Good Food Institute

2022 STATE OF THE INDUSTRY REPORT

Fermentation:

Meat, seafood, eggs, and dairy

Editors' note

Meat production is projected to nearly double by 2050 to meet growing global demand. But the way the world currently produces meat cannot meet this demand and still achieve global climate, food security, public health, and biodiversity goals. Making meat differently via alternative proteins can help feed a growing world safely and efficiently, and will be as essential to mitigating climate change as the global transition to renewable energy. When compared to conventional meat production, alternative protein production dramatically reduces emissions, requires far less land, eliminates the use of antibiotics in our food system, and feeds more people with fewer resources.

By reimagining protein, we can produce food that people love and usher in a more sustainable, secure, and just food future. Countries have committed to halve emissions and protect 30 percent of global land and ocean ecosystems by 2030. With just seven years to go, investing in alternative ways of making meat, seafood, eggs, and dairy is essential.

GFI's annual State of the Industry Reports equip food system stakeholders with a solid, in-depth understanding of the alternative protein market, issues, and opportunities. These reports also serve as a global call to action:

Alternative proteins are a scalable solution that, with proper levels of public and private support, can help address the biggest challenges of our time and transform our global food system for the better.

One powerful tool to tackle such challenges is the use of microbial fermentation to produce animal-free alternatives to conventional proteins. At scale, alternative proteins made via microbial fermentation could enable a shift away from the more resource-intensive ways we rely on today to make food. A study published last year in Nature simulated swapping 20 percent of all beef eaten for microbial protein by 2030 and showed that doing so could halve deforestation and food system emissions.

One report in this year's series, *Fermentation: Meat, seafood, eggs, and dairy*, details some of the promising developments that moved the field of fermentation-enabled alternative proteins forward in 2022. The sector still has miles to go, however, to reach full potential. Funding and workforce constraints pose two of the biggest bottlenecks at the top of the funnel for scientific innovation and scaling. The alternative protein industry is still very early in its development, with growth patterns similar to other emerging markets and technologies. As companies continue to innovate, and as more talent, research funding, and investments flow into alternative proteins, the entire sector will accelerate, offering the world a fundamentally different and far more sustainable food future.

With gratitude and deep respect to all those on this journey, we invite you to dig deep into our 2022 State of the Industry Report, *Fermentation: Meat, seafood, eggs, and dairy*.

Best,

Caroline Bushnell
VP of Corporate Engagement

Liz Specht, PhD
VP of Science and Technology

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VP of Policy

About GFI's State of the Industry Report series

GFI's State of the Industry Report series serves as our annual alternative protein sector deep-dive. The series compiles business developments, key technologies, policy updates, and scientific breakthroughs from around the world that are advancing the entire field. This year's reports include:

- *Cultivated meat and seafood*
- *Fermentation: Meat, seafood, eggs, and dairy*
- *Plant-based meat, seafood, eggs, and dairy*
- *Global policy: Public investment, regulation, and labeling*

The *Fermentation: Meat, seafood, eggs, and dairy* report synthesizes 2022 updates across the global fermentation industry focused on animal-free alternatives to conventional proteins. This report focuses on developments across the commercial, investment, policy, and scientific landscape related to the use of fermentation in the production of alternative proteins—meat, seafood, eggs, and dairy made via microorganisms. For a full primer on the emerging role of microbial fermentation in building the next generation of alternative proteins, please visit GFI's science of fermentation deep dive.

Symbols to look for

Throughout the 2022 State of the Industry Report series, look for symbols highlighting how developments in the past year advanced the alternative protein sector in the areas of health and nutrition, sustainability, and path-to-market progress. Dig deeper and opportunity icons are calls to action for researchers, investors, and others seeking to learn more and advance the field.

Health **Sustainability** **Opportunity** **Path-to-market** **Dig deeper**

Please note that The Good Food Institute is not a licensed investment or financial advisor, and nothing in this report is intended or should be construed as investment advice.

About the Good Food Institute

As a nonprofit think tank and international network of organizations powered by philanthropy, GFI works alongside scientists, businesses, and policymakers to make alternative proteins as delicious, affordable, and accessible as conventional meat. In Asia Pacific, Europe, Brazil, India, Israel, and the United States, our teams are mobilizing the international community to use markets and technology to replace harmful practices with ones that are better for the climate and biodiversity, for food security, and for global health.

We focus on three programmatic priorities:

Cultivating a strong scientific ecosystem

GFI's science and technology teams map out the most neglected areas that will allow alternative proteins to compete on taste and price. We develop open-access research and resources, educate and connect the next generation of scientists and entrepreneurs, and fund research that benefits alternative protein development across the sector.

Influencing policy and securing government investment

GFI's policy teams ensure that alternative proteins are a part of the policy discussion around climate change mitigation and global health. In every region where we have a presence, we advocate for government investment in alternative proteins and are paving the way for the approval of novel proteins such as cultivated meat.

Supporting industry to advance alternative proteins

GFI's corporate teams are replicating past market transformations and partnering with companies and investors across the globe to drive investment, accelerate innovation, and scale the supply chain—all faster than market forces alone would allow.

Stay connected

- **Newsletters** | GFI's suite of expertly curated newsletters puts timely news, insights, and opportunities right in your inbox, Check out gfi.org/newsletters to find the ones most suitable for your interests.
- **Monthly seminar series** | Each month, we host online seminars with leading experts from around the world: The *Business of Alt Protein* series is geared toward a commercially focused audience on topics related to starting and scaling a good food business. The *Science of Alt Protein* series addresses a technical audience and focuses on cutting-edge research developments that enable alternative protein innovation.

This State of the Industry Report series, as well as all of GFI's work, is made possible by gifts and grants from our global family of donors. If you are interested in learning more about giving to GFI, please visit here or contact philanthropy@gfi.org.

Table of contents

Executive summary

Executive summary

The global fermentation industry focused on animal-free alternatives to conventional proteins continued to break new ground in 2022. Scientific advances, new products and prototypes, manufacturing facilities, and partnerships brought the world more meat, seafood, eggs, and dairy made via microorganisms—a nature-inspired technology primed to transform the future of food.

Commercial landscape

New industry associations.

A group of 12 companies and two nonprofits cofounded the new **Fungi Protein Association**, a milestone for the industry in advancing fair policies and consumer research.

In early 2023, nine precision fermentation companies cofounded the **Precision Fermentation Alliance**, which will focus on regulatory engagement and consumer messaging.

Known companies.

The number of companies focused on fermentation for alternative proteins rose to 136, an increase of 12% over the number of known companies in 2021.

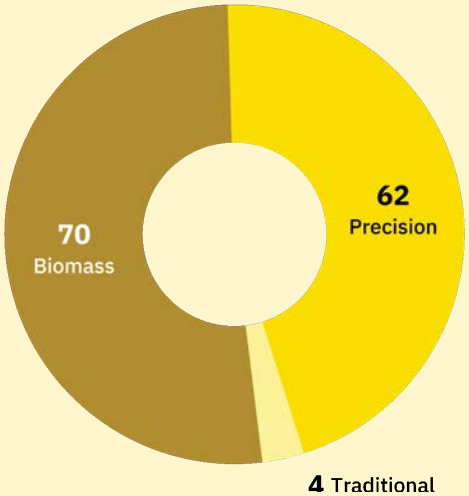
Business lines.

At least 100 additional companies have a business line in alternative protein fermentation, including major food companies such as **Nestlé**, **Unilever**, and **Bel Group**.

Partnerships and capacity building.

In 2022, 21 new partnerships focused on end products and bioprocess scaling. Two startups launched to focus on building contract manufacturing facilities specifically for precision fermentation for alt proteins. BioP2P and Capacitor established open-access resources for capacity planning in biomanufacturing.

Figure 1: Total number of fermentation companies by category



Products

In 2022, companies applied fermentation technology to develop end products and ingredients to enhance plant-based products across categories:

Significant expansion in dairy.

A number of companies used **Perfect Day**'s whey protein from fermentation to launch a range of new products, from animal-free milk and ice cream to chocolate and protein powder.

Eggs.

The EVERY Company continued their focus on precision fermentation egg proteins in 2022, partnering with brands to launch macarons and a line of hard juices featuring animal-free egg protein.

Meat.

