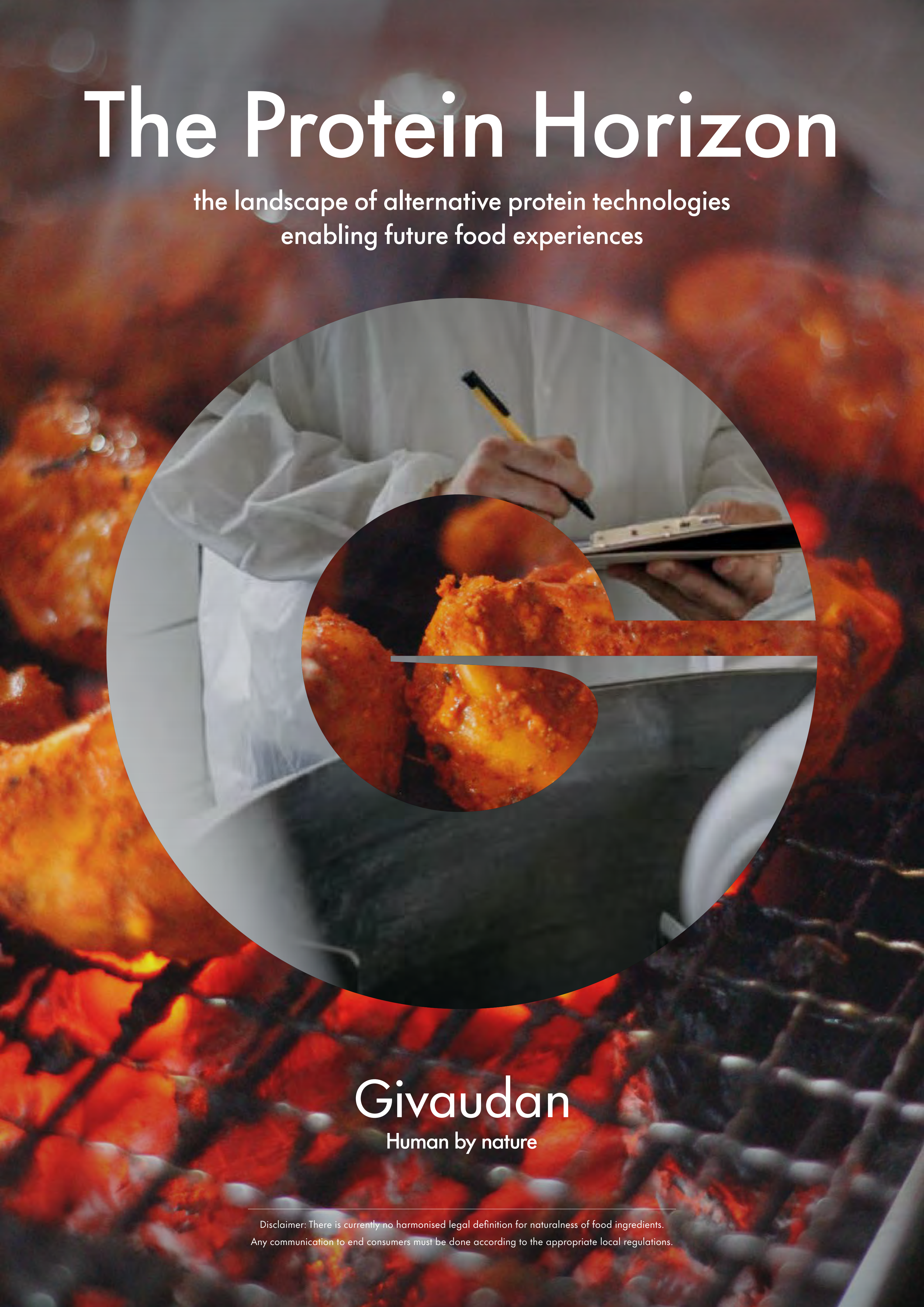
The Protein Horizon

the landscape of alternative protein technologies
enabling future food experiences



Givaudan
Human by nature

A Givaudan white paper, in collaboration with the University of California, Berkeley.

This paper summarises the key findings of a research report prepared by students of the University of California (UC), Berkeley Chemical and Biomolecular Engineering Product Development Program (PDP) on behalf of Givaudan.

It explores current and in-development technologies used in the alternative protein industry to provide insights into adoption, market potential, ongoing challenges and opportunities for future market development.

With special thanks to UC Berkeley's PDP Director, **Keith Alexander**, PDP Coach, **Sudhir Joshi**, and the field project team that conducted the research: **Catalina Villouta**, **Kristina Luong** and **Sichen Liang**.

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01 Innovation in alternative proteins

Products derived from alternative proteins have landed in grocery stores and restaurants worldwide with a bang. Where there once was very little choice, now there is a dazzling array of options on supermarket shelves, in high-street eateries and even on the menus of fast-food chains.

No longer considered a niche dietary preference, the growth of plant-based alternatives has been fueled by rising consumer desire for food products that **do good** and **feel good** for **body, mind and the planet**. But, unlike the vegetarians, vegans and health-conscious eaters of the past, today's consumers are not willing to compromise on flavour, texture or price.

Technical advancement and innovative new technologies have allowed the development of better tasting and better looking products, but there is more still to come. With such an exciting range of innovation in the pipeline, what is next for this vibrant sector and what will it mean for producers and their consumers?

