. Components of IoT systems include sensors, control units, dossier units, dashboards, and communication devices.

Diverse applications such as precision farming, livestock monitoring, smart greenhouse, and fish farming monitoring are expected to benefit from increasing the speed of the agriculture processes.[202] By connecting farms through a platform, it can make them more intelligent by sharing, storing, and analysing the information.

IoT mitigates the conventional challenges of farming, saves time and reduces environmental impacts, by providing thorough data analyses to the farmer. IoT reduces the ambiguity in planting and harvesting by offering visibility and actionable insights through predictive analysis.

Although it can be useful for most farmers in most environments, IoT systems can be particularly useful for urban farmers with busy lifestyles, as it simplifies the process of integrating farming in their everyday lives through real-time notifications that can be received on smartphones and laptop. Another group thought to benefit from this are farmers in large farms, as it is very labour intensive to observe and manage individual patches of land.

In agriculture, IoT is at an earlier stage than in other industry sectors (such as transport), but agricultural applications are still estimated to be worth $14.8 billion in 2018.[203] The main drivers will be lowered technology costs as a result of ongoing R&D in IoT, and efforts by various governments of the countries across the globe to increase the quality and quantity of agriculture production.

Automation of skills and workforce

Automation and controlled systems are increasingly being adopted in the agricultural sector, and are allowing increased efficiency in agriculture, as well as the incorporation of new farming methods and techniques. By 2050, the UN predicts that two-thirds of the world's population will live in urban areas, reducing the rural workforce. Technology can ease workload on farmers by allowing operations to be done remotely and processes to be automated.

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[202] https://www.alliedmarketresearch.com/internet-of-things-iot-in-agriculture-market
[203] https://bisresearch.com/industry-report/iot-in-agriculture-market.html

Automation can be achieved with the use of agricultural robots and chatbots. Agricultural robots (agribots) are digitalised electronic machines, and can be designed to fulfil a wide range of tasks by incorporating different features on them. So far, most agribots are designed for fruit-picking, spraying, and operating tractors.

Agribots have the potential to increase and homogenise production. Robots function at constant speeds, more efficiently, and can perform hazardous processes which pose risks to humans.

Chatbots, in contrast, do not actually complete any tasks, but are instead AI-powered virtual assistants. They are already in use in the media, retail, travel and insurance sectors. Some of the best-known chatbots include Apple's Siri, Amazon's Alexa and Microsoft's Cortana.[204] In agriculture, chatbots could provide answers to farmers' questions and provide product recommendations.

Eco-friendly and sustainable methods of obtaining resources

It is predicted that novel agricultural technologies emerging in the future will be increasingly environmentally sustainable. Two emerging technologies aiming to reduce the environmental impact of agriculture are atmospheric water generation (AWG and agricultural waste upcycling).

AWG is a method of water conservation. It works by using an atmospheric water generation device, which converts atmospheric moisture into usable water.

This can provide one solution to meet water needs of agriculture in places with water scarcity, or simply to reduce water use. Tremendous economic benefits can be obtained by conserving water, as allocation of funds for water use can be reduced drastically. In addition, this technology will help maintain the aquatic ecosystem, minimise water pollution and maintain the water table, and reduces the need for expensive water treatment systems and desalination plants.

This technology is predicted to see mainstream adoption in commercial agriculture by 2023. The global market for atmospheric water generation will reach approximately USD 7.8 billion by 2025, growing at a CAGR of 30% from 2016.

The top three rated AWG system providers are **Atmospheric Water Systems, Inc.**, **EcoloBlue, Inc,** and **Island Sky Corporation**.[205] In an interview carried out by Seedstock, Richard Groden of Island Sky Corp says that he expects AWG to be particularly suited to truck farming, greenhouse farming and hydroponics. However, the cost of the technology is likely to be the main market challenge in widespread commercial adoption.