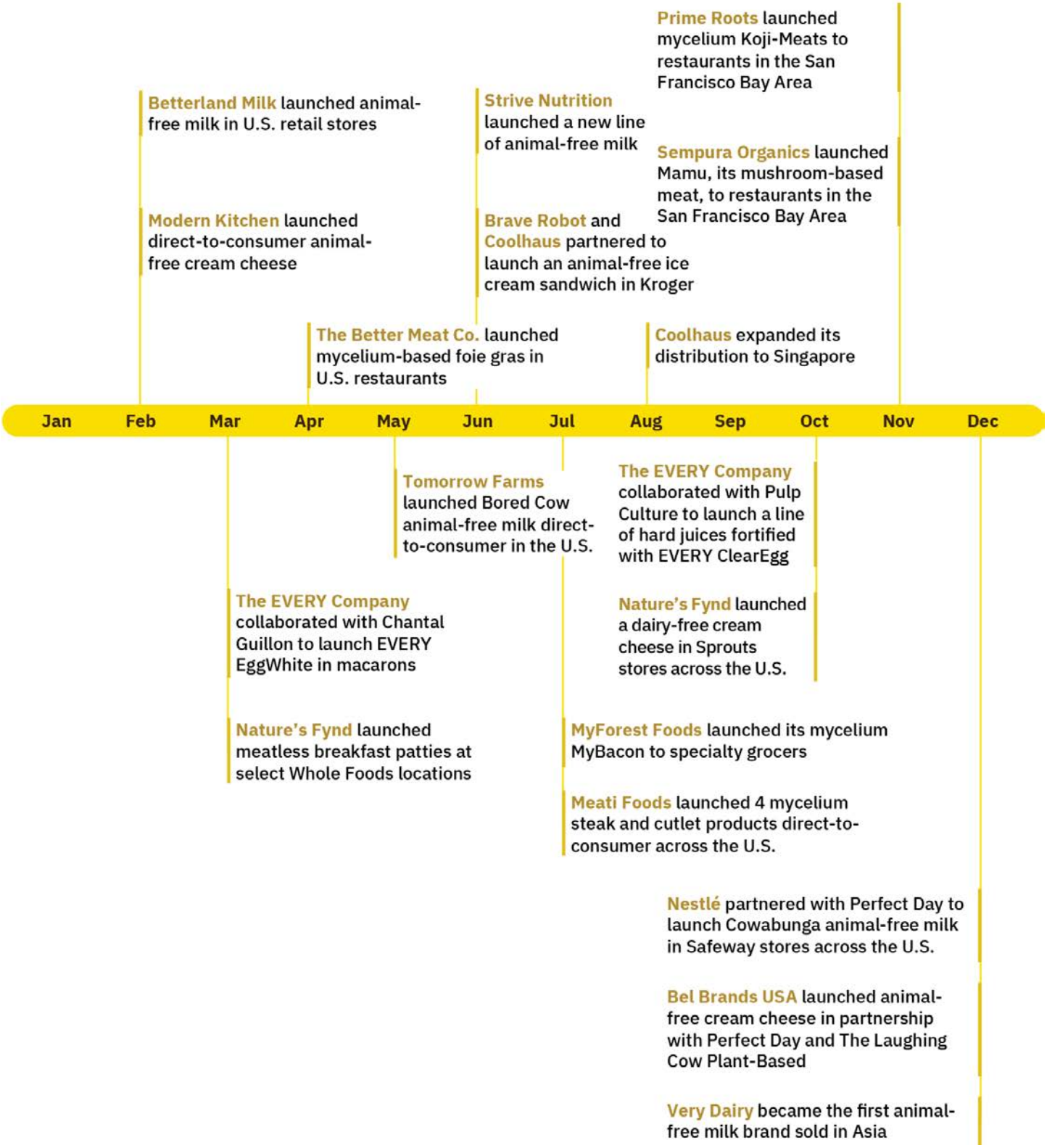
New fermentation-enabled meat products, including breakfast sausage, steak, bacon, and deli meats, launched in 2022.

Product prototypes.

Aqua Cultured Foods created a mycoprotein calamari, **Bosque Foods** showcased mycelium-based pork and chicken fillets, and **Mycorena** developed a mycoprotein-based butter.

Photo: Perfect Day

Figure 2: Fermentation product launches in 2022



Investments

Fermentation companies raised $842 million in 2022, a year-over-year deceleration mirroring similar trends across markets amid challenging macroeconomic conditions and other global factors. Still, investments in 2022 represented almost a quarter of all-time funding, and funding grew in APAC (by 67%), Europe (37%), and the Middle East & Africa (26x). Additionally, the number of unique investors in fermentation grew by 38 percent to 713 investors, a trend likely to continue in 2023 given investors' growing interest in the microbial fermentation market opportunity and environmental, social, and governance-aligned investment.

Table 1: Invested capital in fermentation

Category	2022	2013–2022	Highlights
Total invested capital	$842 MM	$3.69B	From 2013 to 2022, investments in fermentation-derived proteins tripled on average annually.
Invested capital deal count	89	301	2022's largest investment was $150MM (Meati Foods).
Unique investors	196 new	713	The number of new, unique investors grew by 38% in 2022.
Growth-stage fundraising (Series B and above)	5	23	2022 fermentation industry growth-stage fundraising totaled $398MM.
Liquidity events	$0	$1.50B	While no liquidity events occurred in 2022, plant molecular farming company Moolec Science went public via a special purpose acquisition company (SPAC) and began trading on the NASDAQ on January 3, 2023.

Science and technology

Research and development

- The **DSMZ culture collection** published Mediadive, an open-source database to help researchers bioprospect novel strains for use in microbial fermentation.
- Startup **Shiru** pioneered the use of AI and machine learning to aid development of animal-free egg prototypes.
- **Aqua Cultured Foods**, who produce seafood alternatives, doubled their production output through bioprocess improvements.

Environmental and social impact

- Six different teams of researchers published findings on using side streams as feedstock for microbial fermentation, further documenting alternative proteins' role in circular economies.
- Researchers found that replacing just 20% of per-capita beef consumption with microbial protein from sugar-fed fermentation by 2050 would be sufficient to reduce deforestation and related emissions by 50 percent.

Government and regulation

Investments and funding

- Europe funneled more than $155 million into cellular agriculture research and commercialization, including microbial fermentation and cultivated foods. The Netherlands announced a record-breaking $65 million investment in cell agriculture and the completion of one of the world's largest protein facilities, supported by public and private funding.
- The United States supported cellular agriculture at the federal and state levels, including $5.5 million for alt protein research through USDA and a state-level tax credit to support **Perfect Day**'s construction of a precision fermentation facility in Salt Lake City from the Utah Governor's Office of Economic Opportunity.
- The UAE supported the construction of a precision fermentation facility in Abu Dhabi, to be operated by U.S.-based **Change Foods**. The facility will create casein, the key protein in cheese, using 1/10th of the water and 1/5th of the energy required by conventional dairy production.
- The Israel Innovation Authority issued a NIS 50 million ($14.4MM) request for proposals for precision fermentation infrastructure, designed to enable multiple companies to share R&D facilities.

Section 1

Overview of fermentation

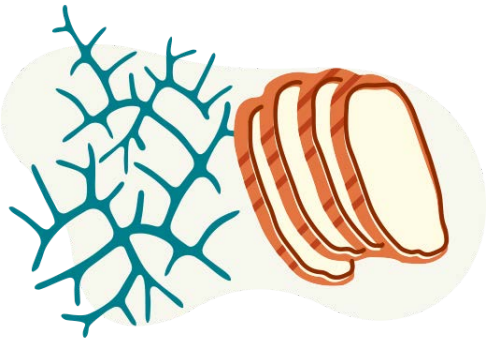
Section 1: Introduction

In the alternative protein industry, fermentation refers to cultivating microbial organisms for the purpose of processing a foodstuff or food ingredient; obtaining more of the organism itself as a primary source of protein; or deriving specialized ingredients, such as flavorings, enzymes, proteins, and fats, for incorporation into plant-based products or cultivated meat.