Our recent research project set out to answer this question by exploring the most important technologies for alternative proteins, including dry and wet extrusion, 3D printing, moulding, cultured meat and biomass fermentation. This white paper provides an overview of our findings, setting out the pros and cons of the available technologies, the opportunities they offer to producers and the potential hurdles they pose, as well as providing a glimpse into what is on the horizon in this dynamic space.

What’s fueling the appetite for alternative proteins?

Today’s consumers are hungry for protein alternatives that possess the organoleptic properties of meat and seafood, but without the health, environmental and welfare concerns of traditional meat products. What’s driving this growth?

Environmental and animal welfare concerns

Concerns over animal welfare, human health and global warming have further focused interest on the development of meat alternatives:

- Food of animal origin is a high source of environmental destruction, both because of the production of greenhouse effect gases and because of the huge demand on soil and water needed for meat production.
- Animal welfare is a growing concern with the farming and slaughter of animals less palatable for today’s consumers.
- As part of the solution, protein alternatives have been shown to have a better energy and environmental impact than their animal-based counterparts.

The rise of the health-conscious consumer

The movement towards plant-based diets is driven by conscious consumer desire to choose foods that are good or feel good for body, mind and planet:

- 65% of Gen Z say they want a more 'plant-forward' diet.
- 42% of consumers globally are restricting animal-based products.

Market necessity

The world’s population is growing and becoming more affluent, leading to increased demand for animal-based products:

- An estimated 70% more food will need to be produced over the coming decades to meet rising worldwide demand.[1]
- In China, for example, consumers increased their meat consumption by 49% from 2000 to 2020[2], while the population only grew by 11.5% during this period.

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[1] Kyriakopoulou, Konstantina, et al. “Alternatives to Meat and Dairy.” Annual Review of Food Science and Technology, vol. 12, no. 1, 2021, pp. 29–50. View online

[2] OECD (Organ. Econ. Co-op. Dev.). 2020. Agricultural output—meat consumption. Data Set, OECD, Paris. View online

02

State of the market: today's technological landscape

While each of the existing technologies has its own advantages and disadvantages, as a whole, they are all important technologies for developing new products to meet market demand. Here, we compare some of the most important and promising innovations in this space: dry and wet extrusion, 3D printing, moulding, cellular meat and Mycelium Biomass fermentation.

Overview of technologies[3]

TECHNOLOGY	PRINCIPLE	STRUCTURE	RAW MATERIALS	PROTEIN SOURCES	ADVANTAGES	CHALLENGES	APPLICATION	LEVEL OF TECHNOLOGY
DRY EXTRUSION	High temperature / high shear transform globular protein to linear protein	Sponge-like	Defatted plant protein	- Soy protein - Wheat protein - Potato protein - Rice protein **Pulse proteins:** - Pea - Lentil - Faba bean - Mung bean **Algae based:** - Microalgae - Seaweed (macroalgae)	- Shelf stable - High output - Low cost - Longstanding industrial application	- Lack of fibrous meat-like structure	Textured vegetable proteins (TVP)	Industrial practice
WET EXTRUSION	High temperature/ shear transform globular protein to linear protein + long cooling die form the final fibrous structure.	Layered fibres	Defatted plant protein (below 5%)		- Meat-like fibres - Highly scalable - High output	- Unknown exact mechanism - Not scalable in diameter	Small fillets of chicken, pork & chunks meat, seafood	Industrial practice
3D PRINTING	Food ink printed in layers to mimic fibrous texture	Layered fibrous structure	All the ingredients required for the final product		- Mimics meat appearance perfectly - Fatty mouthfeel	- Slow - Appearance - Texture	Whole cuts of meat, scaffolding	Bench scale
MOULDING	Moulds mimic the shape of the desired product	–	All the ingredients required for the final product		- Generally used as a final step in all technologies	–	Patties, seafood products	Industrial practice
CULTURED MEAT	Mimics biological growth of complete (muscle) tissue	Single fibres (potencial co-cultivation of myocytes and adipocytes)	Initial animal donor required	- Poultry cells - Livestock cells - Fish cells - Crustaceans cells	- Almost exact meat replication possible	- Extremely complex - Scalability/cost are a big challenge	From ground meat to whole cuts	Pilot phase
BIOMASS FERMENTATION	Uses intrinsically fibrous material to mimic the fibrousness of meat	Single fibres (needs to be cross-linked to higher order structures)	- Fungus filaments with high amino acid value - Removal of RNA is necessary	**Mycelium based** - Fusarium venenatum (Quorn™) - Aspergillus oryzae (Koji) - Flavolapis (Fy) Rhiza	- Good texture - Highly scalable	- Process is not very resource efficient - Texture cannot be easily improved	Various products ranging from minced meat to burger patties	Industrial practice

3 This table was inspired by the information presented in the article "Alternatives to Meat and Dairy" by Kyriakopoulou et al.

03 Getting technical with plant-based meat alternatives: process v. product

For the purposes of our research, we have categorised existing meat alternative innovation into two groups: process-based and product-based technologies. The first group includes dry and wet extrusion, 3D printing and moulding, while the second covers cultured (also known as lab-grown) meat and Mycelium Biomass fermentation.