Agricultural waste upcycling is a form of waste management that relies on converting agricultural wastes into organic matter to increase soil fertility and decrease reliance on fertilisers. It seeks to provide economic benefits from agricultural waste to protect the environment and maintain sustainability.

[204] https://www.forbes.com/sites/forbestechcouncil/2018/08/29/chatbots-a-powerful-weapon-in-the-business-arsenal/#1820f9744960

[205] http://seedstock.com/2013/03/25/could-atmospheric-water-generation-power-the-farms-of-the-future/

Blockchain

Blockchain is the distributed ledger technology behind bitcoin and other cryptocurrencies. In agricultural transactions, blockchain could reduce inefficiencies and fraud and improve food safety, farmer pay, and transaction times.[206]

In addition, by increasing traceability in supply chains, it would enable regulators to rapidly identify the source of contaminated foods and determine the scope of affected products, giving consumers increased trust in the products that they buy.[207] By detecting bottlenecks in food spoilage, blockchain technology can also reduce waste.

Furthermore, it can prevent price extortion and delayed payments, as well as reducing transaction fees through the elimination of middle men, enabling farmers to capture a larger part of their crop value.

Food companies are already starting to adopt blockchain technology – **Barilla**, an Italian pasta and pesto manufacturer, has opted for blockchain to tackle transparency in its production cycle. Making a deal with **IBM Italia**, blockchain based on IBM cloud infrastructure has been inserted into all data related to cultivation, irrigation and plant protection regarding plantations of basil.[208] If the project is successful, the company will insert all of its products in its blockchain.

The food giant **Nestlé** has also opted for blockchain technology, with its chocolate factory in Perugina, Italy, also launching a blockchain technology for its exports.

[206] https://futureofag.com/5-potential-use-cases-for-blockchain-in-agriculture-c88d4d2207e8
[207] http://www.fao.org/3/ca2906en/CA2906EN.pdf
[208] https://bitnewstoday.com/market/blockchain/icons-of-italian-business-opt-for-blockchain/

11 APPENDIX 2: PATENT ANALYSIS

11.1 SEARCH STRATEGY

The following keywords were searched for within the Title/Abstract/Claims (/TI/AB/CLMS) fields of patents in the database:

Section	Search string	No of patent families
Broad search: Alternative Protein Sources	((ALTERNATIVE OR VEGAN+ OR VEGETARIAN+ OR VEGETABLE OR BACTERIA OR BACTERIUM OR INSECT OR CRICKET OR PLANT OR INVERTEBRATE OR ALGA+ OR MICROALGA+ OR CYANOBACTERIA OR SPIRULINA OR CHLORELLA) AND (((PRODUC+ OR SYNTHESIS OR MANUFACTUR+ OR PREPARE) 5D PROTEIN) 5D ((ANIMAL D FEED) OR FOOD OR INGREDIENT OR DIET OR ALIMENT OR FOODSTUFF OR (HUMAN D CONSUMPTION) OR NUTRITION+)))/TI/AB/CLMS AND (APD >= 2009-09-17) AND (APD <= 2019-09-17) AND (A01? OR A21? OR A22? OR A23? OR C12N?)/IPC	864
Broad search: Future Farming Technologies	((AGRICULTURE OR FARMING OR (PLANT D GROW*)) 3D (VERTICAL OR PRECISION OR URBAN OR INDOOR OR ROOFTOP OR SOIL_LESS OR AEROPONIC OR HYDROPONIC OR AQUAPONIC OR (DEEP D WATER D CULTURE)))/TI/AB/CLMS AND (APD >= 2009-09-17) AND (APD <= 2019-09-17) AND (A01?)/IPC	1188
Focused search: Cultured meat and dairy	((((MEAT 5D (CULTURE+ OR CULTIVAT+ OR GROW+)) AND ((IN D VITRO) OR (EX D VIVO) OR (MUSCLE D (TISSUE OR CELL+)))) OR ((CULTURED OR (IN D VITRO) OR (EX D VIVO) OR SYNTHETIC) D MEAT) OR ((FOOD OR MEAT) 5D (CULTURED D MUSCLE))OR ((TISSUE D ENGINEER+) D MEAT))/TI/AB/CLMS OR ((MOSA D MEAT) OR (MARK D POST) OR (ALEPH D FARMS) OR (MEMPHIS D MEATS) OR (NEW D AGE D MEATS) OR (MISSION D BARNS) OR (HAMPTON D CREEK) OR SUPERMEAT OR HIGHERSTEAKS OR (FUTURE D MEAT D TECHNOLOGIES) OR (NEW D HARVEST) OR (MEAT D THE D FUTURE) OR (FINLESS D FOODS) OR (WILD D TYPE) OR BLUENALU OR (CLARA D FOODS) OR (PERFECT D DAY) OR MUUFRI OR INTEGRICULTURE)/PA) AND (APD >= 1994-09-17) AND (APD <= 2019-09-17)	107