Traditional vs. biomass vs. precision fermentation

The alternative protein industry uses fermentation in three primary ways:

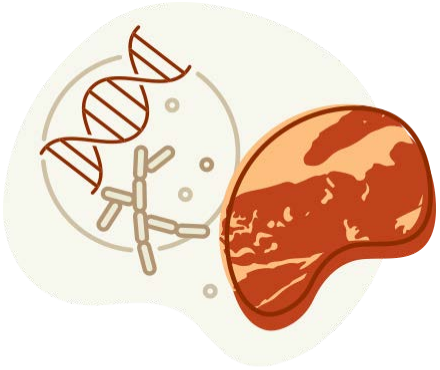
Traditional fermentation has been used for thousands of years to produce items such as bread and beer. It uses intact, live microorganisms to modulate and process plant-derived ingredients, resulting in products with unique flavor and nutritional profiles and modified texture. Examples of this include using the fungus *Rhizopus* to ferment soybeans into tempeh and using various lactic acid bacteria to produce cheese and yogurt. Traditional fermentation can improve the sensory, functional, and nutritional attributes of many alternative protein ingredients. The majority of companies using traditional fermentation, such as in cheese production, can be found in GFI's 2022 State of the Industry Report: *Plant-based meat, seafood, eggs, and dairy*.



Biomass fermentation leverages the fast growth and high-protein content of microorganisms to produce large quantities of protein efficiently. Biomass fermentation offers the greatest opportunity to produce protein at scale owing to the ability of many microorganisms to grow quickly and efficiently, often doubling their weight in just a few hours. The microbial biomass itself can serve as an ingredient, with the cells intact or minimally processed. An example of minimal processing is when the cells of microorganisms are broken open to improve

digestibility or to enrich ingredients for even higher protein content. Microbial biomass can be the main ingredient of a food product or serve as one of several ingredients in a blend. Seventy percent of known biomass fermentation companies focus on developing ingredients and inputs for alternative protein end products.

A range of microorganisms is being explored for their applications in biomass fermentation, from yeast to filamentous fungi to microalgae. An increasing number of biomass companies are focusing on microalgae that are grown without sunlight and are instead fed sugar, known as heterotrophic growth.



Precision fermentation is a form of specialized brewing that uses microbes as "cell factories" for producing specific functional ingredients. Capable of producing proteins, vitamins, enzymes, natural pigments, and fats, precision fermentation is well-positioned to create high-value ingredients that improve the sensory characteristics and functional attributes of plant-based products or cultivated meat.

Precision fermentation can be used to make products like egg proteins, dairy proteins, pepsin, animal-free meat proteins including heme, and fats. Proteins like myoglobin give meat its signature taste and aroma, and incorporating these proteins into plant-based products can help companies develop products that more closely resemble conventional ones.

A spectrum of fermentation approaches and products

While fermentation is generally divided into products of traditional fermentation, biomass, and functional ingredients (produced via precision fermentation), how they relate is best understood along a spectrum of overlapping solutions. Some biomass products also impart special functionality to the end product, and some functional ingredients make up a significant portion of an end product's mass. Alternative protein end products can also use ingredients created from different production pillars (plant-based, cultivated, and fermentation-derived) to develop hybrid products with enhanced functionality, taste, and texture.

The following figures illustrate the fermentation sector as it relates to alternative proteins and highlight this landscape of possibilities for fermentation-enabled proteins.

Figure 3: A conceptual landscape of fermentation-derived and fermentation-enabled products

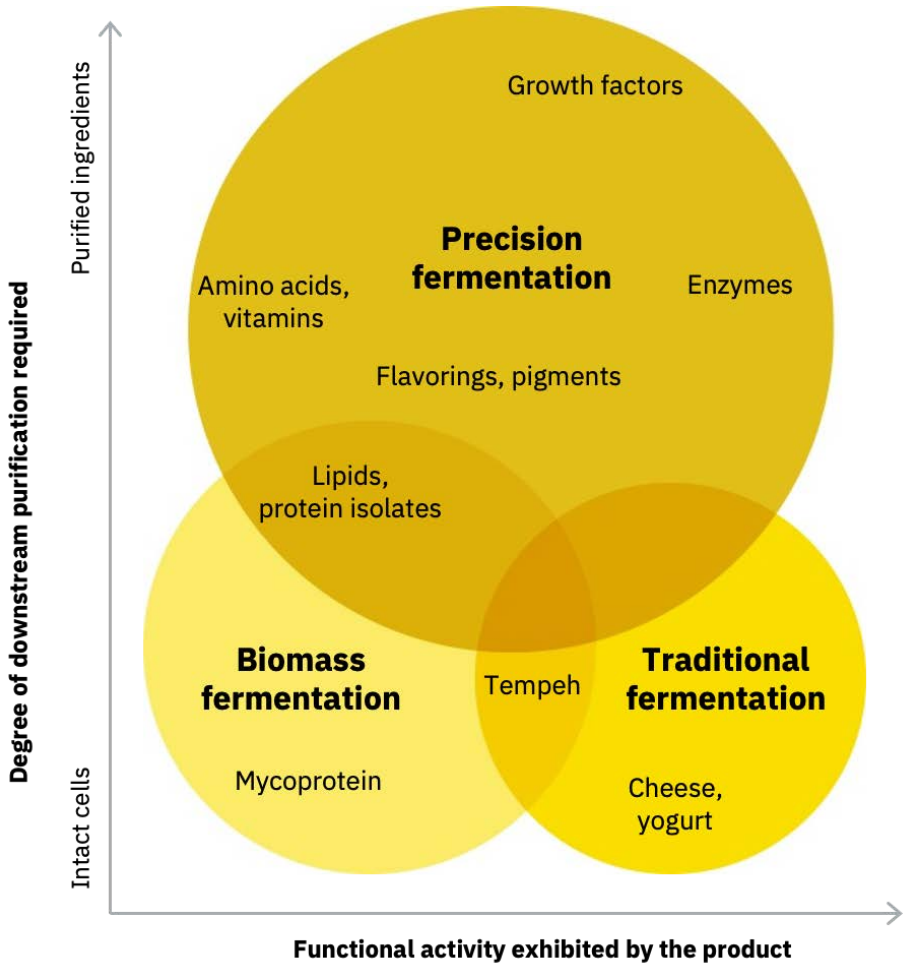
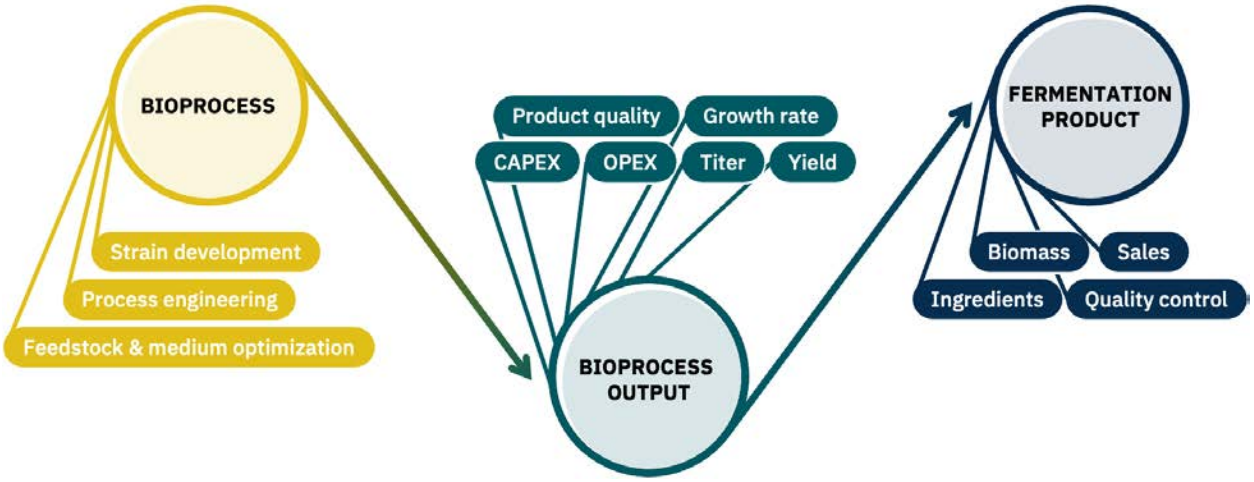
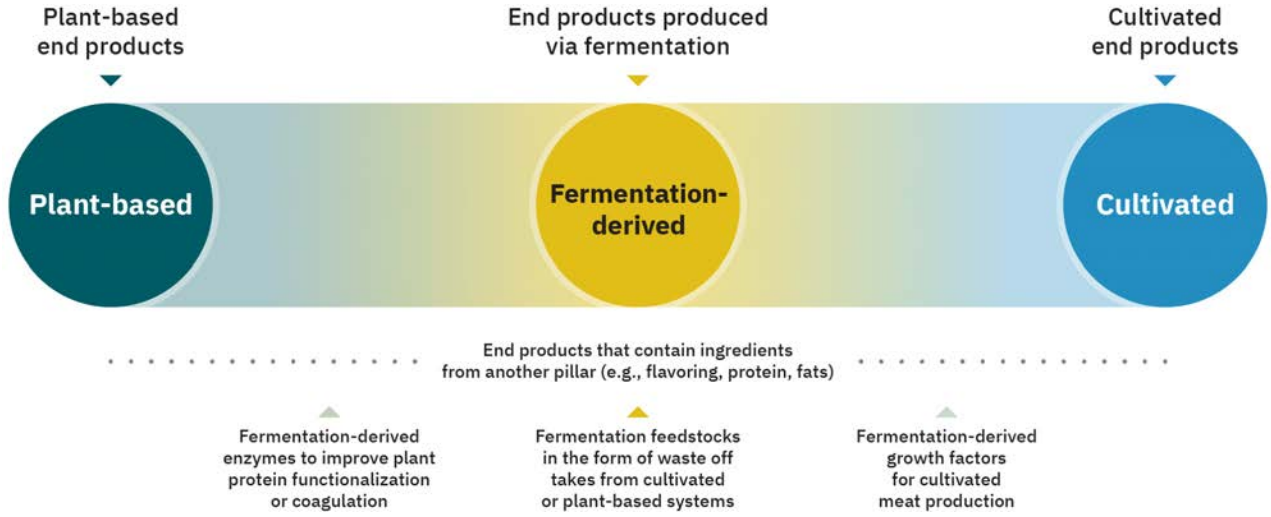