Process-based: Technologies designed to mimic animal proteins

DRY EXTRUSION

Dry (low moisture) extrusion is a well-established technique for producing foods such as snacks that has been widely adopted by the alternative meat industry. It provides manufactures both production accessibility and capacity, not to mention decades of industry experience, making it a cost-effective and, therefore, popular choice.

Dry extrusion produces textured vegetable proteins (TVP) that can be further processed to adjust flavours and nutritional balance. However, the technology has not been able to provide the fibrous meat-like structure or texture that today's consumers have come to expect.

Notable innovations:

PowerHeater™ is a new and promising indirect thermal cooking processing technology that can be used as a post-processing step after dry extrusion to achieve a similar muscle-like fibre structure to that produced by wet extrusion (see below).

From left: PowerHeater working mechanism, PowerHeater™ Screw Configuration, vegan beef processed by PowerHeater

Advantages/disadvantages of dry extrusion:

- \+ Well-established and easily available technology
- \+ Versatile, low cost and energy efficient
- \+ Light weight due to its low moisture content, making it cheaper to transport
- \+ Lower water content also ensures stable and long shelf life
- \+ Continuous process makes it a scalable technique

- – Products with too much expansion can have a hard time retaining their structure after rehydration, turning to mush during processing/eating
- – Products with too little expansion can be slow to rehydrate, lack texture, and can be difficult to flavour pre-extrusion.

WET EXTRUSION

While dry extrusion has been around for quite some time, wet (high moisture) extrusion technology is a rapidly evolving field. Prized for its ability to mimic the texture of meat, wet extrusion is already one of the most popular process-based solutions used by companies worldwide.

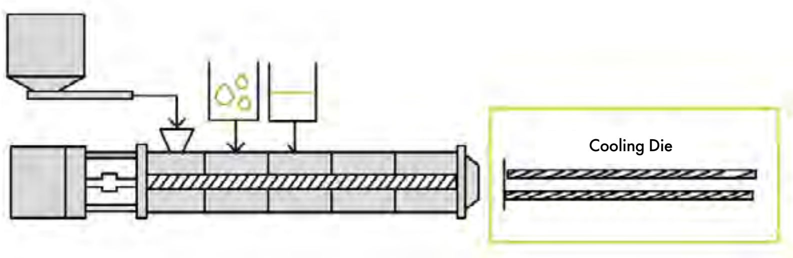
Despite its high throughput, wet extrusion does have certain limitations; in particular, when it comes to manufacturing products past a certain size. The production process is also energy intensive, although the environmental impact of extrusion is still low compared to that of animal meat.

Wet extrusion systems differ from dry systems due to differences in the concentration of water. They transform raw materials into a high-moisture semi-solid output by passing them through a screw system within a barrel conveys mass (a combination of dry ingredients, water and/or oil) and a cooling die, using heat, shear, pressure and moisture.[4] This cooling die provides the fibrous structure that is missing from dry extrusion by minimising water evaporation to generate smaller pockets of air. Fibre formation can be further enhanced by the addition of certain polysaccharides into the food mix before extrusion. Further, clean label products are possible as ingredients such as Methyl-Cellulose are not needed.

Advantages/disadvantages of wet extrusion:

+ Ability to mimic meat-like fibres
+ Clean label products possible only using proteins and water
+ Well-established technology and experience enables speed to market
+ Cost of production is relatively low
+ Process is scalable in size with a high throughput of up to 1,000kg/hr[5]

– Product is not scalable in diameter: thickness is limited to around 1 to 1.5 cm by the cooling die
– Produces only horizontal and v-shape fibres
– Products are hard to differentiate because of the similar structure of the final product
– The production process and nutritional profile of the end product is hard to optimise[6]



Wet Extrusion

We add more water and the cooling die piece is needed to texturise the plant proteins in this moist environent

[4] "Asian Perspective on High-Moisture Extrusion." Cereal Foods World, vol. 65, no. 4, 2020. View online
[5] Bühler's PolyCool 1000 model (Bühler Group, 2022).
[6] Morrison, Oliver. "Why High Moisture Extrusion Could Solve Alt Meat's Nutritional as Well as Structural Challenges." Foodnavigator.com, William Reed Ltd, 24 Mar. 2022. View online

3D PRINTING

Foods printed with 3D technology may intrigue consumers, but they are still very much a novelty in the current market. While the technology in itself isn't new, its use at present is concentrated mainly on gourmet dining, whether in molecular kitchens or fancy bakeries. The printers use plant-based viscous inks and computer-aided design (CAD) files to build products layer by layer. Not only can this mimic the muscle, fat, and blood found in animal meat, but it can also be customised by colour, shape, flavour, texture and nutritional content, making this technology an attractive proposition. Although the application of the technology requires more time and development to mature, headway is being made to scale up the use of 3D printing and to expand it into new product lines.

At present, most food-based 3D printers use hot melt/room temperature extrusion technology to extrude food materials through nozzles according to a preset path, stacking layers to obtain the final 3D-printed products. A key requirement of any raw material to be used as an ink in this process is that it must flow smoothly from the print cartridge to the printing platform. Various combinations of protein source and ingredients have been tested to provide food with the required structure as it's printed. For example, soy protein isolate mixed with sodium alginate and gelatin was found to create excellent geometries and improve the hardness and chewiness of the formed products.[7]

Studies on how animal muscle tissue behave when 3D printed would help in understanding how textured plant based food inks would also extrude. To date, however, there has been little published work describing the printability of fibrous meat materials (e.g., pork, turkey, chicken, fish), with none for beef. There is also concern in the market about the long-term effects of eating products that are artificially manufactured in this way.