The number of patent families returned by each search string is provided in the table above. The patent searches were restricted to patent applications published over the last 10 years in the fields of Alternative Protein Sources and Future Farming technologies and past 25 years for the Cultured Meat research field. Additionally, in order to identify the most relevant patent set for new food sources and technologies, the first two search queries were limited by International Patent Classification (IPC) subclasses.

While for the Future Farming Technologies space, we only searched in the IPC subclass A01 (agriculture; forestry; animal husbandry; hunting; trapping; fishing), to ensure that the search for patents related to the Alternative Protein Sources also identifies filings related to not only agriculture technology but also to food production and processing more broadly, the search criteria were expanded to cover additional IPC subclasses: A21* (baking; equipment for making or processing doughs; doughs for baking); A22* (butchering; meat treatment; processing poultry or fish); A23* (foods or foodstuffs; their treatment, not covered by other classes) and C12N* (chemistry; metallurgy / biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation or genetic engineering / microorganisms or enzymes; compositions thereof; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media).

To narrow down the search, we used operators *5D, 3D* and *D*, which search for keywords inside the same sentence that are separated by a maximum of 5, 3 and 0 words, respectively. By using this condition, the queries were constructed to return compound word i.e. '*ex vivo*'. Equally, the keywords such as '*vertical*' would be searched for only in the context of farming methods and agricultural technology and not any vertical structures. Through performing a series of iterative searches, we optimised the queries listed above by removing terms returning spurious results. The plus sign stands for an unlimited truncation, which means that the search would also cover a series of related words such as '*product*', '*production*' or '*produce*'.

The results from patent searches were organised into invention-based 'FamPat' families developed by Questel (Orbit Intelligence), which combine the family rules of the European Patent Office (EPO) with complementary rules that consider links with the EP and/or the Patent Cooperation Treaty (PCT) as well as the links between US provisional application and US published applications.[209] The Fampat Collection[210] comprises comprehensive family coverage of worldwide patent publications published by more than 100 patent authorities (including first page information, search reports and extracted key content). The search pulls data from all available patent authority collections within the database, including the full text of the description and claims for publications from 22 patent offices (WO, US, EP, AT, BE, BR, CA, CH, CN, DE, ES, FR, GB, JP, RU, DK, FI, SE, IN, TW, TH and KR). The following sections include patent analysis divided by the three main focus areas of this white paper.

11.2 FOCUSED SEARCH: CULTURED MEAT

With an aim to construct a patent search query that would be focussed in the field while still being able to capture the key inventions, we:

- Searched for patents assigned to key companies mentioned previously in the cultured meat sector. This confirmed that while some of these companies hold patents covering inventions relevant to production of cultured meat, these documents often do not mention any key words related specifically to *ex vivo* meat production processes. We also included cultured dairy and eggs companies as these are likely to use similar methodologies e.g. stem cell cultivation that could also be applicable in cultured meat sector. However, we:
    - excluded companies JUST and Supreme as the outputs included a high number of unrelated patent assignees with these words used as part of their names.
    - excluded companies focused on plant-based 'animal products', some of which might be using 3D printing such as Impossible Foods, Beyond Meat, New Wave Foods, NovaMeat, Jet Eat, The Better Meat or Soylent.