Figure 4: Fermentation in the alternative protein industry



Fermentation companies can leverage diverse production platforms, organisms, and feedstocks to deliver protein, fat, and functional elements—such as structure and texture—for a broad set of animal-free meat, egg, and dairy products.

Figure 5: A spectrum of hybrid fermentation-enabled end products



Increasingly, hybrid products are coming to market that combine ingredients from across alternative protein production platforms. An example of this is the Impossible Burger. Impossible Foods incorporates soy leghemoglobin produced via precision fermentation into their plant-based burger to give the finished product a meatier taste and appearance. Figure 3 demonstrates the range of end products that can be produced using inputs from each production pillar.

In this report, we provide an overview of companies working in the fermentation-enabled alternative protein sector either as their core function or as part of a broader business initiative. All company references are purely illustrative, and while intended to be comprehensive, lists are not exhaustive. Rather, they offer a snapshot of the broad range of companies and technology applications for fermentation. Table 1 outlines the types of companies included in this report.

Table 2: Types of companies included in report scope

Included	○ Microbes (bacteria, microalgae, protists, and single-cell fungi) used to produce edible biomass or functional ingredients for plant-based meat, eggs, and dairy, as well as functional ingredients for cultivated meat (such as cell growth factors). ○ Mycelium to produce edible biomass or functional ingredients for plant-based meat, eggs, and dairy. ○ Fermentation to produce pet food (which is highly relevant to human food applications).

Note: Companies that produce other ingredients conventionally derived from animals, such as honey, collagen, and gelatin, are highlighted in the commercial landscape but not included in counts of alternative protein-focused companies or investment calculations.

Not included

- Fermentation to produce food ingredients that are not replacements for meat, eggs, or dairy (such as sweeteners and baking enzymes).
- Fermentation to produce food items other than for humans or pets.
- Fermentation to produce molecules for other non-food applications (such as biofertilizer, farmed animal feed, aquaculture feed, chemicals, biofuel, cosmetics, and biologics).
- Large corporations with R&D efforts in fermentation that are not publicly disclosed, as well as startup companies in "stealth mode."
- Nut-based and other fermented cheese and butter made from plants (such as Miyoko's Creamery), which are covered in GFI's State of the Industry Report: Plant-based meat, eggs, and dairy.
- Tempeh and other traditional fermented foods, such as sourdough or kimchi, which are not analogs for meat, egg, or dairy products.
- Mushrooms (the fruiting bodies of some fungi).
- Macroalgae (such as kelp, seaweed, dulse, and sea vegetables).
- Nonprofit organizations and academic research labs.

Note: Companies with current applications of fermentation technology for alternative proteins and lipids as part of a broader business are included in Table 4 but not in investment calculations.

For more background on fermentation, its definitions, and its applications, check out GFI's fermentation page.

Section 2

Commercial landscape

Section 2: Commercial landscape

Overview

While the power of fermentation has been used to modify, enrich, and preserve foods for millennia—and to produce vitamins, supplements, and medicines in recent decades—using fermentation to mimic or recreate animal proteins is relatively new. Nearly 57 percent of the 136 companies focused on fermentation for alternative proteins were founded in the past three years, and the first animal-free dairy products only hit store shelves in 2020.

While still in its early stages, the fermentation industry has made significant progress in a short amount of time. There are now at least 30 animal-free dairy SKUs available at retail in the United States with more products in development. Fermentation companies span 31 countries and every major world region. And manufacturers are finding new ways to collaborate, including through an industry association and a number of strategic partnerships.

In 2022:

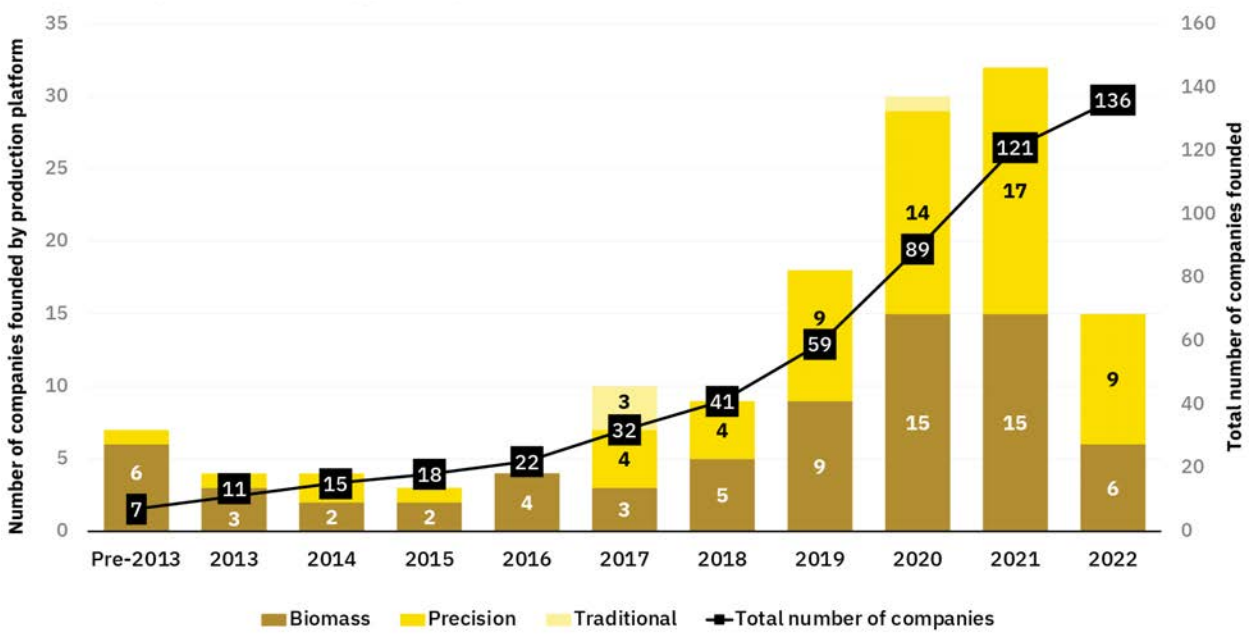
- At least 100 other companies from across the food, life science, pharmaceutical, nutrition, and agricultural industries are developing fermentation specifically for use in the alternative proteins industry.
- GFI and ProVeg joined 12 food companies as founding members of a new Fungi Protein Association, marking an important milestone in the industry's development.
- Companies collaborated to scale up and develop new products: We count 19 new strategic partnerships in 2022.
- A number of companies announced new or expanded facilities, bringing the number of known company-owned facilities to 17.
- A number of fermentation-enabled products launched to consumers for the first time, including mycelium steak and bacon, biomass protein breakfast sausages, macarons made with animal-free eggs, and a big expansion in animal-free dairy.

Fermentation ventures

Today, there are 136 companies focused primarily on fermentation for alternative proteins, and more than 100 additional companies have joined the industry through partnerships or business-to-business (B2B) product/service offerings.