NovaMeat steak printed and cooked at the Culinary School of Barcelona, Spain (Reuters, 2020)

3D printing technology has been used by companies such as Redefine Meat, NovaMeat, and Juicy Marbles to imitate the fibrous textures of meat with plant-based ingredients. Each of these companies overcome one of these challenges detailed above. For example, Redefine Meat has been able to perfect the speed challenge to produce more than 20kg per hour; however, the fibres of the meat are quite large compared to animal meat. NovaMeat has been able to overcome the challenge of texture to create very fibrous looking meat; however, printing is extremely slow. Finally, Juicy Marbles has been able to overcome the appearance challenge, but is also struggling with the speed component.[8]

Advantages/disadvantages of 3D Printing:

- + Low environmental impact (only requiring electricity)
- + Lower material cost as ink is placed exactly (no scraps or trimmings left over)
- + Potential to mimic the fibrous texture of meat
- + Ability to customise the final product relatively easily

- – Slow to produce the final product (one product produced line by line at a time)
- – Food ink must be formulated to produce the required texture, even after cooking
- – Appearance and cooking ability of meat is less easy to replicate, as it include fat, not only muscle tissue

[7] Watkins, Peter, et al. "Three-Dimensional (3D) Food Printing—an Overview." Food Engineering Innovations Across the Food Supply Chain, 2022, pp. 261–276. View online
[8] Rubinsky, Dan. Interview. Conducted by Catalina Villouta, Kristina Luong, and Sichen Liang. 11 February 2022.

MOULDING

Moulding is one of the simplest process-based technologies and is often used as the final step when producing animal alternative products in minced and whole/cut forms. The technology can easily replicate the texture properties of certain seafood proteins, is scalable and does not require a high level of expertise to employ. It has minimal environmental impact compared to other technologies, although its use can be limited by production speed. However, it is not capable, by itself, of mimicking the fibrous texture of real meat.

Product-based: Innovations designed to bring products to life

CULTURED MEATS

Cellular-cultured (or cultivated) meats produce meat alternatives by growing real animal cells in a lab, as opposed to seeking to replace them with plant-based alternatives. By growing these animal cells in specialist bioreactors, cultured meat technology is not only able to replicate the sensory and nutritional profile of conventionally produced meat more effectively, but it does so more sustainably and without the need to slaughter the source animal.

At present, capital and operating costs remain high due to the cost of the specialist equipment required, the challenges associated with scaling the resulting products, and the need to sterilise bioprocessing equipment. Not only will further innovation be required to increase batch volumes and decrease the cost of the final product, but producers will also need to work with national governments to develop the regulatory guidelines needed to open the door to the sale of cultivated meat products.

Cultured meat is one of the most exciting innovations in product-based technology. By harvesting real animal cells and then mimicking the process by which those cells grow and divide in vivo, it is possible to produce products with the same nutritional and organoleptic properties as their conventional counterparts.

Phase I: Cell isolation and initial expansion

The first step is to isolate and characterise appropriate cells from the species of interest and bank these cells for future use. Cell lines must be capable of differentiating into muscle fibres, adipocytes and a handful of other important cell types that make up meat (such as fibroblasts). In many cases, this step will encompass the development of a stable, immortalised cell line. Companies may undertake the cell isolation and cell line development steps themselves or licence an existing line.

Phase II: Large-scale cell expansion

In this phase, cells are expanded to increase the total biomass. The goal is to produce a large number of cell doublings while keeping the cells in an undifferentiated, and therefore proliferative, state. In this example, cells are grown in a stirred-tank bioreactor and may be grown on microcarriers, as aggregates, or as single cells.

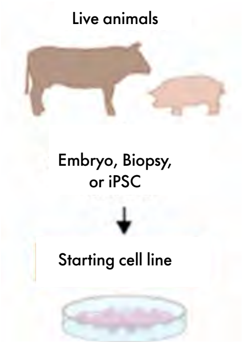
Phase III: Tissue Maturation

Cells are grown under conditions that promote differentiation and maturation of the cells, typically but not always on scaffolds. The choice of media and bioreactor are crucial in both phases II and III and will likely differ between the two phases.

Phase IV: Processing into a food product

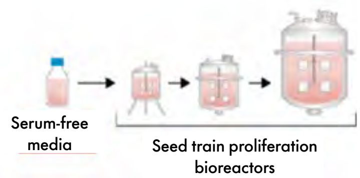
For some product types, a final processing step will be necessary to transform the engineered tissues into a final product. For example, scaffolds laden with mature myofibers might be combined with edible microcarriers on which adipocytes have been differentiated in a separate phase III process to form a burger patty.

Cell line



- Tissue is taken from the animal to extract stem cells and create cell lines.