[209]https://static.orbit.com/orbit/help/1.9.8/en/index.html#!Documents/groupingfamilies.htm
[210]https://static.orbit.com/orbit/help/1.9.8/en/index.html#!Documents/thefampatcollection.htm

- Removed a number of terms which returned spurious results, such as:
    - ‘clean’ meat, which returned results related to easy-to-clean meat processing equipment and machines for processing of clean[ed] meat, such as grinders or roasting machines.
    - ‘slaughter_free’, ‘vat_grown’, ‘lab_grown’, ‘laboratory_grown’ and ‘cell_based’ as these terms did not return relevant results in the context of meat production.
    - ‘laboratory’/’lab’ since the terms returned unrelated hits when searched in a context of meat culture/cultivation.
    - ‘Cell(ular) agriculture’ and ‘cell’ term used in relation to culture or cultivation, which returned a high number of hits related to e.g. cell culture media, growth factors and methods of growing cells (even when restricted by the past 10 years and IPC subclasses).

We also conducted a search for seafood analogue products - (((analog or analogue) D (Meat or seafood)))/TI/AB/CLMS. By manually reviewing the patents generated by the search, we determined that the majority of these records were related to the manufacturing processes for food products using proteins obtained from vegetables or yeasts, For some of these products, the composition is specified and contains fat, water, colourants and a binding agent (e.g.: egg protein, whey, cellulose derivatives, potato- or pea-derived starches, natural gums etc.). Again, these inventions were outside of the scope of the focused search. In addition, the output of another search for ‘cultured seafood’ included patents unrelated to synthetic, or lab-grown products, such as inventions around cultivating live fish, oysters, shrimps etc. and not. This could be explained by the fact that aquaculture, also known as aquafarming or pisciculture, is used as a standard term for fish farming, rather than a process of synthetically growing fish muscle cells and tissues.

The patent search was restricted to the last 25 years. This is a longer period than used in the two previous broad searches as we aimed to include patents that cover any technologies that enabled development of cultured meat products. At the same time, this allowed us to exclude older patents, such as records containing references to ‘synthetic meat’ which covered e.g. processing method of animal meat to manufacture products resembling natural steak meat from by extruding minced meat, and not to growing muscle cells and tissues in a laboratory.

In the discussion of the Focused Search above, only publication numbers and titles of key patents are mentioned. Further details on the patents returned by the search are listed in Key Patents table. Considering the focused nature of the search, which resulted in a relatively low number of patent families returned by the search, the analysis presented in the Focused Search Analysis section above is limited.