Over the past year, we saw the launch of a number of B2B companies focused on solving key challenges in fermentation. For example, Liberation Labs, Planetary, and Boston Bioworks, all founded in 2022, focus on developing production capacity, currently a major bottleneck in precision fermentation. HERLab, founded by GFI's 2022-2023 Entrepreneur-in-Residence, and New Wave Biotech focus on precision fermentation strain discovery and optimizing downstream processing, respectively. Companies focused on end-product formulation and manufacturing currently represent a huge share of fermentation companies, but we expect to see more companies specialize in one or two stages of the technology stack as the industry matures.

Figure 6: New and total number of fermentation companies



Sources: GFI company database, PitchBook Data, Inc., Crunchbase, manufacturer websites.

This graphic includes all publicly announced fermentation companies that GFI is aware of, but it may not include all fermentation companies founded in 2022 as many companies begin in stealth mode. For example, in our 2021 Fermentation Report, we reported that 15 new companies were founded in 2021, and that number has since increased to 34 as companies founded in 2021 launched out of stealth mode in 2022. We anticipate that the 15 companies founded and announced so far in 2022 is similarly an underestimate, and we expect more companies founded in 2022 to announce their work in 2023. Readers can refer to GFI's company database for an up-to-date count of announced cultivated meat companies.

Table 3: Distribution of companies by country and region

Africa and Middle East					Count 12
Israel	11	South Africa	1		
Asia Pacific					Count 21
Australia	3	New Zealand	3	South Korea	1
China	3	Malaysia	1	Vietnam	1
India	3	Singapore	6		
Europe					Count 55
Austria	2	France	6	Spain	6
Belgium	5	Germany	10	Sweden	3
Denmark	2	Ireland	1	Switzerland	2
Estonia	2	The Netherlands	4	Turkey	1
Finland	3	Norway	1	United Kingdom	7
Latin America					Count 3
Argentina	1	Brazil	1	Chile	1
North America					Count 45
Canada	3	United States	42		

1–9 companies 10–19 companies 20+ companies

Figure 7: Number of companies by type of fermentation

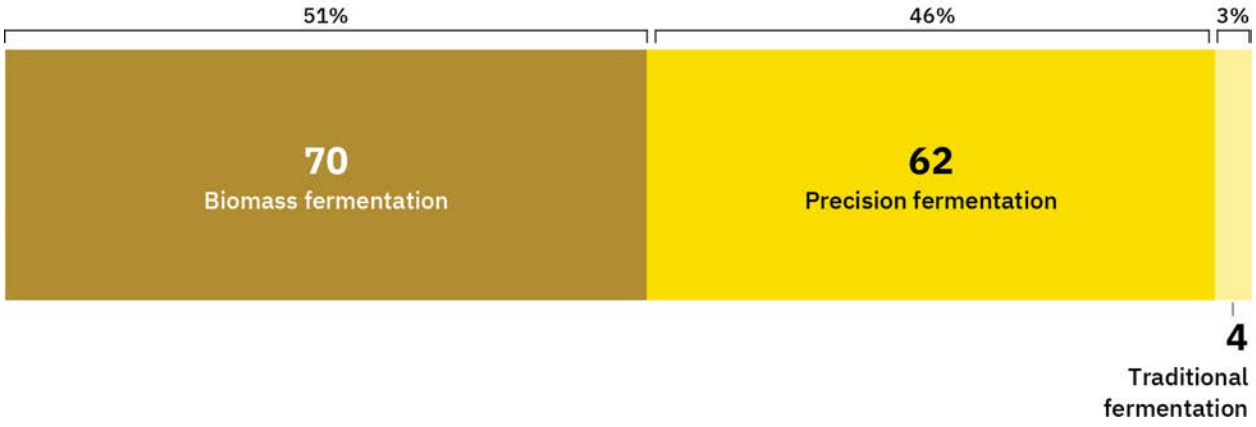


Table 4: Sampling of companies focused on fermentation for animal-free meat, seafood, eggs, and dairy (ordered alphabetically)

Company	Brief Description	Year Founded	Website	Company Focus	Protein Category
70/30 Food Sci & Tech	Shanghai-based mycelium protein compan...	2022	https://7030foodtech.com/	Meat	Biomass fermentation
Adamo Foods	UK-based company working on fungi-base...	2022	https://www.adamofoods....	Meat	Biomass fermentation
Air Protein	U.S.-based startup focusing on using a clo...	2019	https://www.airprotein.co...	Ingredients and inputs M	Biomass fermentation
Algama	Platform for microalgae-based plant-based...	2013	http://algamafoods.com/	Food processing infrast...	Biomass fermentation
Algenuity	UK-based company that provides microalg...	2009	https://www.algenuity.com/	Ingredients and inputs	Plant-based Biomass fer
Algrow Biosciences	Singapore-based company creating alterna...	2022	https://algrowbiosciences...	Dairy	Plant-based Biomass fer
All G Foods	Australia-based company that produces pl...	2020	https://allgfoods.com	Meat Dairy	Precision fermentation Pl
Aqua Cultured Foods	U.S.-based company that produces whole-...	2021	https://www.aquacultured...	Seafood	Biomass fermentation
Arkeon Biotechnologies	Austria-based company using gas ferment...	2021	https://arkeon.bio/	Ingredients and inputs M	Biomass fermentation
Arxada	With 26 manufacturing sites, we help our c...	1899	https://www.arxada.com	Contract manufacturing...	Fermentation-derived Bio
Asterix Foods	Israel-based company using plant cell cult...	2022	https://pitchbook.com/pr...	Ingredients and inputs	Plant molecular farming
Balletic Foods	Startup working on creating proteins desig...	2017	http://www.balleticfoods....	Meat	Precision fermentation
Better Dairy	UK-based company producing animal-free ...	2019	https://betterdairy.co.uk/	Dairy	Precision fermentation
betterland foods	US-based company that develops and man...	2021	https://www.betterlandfo...	Dairy Other	Plant-based Precision fer
BioBrew	BioBrew, division of ZX Ventures, is a techn...	2019	https://biobrew.com/	Bioprocessing infrastru...	Precision fermentation
Bolder Foods	Combined fermentation and plant-based te...	2014	https://www.bolderfoods....	Dairy	Biomass fermentation

For a full list of companies focused primarily on fermentation for alternative protein applications, please visit this link.

You can learn more about these companies in the GFI company database. Are we missing something? Let us know by filling out our company database edits form.

Highlight

Plant molecular farming: Plants as a scalable expression platform

Plant molecular farming is a potential fourth pillar of alternative protein production that combines plant agriculture and techniques similar to those used in precision fermentation to enable the production of animal proteins in plants, like dairy or egg proteins. This process allows the production of alternative proteins inside a plant using photosynthesis and well-established farming techniques.

Nomenclature note: For consistency, we've repeatedly referred to this technology as "plant molecular farming" throughout this and other reports. However, like in any emerging industry, the language used to explain the technology, the terms adopted in the business landscape, and the terms eventually used for describing end products to consumers may vary and coalesce as the industry grows. Thus far, companies have used different terms to describe their products. For example, **Nobell Foods**, which uses this technique to make casein using soybeans, describes their process as using "plant grown proteins," and refers to their final product as "animal-free cheese," the same nomenclature used by precision fermentation dairy companies to describe their product to consumers.

Currently, 12 known companies are advancing plant molecular farming for the alternative protein sector. Here are a few examples of product approaches:

- **Forte Protein** uses plants to produce lactoferrin, casein, albumen, collagen, and myosin.
- **Miruku** produces animal-free dairy proteins for use in cheese, ice cream, and yogurts.
- **Tiamet Sciences** creates growth factors for cultivated meat media and medicine.

Additional companies applying molecular farming to develop alternative protein ingredients and cultivated meat media include **Greenovation Protein**, **Nobell Foods**, **Mozza**, **Bright Biotech**, **Imagene**, **Moolec Science**, **Veloz Bio, Asterix Foods**, and **PoLoPo.**

A note on categorization: Plant molecular farming is an emerging area within the alternative protein production landscape that does not fit neatly into any of the three pillars: plant-based, cultivated, or fermentation. Although it is not a fermentation technology, it is being included separately in this state of the industry report because of its similarity to precision microbial fermentation in terms of the range of potential products it can provide.