Media



- The cell culture media is a liquid that contains the nutrients needed to support growth, differentiation and proliferation
- Very complex and expensive composition

Scaffold

- Scaffolds permit cells to attach and differentiate in a 3D architecture of the meat product
- Edible, removable with textural properties

Bioreactors

- Bioreactors must be explicity designed for cellular meat capable of supporting high-density and a large volume of cell cultures

Advantages/disadvantages of cultured meat:

- \+ Overall more animal friendly and sustainable while providing the same proteins
- \+ No animal farming is necessary, decreasing expensive labour and risk of zoonotic diseases
- \+ Could reduce land use by up to 95%[9] and require 77% less water than conventional meat[10]
- \+ Cells from a single animal could cultivate the same amount of product as hundreds (or thousands) of animals

- – Upscaling this technique requires large bioreactors
- – High control over the growing conditions necessary to avoid contamination
- – Nutrients (amino acids and protein growth factors) must be determined uniquely for each cell line
- – Regulatory barriers: to date, only Singapore has approved the use of a cultivated meat product (Good Meat chicken nuggets)
- – Cost remains a challenge

One possible solution to the scale and cost barriers would be to use genetically engineered cells; however, it remains questionable whether consumers will accept GM foods.

Despite the hurdles to be overcome in this sector, the number of startups focused on developing cultivated meat inputs or end products continues to rise. Some of the main players in this industry are Upside Foods (previously Memphis Meat), Good Meat, SuperMeat, Mosa Meat, and Finless and BlueNalu (both seafood producers). Notable innovations include the world's first beef meatball (developed by Memphis Meat in 2016), 100% chicken products (i.e. cultured chicken without any use of plant-based carrier or scaffolding, developed by SuperMeat in 2022), and Mosa Meat's non-GMO and full tissue burgers (producing up to 80,000 patties from a sesame-seed size sample of cells in 2022).

Snapshot of the regulatory status for cultured meats[11]

COUNTRY	REGULATOR	STATUS	INITATIVES
BRAZIL	General Food Office at the National Health Agency (ANVISA) and the Animal Products Inspection Department, under the Ministry of Agriculture	GFI expects Brazil to undertake a regulatory impact analysis in 2022. According to ANVISA, Brazil plans to adopt a model similar to that of the US and EU.	Throughout 2021, GFI Brazil promoted discussions on regulatory best practices with international regulators and proposed a unique protocol for cultivated meat within Brazil's existing novel foods framework.
CHINA	Ministry of Agriculture and Rural Affairs	China has not yet announced how it will regulate or oversee the manufacturing and sale of cultivated meat.	China included cultivated meats and other "future foods" in its official five-year agricultural plan (released in January 2022).
EUROPEAN UNION	Companies must apply to the European Commission for premarket authorisation of products. This includes a safety evaluation by the European Food Safety Authority (EFSA).	When cultivated meat is produced without genetic modification, it is regulated under the novel foods regulation of the EU. Premarket authorisation is handled centrally, so once a product is approved that approval applies across all EU member states.	REACT-EU, a government funding programme launched in response to the Covid-19 pandemic, awarded cultivated meat company Mosa Meat and partner Nutreco a €2 million grant for research into lowering the cost of cell culture media.
SINGAPORE	Singapore Food Agency (SFA)	SFA has not indicated whether it will issue a comprehensive regulatory framework or approve cultivated meat products on a case-by-case basis. Companies must still submit regulatory filings for their specific formulations. SFA updated a guidance document on novel food safety assessments in December 2021.	SFA became the first national regulator to green-light the sale of a cultivated meat product in 2020.
UNITED STATES	Cell collection/banking and all cultivation inputs and processes overseen by the Food and Drug Administration (FDA). Processing and labelling for terrestrial meats regulated by the Department of Agriculture (USDA).	USDA has issued an advance notice of proposed rulemaking on the labelling of cultivated meat products. Companies seeking to retail their products before USDA completes this process can submit labels to USDA's Food Safety and Inspection Service for review.	USDA granted US$10 million (m) in 2021 to create a centre for excellence in cellular agriculture at Tufts University. National Institutes of Health granted US$1.5m to Defined Bioscience to develop a cell culture medium supplement.

9 CE Delft. 2021. LCA of Cultivated Meat—Future Projections for Different Scenarios. Delft, NL: CE Delft.
10 UPSIDE Foods, 23 Feb. 2022. View online
11 Good Food Institute (GFI) 2020/2021 State of the Industry for Cultivated Meat reports. *See the Appendix for a regulatory overview of other territories of interest, incl. Africa, Australia, Canada, India and Japan.*

MYCELIUM BIOMASS FERMENTATION

Whereas cultured meats employ real animal cells to grow meat in the lab, biomass fermentation does so using mycelium, a filamentous fungi with a protein that has a similar fibrous texture to animal meat as well as a desirable nutritional profile. While mycelium is easily grown via submerged fermentation in airlift fermenters or via solid-state fermentation in trays, biomass fermentation does have its limitations. Only specific strains of filamentous fungi are both safe to eat and capable of successfully mimicking the desired texture. Discovering new strains and/or effective feedstocks (sugars, starches and nutrients) would require considerable research and development (R&D) time and budget.

Of the companies growing different strains of fungi, the oldest and most recognised brand is that of Quorn™ (Marlow Foods). It produces mycoprotein, a low energy and protein-rich whole food source derived from the fermentation of filamentous fungus such as *Fusarium venenatum*, on a large industrial scale, adding egg albumen, colour and flavour compounds to create a texture similar to meat.