11.3 CULTURED MEAT: KEY PATENTS

Pub. No.	Title	Abstract	Current assignees	1st app. date	Latest pub. date
EP1789063	Tissue engineered meat for consumption and a method for producing tissue engineered meat for consumption	A non-human tissue engineered meat product and a method for producing such meat product are disclosed. The meat product comprises muscle cells that are grown ex vivo and is used for food consumption. The muscle cells may be grown and attached to a support structure and may be derived from any non-human cells. The meat product may also comprise other cells such as fat cells or cartilage cells, or both, that are grown ex vivo together with muscle cells.	CHOWNINVEANE UNITED STATES JON VEIN VEIN JON	2004-09-17	2016-01-26
EP1037966	Industrial production of meat from in vitro cell cultures	A process for production of a meat product said process comprising the culturing in vitro of animal cells in medium free of hazardous substances for humans on an industrial scale thereby providing three dimensional animal muscle tissue suited for human and/or animal consumption, optionally followed by further processing steps of the cell culture to a finished food product analogous to known processes for meat comprising food products without requiring deboning, removal of offal and/or tendon and/or gristle and/or fat, preferably said meat product comprising solidified cell tissue, said cells being selected from muscle cells, somite cells and stem cells. A meat product, consisting of in vitro produced animal cells in a three dimensional form i.e. comprising multiple cell layers of animal cells in three dimensions, said meat product being free of fat, tendon, bone and gristle, sais cells being selected from muscle cells, stem cells or somite cells.	EELEN WILLEM FREDERIK VAN KOOTEN WILLEM JAN VAN WILLEM FREDERIK VAN EELEN	1997-12-18	2004-04-01
EP3481191	Systems and methods for growing cells in vitro	A system for growing cells comprising a bioreactor chamber for growing the cells, a delivery system delivering a perfusion solution to the bioreactor chamber for perfusion of the perfusion solution through the cells, a dialysis system having a dialyzer, a dialysate for performing a dialysis and a filter for reducing ammonia content in said dialysate, and a controller that circulates the perfusion solution through the dialyzer and the dialysate through the filter.	YISSUM RESEARCH DEVELOPMENT	2017-07-11	2019-05-15
WO2018/189738	Cultured meat-containing hybrid food	A method of producing a hybrid foodstuff is provided. The method comprises combining a plant-originated substance with an amount of cultured animal cells so as to enhance a meat organoleptic and/or meat nutritional property in the hybrid foodstuff, wherein the animal cells do not form a tissue, and wherein the amount is below 30 % (w/w) of the hybrid foodstuff.	SUPERMEAT THE ESSENCE OF MEAT	2018-04-04	2018-10-18

Pub. No.	Title	Abstract	Current assignees	1st app. date	Latest pub. date
US20170145367	In vitro biosimulator to induce pattern formation in non-adherent cells	It is not understood what causes or influences pattern formation in cells during the development of an organism. When animal/human cells are cultured in a Petri dish the adherent cells attach to the bottom of the dish, whereas the non-adherent cells float in the growing medium. Currently there are no specialized dishes for culturing non-adherent cells. We now show that non-adherent cells could be induced to form distinct patterns when cultured in an etched plastic dish (Biosimulator). The non-adherent cells showed polarity when cultured in the etched plate. The polarity/pattern formation could be reversed with inhibitors specific for adhesion proteins. The phenomenon of pattern formation by non-adherent cells has wide applications in cell and developmental biology, diagnostics, microbiome research, biofluidics, drug discovery, industrial production of biological products, and also in biotechnology and bioengineering.	THOMAS SUNIL	2015-11-21	2018-09-13
CN104750022	Tissue engineering and 3D printing meat tissue production processing system and method	A tissue engineering and 3D printing meat tissue production processing system and method are provided. The system comprises a pump, a valve, a cultivation cavity, a cultivation liquid circulating unit, a stimulation unit, a temperature control unit, a nutrient substance adjusting unit and a feedback adjusting unit. The invention further discloses a meat tissue processing method. The method comprises the following steps of circulating cultivation liquid, applying stimulation factors, supplementing nutrients and adjusting the taste. With the adoption of the system and method provided by the invention, the meat tissues can be promoted to amplify in vitro busing a multi-factor coupling cultivation mechanism, and the meat tissues are close to, even better than natural meat tissues in the aspects of shapes, colors and lusters, tastes and nutrient content; meanwhile, the meat tissues which are applicable to people with special requirements are manufactured through adjusting component ratios in the nutrient aspects.	XI'AN JIAOTONG UNIVERSITY	2015-02-05	2015-07-01
WO2018/227016	Ex vivo meat production	Systems and methods for producing cell cultured food products. The cultured food products include sushi-grade fish meat, fish surimi, foie gras, and other food types. Various cell types are utilized to produce the food products and can include muscle, fat, and/or liver cells. The cultured food products are grown in pathogen-free culture conditions without exposure to toxins and other undesirable chemicals.	WILD TYPE	2018-06-07	2018-12-13
EP3071040	Method for scalable skeletal muscle lineage specification and cultivation	The present disclosure relates to methods for enhancing cultured meat production, such as livestock-autonomous meat production. In certain aspects, the meat is any metazoan tissue or cell-derived comestible product intended for use as a comestible food or nutritional component by humans, companion animals, domesticated or captive animals whose carcasses are intended for comestible use, service animals, conserved animal species, animals used for experimental purposes, or cell cultures.	MEMPHIS MEATS UNIVERSITY OF MISSOURI	2014-10-30	2019-04-18