"The need for more sustainable ways of production is increasing the demand for plant molecular farming products. Long-term, I see plant molecular farming used in many different species to provide a variety of products and applications. I think this technology has the potential to go beyond what biomanufacturing has achieved so far for complex products."

– France-Emmanuelle Adil
Co-founder & CEO, Tiamet Sciences

Involvement from conventional meat and food companies

Involvement from existing meat and food producers can serve as a force multiplier for the industry. These companies already have funding, infrastructure, and distribution access. Incumbent companies can enter the industry through partnerships, investment, acquisition, purchasing ingredients made through fermentation, or selling inputs or services to startups.

All of the top five U.S. meat companies as well as the top five U.S. consumer packaged goods (CPG) food companies are involved with alternative proteins in some capacity. As of 2022, three of the top meat companies and three of the top CPG companies are publicly involved in the fermentation industry.

In 2022:

- **Tyson** invested in mycelium startup **MycoTechnology** through their venture arm, Tyson Ventures.

In 2021:

- **Kraft Heinz** invested in animal-free dairy startup **New Culture Foods** through their Evolv Ventures venture arm.
- AB InBev-backed **BioBrew** partnered with animal-free protein company **The EVERY Company** to support the scale-up of The EVERY Company's precision fermentation process.
- **General Mills** launched precision fermentation-enabled cream cheese under their new brand Bold Cultr in partnership with Israel-based startup **Remilk**.
- **Cargill** partnered with biomass fermentation startup **ENOUGH** to support the construction of a facility next to a Cargill site in the Netherlands and supply the facility with feedstock, an agreement that will cut down on transportation miles.
- **Hormel** partnered with **The Better Meat Co**. to codevelop products with The Better Meat Co.'s Rhiza mycoprotein ingredient.

Multiple major food companies launched or teased products made with animal-free dairy in 2022, a particularly active year for precision fermentation progress:

- **Nestlé** partnered with precision fermentation company **Perfect Day** to launch Cowabunga, a milk made with animal-free whey, in **Safeway** stores in California.
- **Unilever** announced that they are developing a precision fermentation dairy product and may launch animal-free ice cream in 2023.
- **Bel Group**, maker of Babybel cheese, announced a partnership with **Standing Ovation**, a Paris-based precision fermentation company that produces animal-free casein, and with **Superbrewed** to develop fermentation-enabled cheese.

Table 5: Conventional companies with involvement in alternative proteins

Table 6: Conventional meat and food companies with involvement in fermentation

Partnerships

Collaborations between companies focused on research, production, and distribution are key to scaling the fermentation sector. Notably, 2022 saw a number of new partnerships focused on either end-product development or bioprocess scaling, both critical for the mainstream adoption of fermentation-enabled products. Here are a few of the year's publicly announced partnerships (in chronological order):

- Mycelium company **MyForest Foods** (formerly Atlast Food Co.) announced a partnership with **Whitecrest Mushrooms Ltd.** to scale up production of MyForest's MyBacon strips.
- Precision fermentation company **Change Foods** entered into two strategic partnerships: one with Violife owner **Upfield**, and one with international yogurt and cheese company **Sigma**. The partnerships aim to accelerate product development and support production and distribution scale-up.
- Precision fermentation company **Formo** and established biotechnology supplier **Brain Biotech** announced a partnership to scale up Formo's animal-free dairy protein production.
- Ingredient manufacturer **CP Kelco** announced a partnership with California-based fermentation startup **Shiru** to scale up the production of ingredients made with precision fermentation, starting with an emulsifying ingredient with the same functionality as methylcellulose.

- Fermentation startup **Motif Foodworks** announced a strategic partnership and investment with microfluidics company **NemaLife** to use NemaLife's platform for in-vivo testing and protein characterization.
- Israel-based cultivated meat company **Steakholder Foods** (formerly MeaTech 3D) announced that their subsidiary **Peace of Meat** signed a strategic agreement with mycoprotein company **ENOUGH** to develop hybrid cultivated and fermentation-based products.
- Sweden-based agriculture company **Lantmännen Cerealia** formed a partnership with mycelium protein company **Mycorena**. **The partnership will focus on upcycling food waste to create fermentation-enabled protein ingredients.**
- France-based alternative dairy startup **Bon Vivant** formed a strategic partnership with large biotech company **Abolis** to scale up the production of Bon Vivant's animal-free dairy produced through precision fermentation.
- Animal-free dairy startup **Remilk** partnered with Israel-based **CBC Group**, who bottles Coca-Cola and owns dairy processor **Tara Dairy**, to develop a line of drinks, cheeses, and yogurts using Remilk's precision fermentation dairy protein.
- **India-based biotechnology company String Bio has partnered with Australia-based Woodside Energy Technologies to develop a platform to convert trapped methane emissions into protein.**
- Animal-free dairy company **New Culture** partnered with large agricultural company **ADM**, enabling New Culture to access ADM's product development resources, ingredients, and manufacturing infrastructure.
- Fermentation startup **Shiru** announced a new partnership with **Puratos**, a baked goods company, to develop functional animal-free egg prototypes.
- Plant-based startup **Peas of Heaven** partnered with mycoprotein company **Mycorena**, based in Sweden, to launch a new range of frozen pea and mycelium-based plant-based meats.
- Finland-based **Rebl Eats** partnered with **Mycorena** to formulate new cobranded dishes with Mycorena's flagship mushroom-based ingredient, **Promyc.**
- **Motif FoodWorks** partnered with Norway's **Vectron Biosolutions** to use precision fermentation to develop technologies that improve the taste and texture of dairy alternatives and the nutrition of plant-based foods.

- Fermentation startup **Aqua Cultured Foods** partnered with hospitality and catering company SV Group to launch Aqua Cultured's alternative seafood products in smart fridges, cafeterias, and event venues across Switzerland.
- Plant-based startup **Vgarden** and microalgae alternative protein supplier **Brevel** announced a partnership to develop microalgae-based cheese.
- Delaware's **Ergo Bioscience** announced a partnership with Italy's **Aethera Biotech** to scale their precision fermentation bioprocesses.
- **CJ CheilJedang**, a large food manufacturing company that owns **Schwan's Company**, recently partnered with **New Culture**, a California-based food startup that makes dairy-free cheese using precision fermentation.
- **Fermify**, an Austria-based precision fermentation company, announced a collaboration with **Bilfinger Life Science** to scale the production of animal-free milk proteins.
- Israel's **ICL Food Specialties**, who produces plant-based food ingredients, and Chile's **Protera Biosciences**, who specializes in precision fermentation, have partnered to develop sustainable protein-based ingredients using precision fermentation.

Industry associations

Unlike the plant-based and cultivated industries, the fermentation industry has lacked any formal industry organization or trade association—until recently. In a notable development, 12 companies and two nonprofits, including GFI, united to form the Fungi Protein Association.

The new trade body will advocate for equitable and transparent policies for fungi proteins and conduct consumer research. Founding members include **GFI, ProVeg, Quorn**, **Nature's Fynd**, **ENOUGH**, **The Better Meat Co.**, **The Protein Brewery**, **Prime Roots**, **MycoTechnology**, **Mycorena**, **Aqua Cultured Foods**, **Mush Foods**, **MyForest Foods**, and **Bosque Foods.**

In early 2023, nine precision fermentation companies across the globe—**Change Foods**, **The EVERY Company**, **Helaina**, **Imagindairy**, **Motif Foodworks**, **New Culture**, **Onego Bio**, **Perfect Day**, and **Remilk**—became the founding members of the first-ever Precision Fermentation Alliance. The alliance will focus on regulatory engagement, advocacy, and marketing and communications.

Facilities

Manufacturing capacity is one of the most significant bottlenecks in the fermentation industry, particularly for precision fermentation. In 2022, the National Academies of Sciences highlighted the needs and opportunities for capacity increases for biomanufacturing, including fermentation for alternative proteins.