Overall, the process is highly efficient with 14,000 tonnes produced every year. Mycoprotein is also an excellent source of high-quality protein[12], with a higher weight percentage of protein content (45–54%) than common plant or other fungal protein, although lower than meat.[13]

Other producers grow filamentous fungi to produce a fibrous texture that is analogous to meat. Because of the naturally occurring structure, minimal processing is needed to mimic the texture of meat. For example, The Better Meat Co. uses a 9,000 litre bioreactor with a one day turnover to produce its products.

Advantages/disadvantages of biomass fermentation:

This last category of food seems to address well the challenges faced by the other technologies, although biomass fermentation does have its own unique set of challenges.

- Only specific species of fungi have the required texture, resulting in a high R&D cost associated with discovering and developing these species
- Consumers are generally wary of eating a product that says it is made of fungi and/or is associated with mould
- Perceived risk of developing allergies to this category of food

The future applications of mycelium seem promising, however, with the potential to further develop mycelium to mimic muscle tissue and use it as a scaffolding to build both plant-based and cell-based meats as well as fungi-based products.[14]

[12] Finnigan, T., et al. "Mycoprotein." Sustainable Protein Sources, 2017, pp. 305–325. View online
[13] Ahmad, Muhammad Ijaz, et al. "A Review on Mycoprotein: History, Nutritional Composition, Production Methods, and Health Benefits." Trends in Food Science & Technology, vol. 121, 2022, pp. 14–29. View online
[14] McEvoy, Enda. 2021."Mycelium, a Promising Future." View online

04

New innovations in alt meat

Four new technologies are opening the door to a range of new solutions, including shear cell technology, wet spinning, electrospinning and the mixing of proteins and hydrocolloids.

1. Shear Cell Technology

Originally used as an offline method to study the effect of extrusion-like conditions on biopolymers such as starch or proteins, shear cells were identified as a novel structuring technology when the processing of calcium caseinate led to the formation of fibrils.

As opposed to wet extrusion, the process utilises a well-defined shear flow during heating and cooling to produce fibrous products with calcium caseinate and several plant protein blends (e.g. wheat gluten). So far, the technology has been successful up to the pilot-scale.[15]

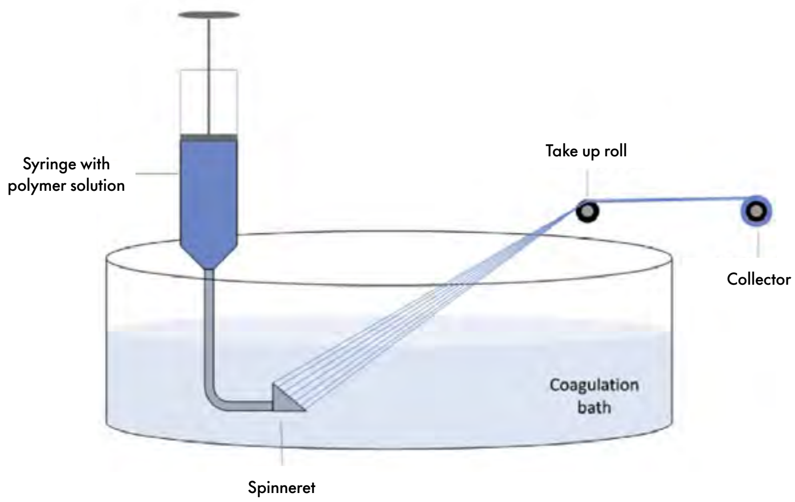
Rival Foods was one of the first companies to use shear cell technology to create whole-muscle products, including mimicking the heterogeneous fibrous texture of red meat products and the finer, more homogenous texture of white meat products.

2. Wet Spinning

Wet spinning is one of the standard techniques for the production of membranes for industrial separation purposes.[16] Mostly used for the creation of individual fibres, it spins plant protein into long and thin strands, which are then formed together to mimic the structural and biochemical features of natural muscle tissues during processing and cooking. To date, this process has been successful at converting soy, pea and faba bean proteins from their native globular state to a fibrous structure.

A protein solution with higher concentrations of protein and higher temperature facilitates the spinnability and results in stronger fibres.[17] However, these fibres must then be solidified in a salt, acid or alkali coagulation bath, making the washing step essential and leaving behind large waste streams.[18]

Illustration: Wet spinning process for producing fibres (Kyriakopoulou et al., 2019)