Pub. No.	Title	Abstract	Current assignees	1st app. date	Latest pub. date
EP3394246	Methods for extending the replicative capacity of somatic cells during an ex vivo cultivation process	A product and process for extending the replicative capacity of metazoan somatic cells using targeted genetic amendments to abrogate inhibition of cell-cycle progression during replicative senescence and derive clonal cell lines for scalable applications and industrial production of metazoan cell biomass. An insertion or deletion mutation using guide RNAs targeting the first exon of the transcript encoding each protein is created using CRISPR/Cas9. Targeted amendments result in inactivation of p15 and p16 proteins which increases the proliferative capacity of the modified cell populations relative to their unaltered parental populations. Combining these amendments with ancillary telomerase activity from a genetic construct directing expression of a telomerase protein homolog from a TERT gene, increases the replicative capacity of the modified cell populations indefinitely. One application is to manufacture skeletal muscle for dietary consumption using cells from the poultry species Gallus gallus; another is from the livestock species Bos taurus.	MEMPHIS MEATS	2017-01-17	2019-05-22
WO2018/208628	Compositions and methods for increasing the culture density of a cellular biomass within a cultivation infrastructure	Provided herein are methods to increase the culture density and/or thickness of a cellular biomass in a cultivation infrastructure, to improve the culture of cells in the absence of serum in a cultivation infrastructure, and to promote anchorage-independent growth of a cellular biomass in a cultivation infrastructure. The methods comprise inhibiting the HIPPO signaling pathway, for example, by activating YAP1, activating TAZ, and/or inhibiting MOB1, LATS1 kinase, LATS2 kinase, WW45, MST1 kinase, and/or MST2 kinase in the cellular biomass. In some embodiments, the cellular biomass is harvested from the cultivation infrastructure for the formulation of cell-based food products or ingredients, such as animal meat manufactured from cells in an ex vivo process or for therapeutic applications such as organ or tissue transplantation or grafting.	MEMPHIS MEATS	2018-05-05	2018-11-15
WO2019/016795	Cultured meat compositions	The invention is directed to a method for producing an edible composition, comprising incubating a three-dimensional porous scaffold and a plurality of cell types comprising: myoblasts or progenitor cells thereof, at least one type of extracellular (ECM)-secreting cell and endothelial cells or progenitor cells thereof, and inducing myoblasts differentiation into myotubes.	TECHNION RESEARCH & DEVELOPMENT FOUNDATION	2018-07-15	2019-01-24
US20060029922	Industrial production of meat using cell culture methods	A meat product containing in vitro produced animal cells in a three dimensional form and a method for producing the meat product.	JUST	2005-05-09	2007-09-18
EP2736357	Engineered comestible meat	Provided are engineered meat products formed as a plurality of at least partially fused layers, wherein each layer comprises at least partially fused multicellular bodies comprising non-human myocytes and wherein the engineered meat is comestible. Also provided are multicellular bodies comprising a plurality of non-human myocytes that are adhered and/or cohered to one another; wherein the multicellular bodies are arranged adjacently on a nutrient- permeable support substrate and maintained in culture to allow the multicellular bodies to at least partially fuse to form a substantially planar layer for use in formation of engineered meat. Further described herein are methods of forming engineered meat utilizing said layers.	UNIVERSITY OF MISSOURI	2012-07-26	2019-06-05