Today, many existing precision fermentation facilities are configured for pharmaceutical production rather than food production and thus support a smaller equipment scale and higher staffing level than would be needed for food production. Because it's often easier and more cost-effective for new food companies to use contract manufacturing facilities, startups must compete for a limited number of facilities, many of which aren't fully optimized for food production. While limited manufacturing capacity remains an obstacle to industry growth, 2022 brought encouraging developments:

- **Synonym Bio** launched Capacitor, a free, open-access global database of available fermentation capacity. GFI served as a thought partner in the development of the tool.
- The **California Biomanufacturing Center**, a public-private partnership focused on biomanufacturing, launched the **BioProcess to Product** (BioP2P) Network, a consortium of companies, researchers, and government agencies working together to scale products commercially.
- Two startups, Liberation Labs and Planetary, launched out of stealth mode and secured funding to build contract manufacturing facilities tailored for precision fermentation for alternative proteins. The companies have also provided consulting to startups constructing their own facilities. After finalizing their $20 million seed round, Liberation Labs is focused on FEL-3 planning for their purpose-built 600,000-liter food precision fermentation facility in the U.S.
- Boston Bioprocess (formerly Boston Bioworks) launched out of stealth mode. The startup offers benchtop and pilot-scale fermentation bioprocess development.

In addition to the above initiatives and startups focused on solving the manufacturing bottleneck for multiple companies, a number of end-product and ingredient companies opened or announced their own new facilities.

Facilities that opened in 2022:

- Mycoprotein producer **ENOUGH** opened their flagship production facility in the Netherlands. The facility is 15,000 square meters and has an initial capacity of 10,000 tons per year, with plans to scale to 60,000 tons by 2027.

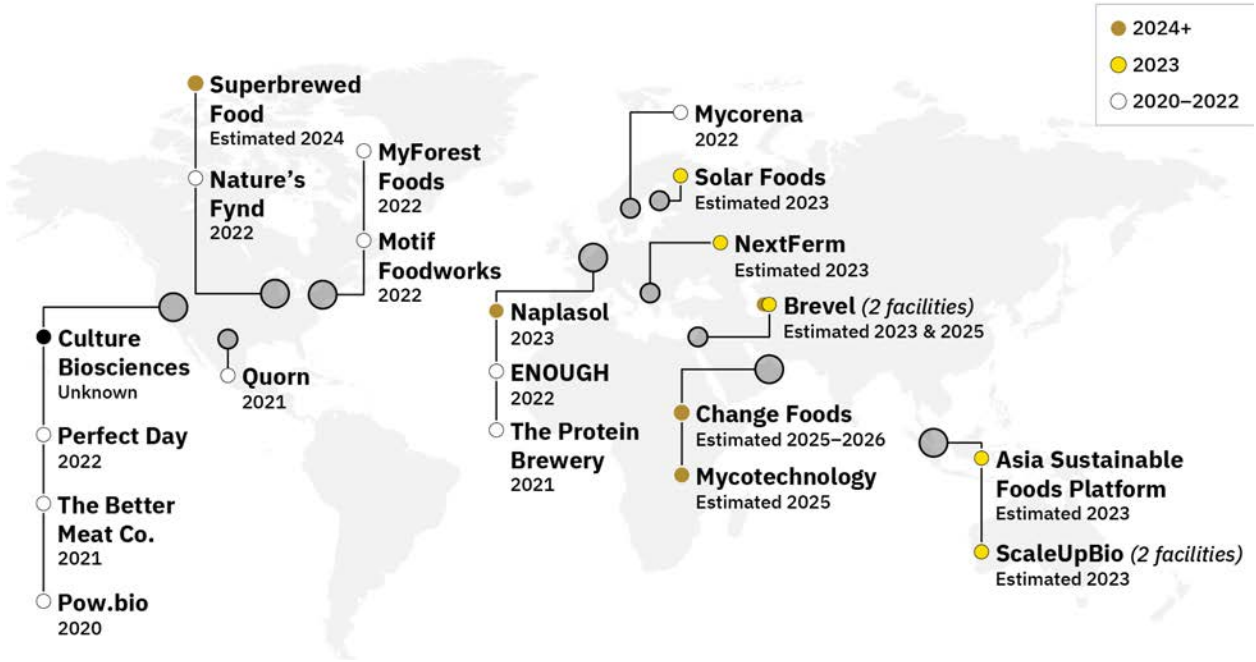
- **MyForest Foods**, producer of the mycelium-based MyBacon, announced the opening of Swersey Silos, a 120,000-square-foot vertical farm dedicated to scaling MyBacon. The facility can produce three million pounds of mushroom bacon per year.
- Fermentation company **Mycorena** expanded their mycoprotein production facility in Gothenburg, Sweden. The company says that the facility, which includes office headquarters, fermentation facilities, a development kitchen, and a pilot production line, is the largest in Europe, with an annual capacity of "thousands of tons."

Facilities that were announced in 2022:

- Fermentation company **MycoTechnology** and the **Oman Investment Authority** partnered to build a production facility in Oman to scale up MycoTechnology's mycelium protein.
- Microalgae protein company **Brevel** reached an agreement with **Kibbutz Yotvata**, who runs the Yotvata Dairy Plant, to build a fermentation facility in Israel.
- Israel-based fermentation company **NextFerm** announced a new protein production facility in the Balkan region.
- **ScaleUp Bio**, a joint venture between large ingredients company **ADM** and **Nurasa** (formerly known as Asia Sustainable Foods Platform), plans to open two precision fermentation facilities in Singapore.
- Animal-free dairy company **Change Foods** plans to open a manufacturing facility in Abu Dhabi with support from the **UAE Ministry of Economy**'s NextGen FDI Initiative.
- Fermentation manufacturing startup **Planetary** partnered with **Glatt** and **IE Group** to design the world's first integrated precision and mycelium fermentation plant in Switzerland.
- Israeli precision fermentation dairy company **Remilk** announced plans to build a 75,000-sq.-m (750K sq. ft) production facility in Denmark for their animal-free dairy product.
- **Superbrewed Foods** made progress on retrofitting a former ethanol plant, the design of which is well-suited for their anaerobic bacterium single-cell protein technology.

Notably, two of the facilities announced in 2022 had government support (**Change Foods** through the UAE's NextGen FDI program and **MycoTechnology** through Oman's sovereign wealth fund). **Public-private partnerships provide an opportunity to fund facilities that may be less attractive to venture capital.**

Figure 8: Current and future fermentation facilities



Product launches

In 2022, consumers were able to try more alternative protein products made with fermentation than ever before. The most developed fermentation product category thus far is dairy, but other products launched across a number of categories in the past year, signaling even more innovation and delicious products ahead:

Meat

Fermentation can be used both to enhance plant-based or cultivated meat products with individual ingredients that replicate the sensory properties of meat (think: heme produced by Motif Foodworks or Impossible Foods) and as the main protein base for plant-based or cultivated meat products (think: mycelium-based meats). In 2022, mycelium meat had a moment, with a number of mycelium-based products launching for the first time.

- Biomass fermentation company **Meati Foods** launched four mycelium-based steak and cutlet products direct-to-consumer across the United States, as well as in **Sprouts Farmers Market** stores and at **Birdcall**, a chicken sandwich franchise.
- **MyForest Foods**, formerly known as Atlast Food Co., launched their mycelium MyBacon to specialty grocers in New York and Massachusetts.
- Fermentation startup **The Better Meat Co.** launched foie gras made with mycelium-derived protein in U.S. restaurants.
- **Prime Roots**, who produce mycelium-based deli products, launched their line of mycelium Koji-Meats to select deli counters and sandwich shops in the San Francisco Bay Area.
- **Sempera Organics** launched their mushroom-based meat product, Mamu, to restaurants in the San Francisco Bay Area.
- **Nature's Fynd** launched meatless breakfast patties made with their proprietary Fy fungi protein at select **Whole Foods** locations.

Dairy

Precision fermentation allows manufacturers to use genuine dairy in their products without the footprint of conventional dairy. While there are currently 28 companies working on precision fermentation dairy (according to GFI's company database), Perfect Day's products are the most widely commercialized. Applications for precision fermentation dairy expanded in 2022 as a number of companies launched new products made with Perfect Day's whey protein ingredient, which the company sells B2B:

Chocolate

- **Betterland Foods** debuted the world's first animal-free dairy chocolate bar.
- International candy company **Mars, Inc.** launched the company's first chocolate made with animal-free dairy.

Protein powder

- Nutrition brand **Natreve** launched **MOOLESS** animal-free whey protein in 690 **Vitamin Shoppe** stores across the United States.
- Texas-based juice bar **Juiceland** added animal-free whey protein to their menu - a return to whey after removing it from their menus.
- **Myprotein** launched an animal-free whey protein brand, Whey Forward.

Ice cream

- Ice cream brands **Brave Robot** and **Coolhaus** partnered to launch an animal-free ice cream sandwich, which debuted in two flavors at **Kroger** stores across the United States. Coolhaus also expanded the distribution of their animal-free ice cream to Singapore.