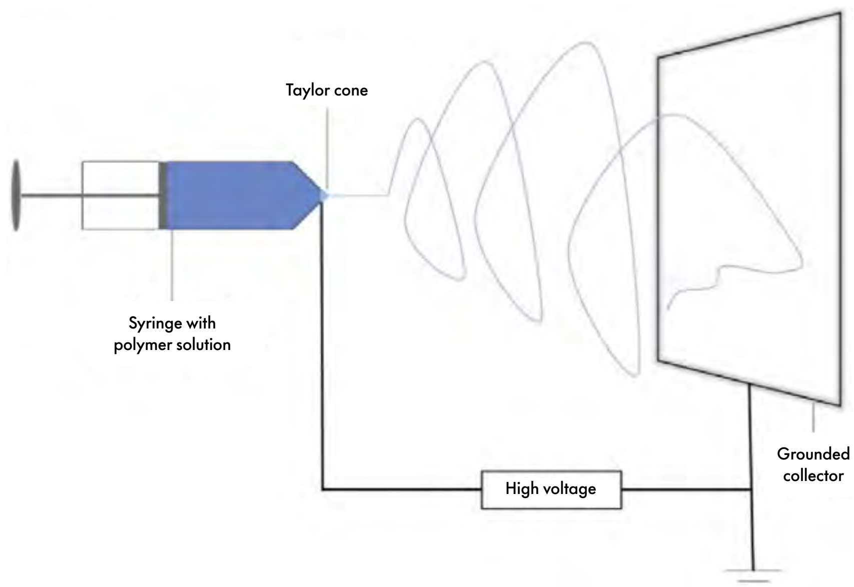


[15] Dekkers, Birgit L., et al. "Structuring Processes for Meat Analogues." Trends in Food Science & Technology, vol. 81, 2018, pp. 25–36. View online
[16] Ho, Stephanie. "The Diet Revolution." StemSide, StemSide, 10 Mar. 2021. View online
[17] Kazir, Meital, and Yoav D. Livney. "Plant-Based Seafood Analogs." Molecules, vol. 26, no. 6, 2021, p. 1559. View online
[18] Kyriakopoulou, Konstantina, et al. "Plant-Based Meat Analogues." Sustainable Meat Production and Processing, 2019, pp. 103–126. View online

3. Electrospinning

Electrospinning produces individual fibres of the smallest scale by applying a high voltage to a polymer solution. This solution needs to satisfy several requirements, not least high solubility, viscosity, conductivity, surface tension and the ability of the components to entangle. Electrospinning of proteins has been reported for several animal-based proteins such as whey, collagen, egg and gelatin, but only sparingly for plant proteins.[19]

Illustration: Electrospinning process for producing fibres (Kyriakopoulou et al, 2019)



4. Mixing of proteins and hydrocolloids

Finally, it is possible to obtain fibrous products by mixing proteins with hydrocolloids that precipitate with multivalent cations. Various combinations of proteins, hydrocolloids and multivalent cations can be used in this process. For example, Valess was a product introduced in 2005 based on caseinate and alginate. Plant proteins such as soy, rice, maize, and lupine can be employed in a similar way. This process is well scalable, yields products with some degree of structure, but still is relatively intensive in its use of resources.[20] New and innovative products like the vegan shrimp developed by New Waves seem to rely on this kind of technology.

[19] Girija, J, et al. "Production Methodologies of Meat Analogues: A Review." Journal of Agricultural Engineering, vol. 58, no. 02, 2021, pp. 137–148. View online
[20] Dekkers, Birgit L., et al. "Structuring Processes for Meat Analogues." Trends in Food Science & Technology, vol. 81, 2018, pp. 25–36. View online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05 Future gazing: recommendations for industry

The rise of meat alternatives is both significant and poised strongly for future growth. But, while existing technologies offer a major opportunity for process and product-based alternatives, the main challenges in this sector remain cost and scale.

The economic opportunity for meat alternatives is sizeable across all of the technologies featured in our research. Not only is each technology and product type viable for a specific consumer market segment, but will continue to be so in the future as ongoing research and development identifies new opportunities and finds new solutions to the challenges highlighted in this report.

In general, the process-based technologies featured in this report are more robust, scalable and have better resource efficiency, whereas the product-based technologies have the potential to mimic meat most closely.

What's next?

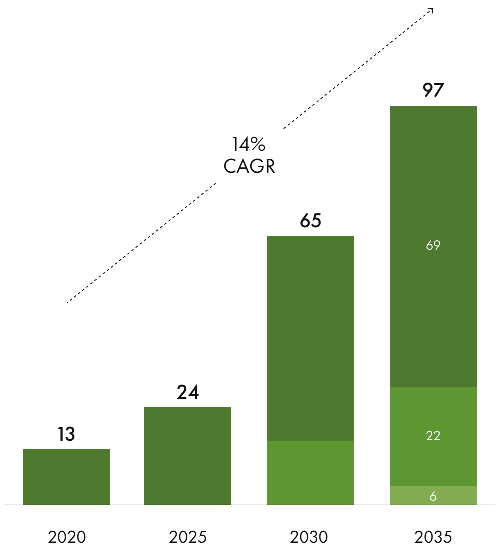
While all the technologies we have featured have the potential to be the next up-and-coming dominant technology in the alternative meat market, plant-based products produced by extrusion are expected to remain as the alternative protein market leader. This trend is expected to last at least the next decade, due to the affordable price and production efficiency. It may even accelerate once PowerHeater technology is integrated into the dry extrusion process to create a more fibrous and meat-like product type.

We also expect to see an increase in the number of products produced by biomass fermentation thanks to its relatively low production cost and ability to produce desirable textures. A similar picture applies for cultured meat, if/when regulations are approved in major markets, due to the volume of interest and investment in this space.[21]

New innovations also have the potential to shake up the market. For example, innovative and well-performing lab scale technologies, such as shear cell, are already emerging as the next major research trend and investment hotspot.

While the industry's precise growth path will remain uncertain for some time, industry stakeholders – startups and established food companies, consumers, investors and global governments – are already making great strides down that path in the direction of a more sustainable and secure food future.