Pub. No.	Title	Abstract	Current assignees	1st app. date	Latest pub. date
WO2019/014652	Compositions and methods for increasing the efficiency of cell cultures used for food production	Provided herein are compositions and methods to make and use engineered cells, for the purpose of increasing the cell density of a culture comprising metazoan cells and for the production of a cultured edible product.	MEMPHIS MEATS	2018-07-13	2019-01-17
EP3416498	Functional adzuki bean-derived compositions	Provided herein are methods for producing an adzuki bean protein isolate having high functionality for a broad range of food applications. In some embodiments, the methods for producing the isolate comprise one or more steps selected from: (a) extracting one or more adzuki bean proteins from an adzuki bean protein source in an aqueous solution, for example, at a pH between about 6.5-10.0; (b) purifying protein from the extract using at least one of two methods: (i) precipitating protein from the extract at a pH near the isoelectric point of a globulin-rich fraction, for example a pH between about 5.0-6.0; and/or (ii) fractionating and concentrating protein from the extract using filtration such as microfiltration, ultrafiltration or ion-exchange chromatography; and (c) recovering purified protein isolate.	HAMPTON CREEK JUS JUST	2017-02-17	2019-02-28
EP3416497	Functional mung bean-derived compositions	Provided herein are methods for producing a mung bean protein isolate having high functionality for a broad range of food applications. In some embodiments, the methods for producing the isolate comprise one or more steps selected from: (a) extracting one or more mung bean proteins from a mung bean protein source in an aqueous solution, for example, at a pH between about 6.5-10.0; (b) purifying protein from the extract using at least one of two methods: (i) precipitating protein from the extract at a pH near the isoelectric point of a globulin-rich fraction, for example a pH between about 5.0-6.0; and/or (ii) fractionating and concentrating protein from the extract using filtration such as microfiltration, ultrafiltration or ion-exchange chromatography; and (c) recovering purified protein isolate.	ALL FOOD HAMPTON CREEK JUST	2017-02-17	2019-06-27
EP3503735	Food products comprising milk proteins and non-animal proteins, and methods of producing the same	Provided are food products comprising milk proteins and non-animal proteins, and methods of manufacturing the same.	PERFECT DAY	2017-08-25	2019-09-19
EP3365841	Systems and methods for identifying entities that have a target property	Systems and methods for assaying a test entity for a property, without measuring the property, are provided. Exemplary test entities include proteins, protein mixtures, and protein fragments. Measurements of first features in a respective subset of an N-dimensional space and of second features in a respective subset of an M-dimensional space, is obtained as training data for each reference in a plurality of reference entities. One or more of the second features is a metric for the target property. A subset of first features, or combinations thereof, is identified using feature selection. A model is trained on the subset of first features using the training data. Measurement values for the subset of first features for the test entity are applied to thereby obtaining a model value that is compared to model values obtained using measured values of the subset of first features from reference entities exhibiting the property.	HAMPTON CREEK JUST	2016-09-30	2019-06-19