Alternative protein consumption will grow in three waves:



CAGR 2020-25	CAGR 2025-30	CAGR 2030-35	
13%	22%	8%	
12%	16%	7%	Plant-based
45%	111%	8%	Microorganism-based
52%	66%	120%	Animal-cell-based

Sources: US Department of Agriculture; Euromonitor; UBS; ING; Good Food Institute; expert interview; Blue Horizon; BCG Analysis. CAGR from 2022-2025, starting from market entry.

[21] For cultivated meat specifically, McKinsey & Company estimates that the market may reach $2 billion in annual sales in just a few years and up to $20 billion or even $25 billion in sales by 2030 if cultivated meat companies are able to "replicate a wide variety of both processed meats and whole cuts" and distribute them globally (Brennan et al., 2021).

06 Become part of the future

Creating delicious meat alternatives not only requires specialised knowledge, resources and technical capabilities. To succeed in this fast-changing and dynamic environment, companies also need to be agile, efficient and innovative.

Collaboration will be the key to solving the many technical challenges that exist in this space by providing access to the latest technologies, production capabilities and industry knowledge.

How to find the right technology to meet your technical challenges

Partnering in research and technology can open up possibilities and help identify and solve your innovation challenges whether you choose to work with established industry players, academics, start-ups or any other type of innovator in the alternative protein space.

Connecting with the right partner or collaborative ecosystem requires active and consistent scouting, however. Choose wisely based on your needs and desire to collaborate, leverage your existing network and keep an open mind when selecting potential collaborators.

Start by identifying and focusing on your main innovation challenges, whether that be to:

- *Achieve authentic taste and texture:* Mask off-notes, increase meatiness and achieve market differentiation.
- *Improve visual appearance:* Mimic the visual transformation of meat alternatives, from raw to cooked, without sacrificing the cachet of a "clean" label.
- *Create healthier products:* Control calories by reducing salt and fat content, switch to natural colours and natural preservatives to meet market demand.

Find business partners with the right mindset that will collaborate with you to resolve those technical challenges, including by defining clear objectives and deadlines, focusing on the technology/solution and ensuring value creation within the partnership.

Partner with Givaudan today

From fundamental scientific understanding to holistic product design, Givaudan delivers customised solutions at every step of our customers' protein journeys based on a collaborative approach to successful innovation. Our ecosystem unites a strong and vibrant community of innovators in the protein space, from industry players to academia and start-ups, to find and accelerate disruptive foodtech.

Plant Attitude: supporting each other and the broader ecosystem

Givaudan manages a global network of protein hubs to provide companies with access to an entire ecosystem of specialists, resources and cutting-edge technologies.

Spread across four continents, our Plant Attitude network includes innovation centres with pilot extrusion capabilities in Zurich, Switzerland and Singapore, a new centre being built in Brazil, and extensive capabilities throughout North America. From these protein innovation spaces, we help our customers to accelerate the development of winning plant-based food experiences at every stage of the product life cycle. From scientific research to holistic product design and prototyping, our centres foster collaboration and co-creation to help customers open a world of opportunities in the fast-changing alternative protein arena.

Our expertise encompasses every aspect of alternative meat and seafood and we're ready to help you as needed to create an outstanding product. Our flavour and taste experts are unparalleled and have extensive knowledge in bringing the absolute best taste attributes to alternative products. Texture, preservation and colour experts are available to support your needs across a range of product types. And at their fingertips, each expert has an unrivalled portfolio they can put to use on your behalf.

Let's imagine together the future of meat alternatives:
Find out more at www.givaudan.com.

Appendix

The regulatory status for cultured meats (additional countries)			
COUNTRY	REGULATOR	STATUS	INITATIVES
ISRAEL	National Food Control Service (FCS)	FCS in process of evaluating the required safety assessments for a cultivated meat regulatory framework.	In December 2020, Benjamin Netanyahu became the first head of government to sample a cultivated meat product.
JAPAN		To comply with existing food regulations, cultivated meat products and production processes must not externally source growth factors or use immortalised cells. Clear regulatory framework still required.	
CANADA	Canada's Food and Drug Regulations have a broad definition of novel foods, that would include cultivated meat.	Similar to the EU, Canada requires a pre-market notification from the government before any novel food is advertised or sold.	Canada does not currently have any of the other stringent requirements in relation to nutrition or additional checks and inspections that the US has.
INDIA	Food Safety and Standards Authority of India (FSSAI)	The Novel Food Regulations require the approval of the FSSAI for such foods to be manufactured or sold in India. The procedure for application and details of the safety assessment are encapsulated in the Food Safety and Standards Regulations, 2017.	
AUSTRALIA and NEW ZEALAND	Food Standards Australia and New Zealand	The Food Standards Code has a provision on novel foods, which also requires compliance with certain conditions. There are currently no permissions or requirements in the Food Standards Code specifically for cultivated meat, however, they are regulated as novel food products.	
AFRICA	Three government bodies in Africa oversee food production: the departments of trade, health and agriculture.	Mzansi Meat is the first company producing cultivated meat products in South Africa. Government bodies have been working on regulation since its inception in March 2020.	

Source: Good Food Institute (GFI) 2020 and 2021 State of the Industry for Cultivated Meat reports.

Join the next global trend

As tried-and-tested specialists in protein function challenges, Givaudan holds in-depth knowledge and wide-ranging experience of many meat alternative technologies. As innovators, we are continually working to build a global community of industry partners, academics and start-ups, as we strive to consolidate our own world-class capabilities for the next generation.

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Human by nature