Pub. No.	Title	Abstract	Current assignees	1st app. date	Latest pub. date
EP3217807	Methods and compositions for egg white protein production	Provided herein are compositions, proteins, polynucleotides, expression vectors, host cells, kits, and systems for producing egg white proteins, as well as methods of using the same.	CLARA FOODS	2015-11-11	2018-12-13
EP3182842	Compositions comprising a casein and methods of producing the same	Disclosed herein are methods and compositions including casein, and methods for making these compositions.	MUUFRI PERFECT DAY	2015-08-21	2018-09-27
EP2773223	Eggless mayonnaise comprising plant-based egg substitute	Disclosed herein are non-egg compositions that can be used as egg substitutes. The disclosure is directed to egg substitutes and methods of manufacturing the same, and compositions comprising the egg substitutes, including edible compositions such as baked goods and edible emulsions.	BEYOND EGGS HAMPTON CREEK JUST	2012-11-02	2019-07-17
GB201813749	Compositions and methods for increasing the efficiency of cell cultures used for food production		BOLLAG BENJAMINA HIGHERSTEAKS SPIROCHEM WALLIS STEPHANIE JADE	2018-08-23	2018-10-10
EP3102043	Dried food products formed from cultured muscle cells	Dehydrated, edible, high-protein food products formed of cultured muscle cells that are combined (e.g., mixed) with a hydrogel (e.g., a plant-derived polysaccharide) are described. These food products may be formed into a chip (e.g., snack chip), that has a protein content of greater than 50%. One or more flavorants may also be included.	MODERN MEADOW	2015-02-05	2018-11-15
SG155930	Tissue engineered meat for consumption and a method for producing tissue engineered meat for consumption	A non-human tissue engineered meat product and a method for producing such meat product are disclosed. The meat product comprises muscle cells that are grown ex vivo and is used for food consumption. The muscle cells may be grown and attached to a support structure and may be derived from any non-human cells. The meat product may also comprise other cells such as fat cells or cartilage cells, or both, that are grown ex vivo together with the muscle cells. Figure: None	VEIN JON	2004-09-17	2009-10-29
WO2015/038988	Edible and animal-product-free microcarriers for engineered meat	Edible microcarriers, including microcarrier beads, microspheres and microsponges, appropriate for use in a bioreactor to culture cells that may be used to form a comestible engineered meat product. For example, the edible microcarriers described herein may include porous microcarriers that may be used to grow cells (e.g., smooth muscle cells) and may be included with the cells in the final engineered meat product, without requiring modification or removal of the cells from the microcarriers. In a particular example, the edible microcarriers may be formed of cross-linked pectin, such as pectin-thiopropionylamide (PTP), and RGD- containing polypeptide, such as thiolated cardosin A. Methods of forming edible microcarriers, methods of using the edible microcarriers to make engineered meat, and engineered meat including the edible microcarriers are also described herein.	MODERN MEADOW	2014-09-12	2017-09-05

Pub. No.	Title	Abstract	Current assignees	1st app. date	Latest pub. date
US20050084958	Tissue engineered meat for consumption and a method for producing tissue engineered meat for consumption	A non-human tissue engineered meat product and a method for producing such meat product are disclosed. The meat product comprises muscle cells that are grown ex vivo and is used for food consumption. The muscle cells may be grown and attached to a support structure and may be derived from any non-human cells. The meat product may also comprise other cells such as fat cells or cartilage cells, or both, that are grown ex vivo together with the muscle cells.	JUST	2001-11-16	2005-04-21
US20160227831	Dried food products formed from cultured muscle cells	Dehydrated, edible, high-protein food products formed of cultured muscle cells that are combined (e.g., mixed) with a hydrogel (e.g., a plant-derived polysaccharide) are described. These food products may be formed into a chip (e.g., snack chip), that has a protein content of greater than 50%. One or more flavorants may also be included.	MODERN MEADOW	2016-04-07	2016-08-11
ZA200702215	Tissue engineered meat for consumption and a method for producing tissue engineered meat for consumption		JON VEIN	2004-09-17	2008-08-27
WO2017/191691	Growth induction system, growth induction control apparatus, growth induction control method, and growth induction control program	In order to suppress the cost of adding a cytokine for each growth stage and induce growth, the growth induction system according to the present invention is provided with: a first culture tank for perfusing an organism-derived growth induction object with a culture medium; a second culture tank for perfusing a cytokine-secreting secretion body with the culture medium; and a growth induction control apparatus provided with a detection unit, a storage unit, and a control unit; wherein a growth induction protocol for prescribing a growth induction procedure is stored, and in the control unit, a growth condition of the growth induction object is detected via the detection unit, and the flow rate at which a culture medium including the cytokine secreted by the secretion body is supplied to the growth induction object is controlled in response to the growth condition of the growth induction object on the basis of the growth induction protocol.	INTEGRATION & CULTIVATION OF CORPORATE SOCIETIES INTEGRICULTURE	2016-06-13	2019-05-30