Milk

- **Tomorrow Farms** launched an animal-free milk brand, Bored Cow, in the United States.
- **Nestlé** launched a trial of animal-free milk, Cowabunga, in Bay Area Safeway locations.
- Shelf-stable conventional milk company **Strive Nutrition**, based in Kansas, launched a new line of animal-free milk.
- **Betterland Milk** launched animal-free milk in the U.S.
- **Very Dairy** became the first animal-free milk brand to hit supermarkets in Asia.

Cream cheese

- Large conventional dairy product company **Bel Brands USA** launched animal-free cream cheese.
- **Modern Kitchen**, a brand by Perfect Day subsidiary **Urgent Company**, launched direct-to-consumer animal-free cream cheese.

Animal-free whey isn't the only ingredient that can be used to create fermentation-enabled dairy analog products. Biomass fermentation company **Nature's Fynd** produces a versatile fungi protein called Fy that can be used in both meat and dairy products. In 2022, the company launched dairy-free cream cheese in **Sprouts** stores across the United States.

Eggs

Eggs are widely used in the food industry for their broad functionality. Producing egg proteins through precision fermentation can functionally and nutritionally mimic conventional egg ingredients. According to GFI's company database, there are only four companies working on precision fermentation egg proteins, and only one has commercialized their products:

- **The EVERY Company** launched their Every EggWhite product in macarons in a collaboration with patisserie brand **Chantal Guillon**.
- **The EVERY Company** also collaborated with alcohol company **Pulp Culture** to launch a line of hard juices featuring animal-free egg protein.

Hybrids

Fermentation is a versatile production platform that can produce alternative protein end products as well as inputs for plant-based and cultivated meat, eggs, and dairy.

For example, the Impossible Burger is made using a heme protein produced through precision fermentation. Other companies including **Motif Foodworks** and **Paleo** have developed heme protein for B2B sales. Companies like **Nourish Ingredients** and **Melt&Marble** are using fermentation to produce animal fats to enhance the taste and texture of plant-based meat. And companies using **Perfect Day**'s whey protein from fermentation—the first precision fermentation dairy available to consumers—combine dairy proteins with plant-based ingredients like coconut milk.

Ultimately, the alternative protein industry is all about producing delicious, familiar, and affordable food more sustainably, securely, and efficiently. We expect hybrid products produced with a combination of fermentation-derived, plant-based, and cultivated ingredients to become common in the near future. Particularly as the fermentation industry develops, using plant-based ingredients can help manufacturers lower end-product costs as they scale up processes.

New product types

The fermentation industry is still young, and there are plenty of product categories that don't yet have a fermentation-derived alternative on the market, but several companies made progress in 2022:

Meat and seafood

- Chicago-based fermentation company **Aqua Cultured Foods** revealed their first prototype: mycoprotein calamari. Aqua Cultured Foods also landed a distribution partnership with hospitality and catering company SV Group to launch their alternative seafood products—including popcorn shrimp, scallops, tuna, and whitefish—in smart fridges, cafeterias, and event venues across Switzerland.
- New York-based **Bosque Foods** showcased prototypes of mycelium-based pork and chicken fillets.
- **MycoTechnology Inc**. debuted their meatless crumbles, made with pea, rice, and mycelium fermentation, at the CES tech conference under the brand **Goodside Foods**.
- Barcelona-based **Libre Foods** debuted their mycelium/plant-based bacon.
- Brussels-based **Paleo** launched out of stealth mode with six different heme prototypes. Heme can be used to give plant-based a "meatier" taste and color, and Paleo plans to sell their heme B2B.

Dairy

- Belgium-based company **Those Vegan Cowboys** announced the development of their first product: cheese made with precision fermentation-derived casein.
- Singapore-based **TurtleTree Labs** announced the development of the first bovine lactoferrin, a dairy protein, created with precision fermentation.
- Sweden-based fermentation startup **Mycorena** announced the development of a mycoprotein-based butter prototype, which the company claims is the first mycoprotein butter.

"Biomass fermentation offers a unique opportunity to create a net new protein at a scale that can truly address future generations' needs for proteins. The efficiency of our microbes, leveraging existing agricultural input, will enable a more climate-resilient and resource-efficient food system. Achieving this vision will require a lot of cooperation; as microbe farmers, we are optimistic about what we can build together."

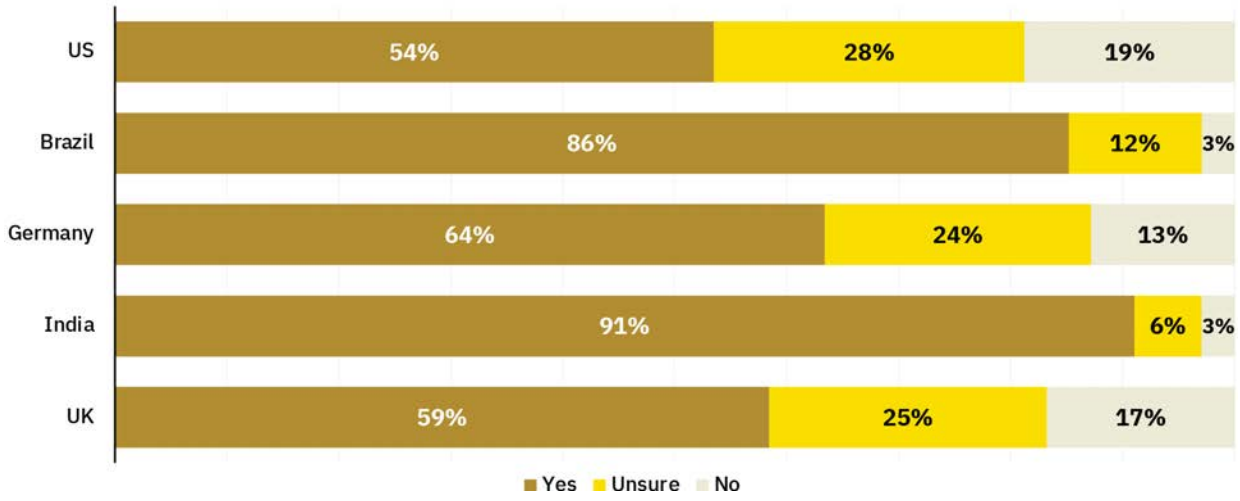
– Thomas Jonas, CEO & Co-founder, Nature's Fynd

Consumer research and insights

Consumer research focused on fermentation-derived proteins is limited compared to plant-based and cultivated meat. However, existing research points to strong consumer acceptance of fermentation-derived products.

One 2021 study surveyed consumers from five countries (Brazil, Germany, India, the United Kingdom, and the United States) about their feelings toward precision fermentation-derived cheese. Beyond simply being interested in trying animal-free cheese, the majority of consumers across all countries were willing to buy the product themselves. Within the United States, nearly four in 10 also reported a desire to buy it on a regular basis.

Figure 9: Consumer willingness to buy animal-free dairy cheese



However, a sizable proportion—from 9 to 47 percent, depending on the region—of consumers were unsure about their willingness to buy or eat animal-free cheese.

Similarly, a recent survey by Moonshot Collaborative found that nearly 50 percent of respondents said they did not know if they were interested in trying foods made from mycelium.

These surveys and others demonstrate an opportunity to build consumer awareness of these products and increase consumer education and marketing on the benefits of consuming foods made with fermentation to drive greater consumer understanding, acceptance, trial, and, ultimately, adoption.

Nomenclature

In early product launches, companies have begun to coalesce around the terms "animal-free" and "non-animal" when referring to proteins made with fermentation. This parallels "non-animal rennet," which is a widely used term by cheese manufacturers referring to rennet produced through precision fermentation (which is already standard practice—more than 90 percent of rennet is produced using precision fermentation).

"Animal-free" terminology is supported by survey research conducted by fermentation startup **Formo**, with most consumers noting that the term "animal-free" was straightforward and appealing. However, additional research will be needed to understand the impact of various naming conventions beyond the dairy category, particularly for biomass fermentation, which doesn't involve genuine animal ingredients, and can be made with a variety of inputs.

Future research

To further validate these findings and to understand the impact of various naming conventions, additional consumer research is needed. Some key areas of focus for both precision and biomass fermentation include:

- Motivations and barriers to consumption
- Consumer perceptions and attitudes
- Nomenclature
- Effective messaging
- Target consumer demographics

If you are interested in conducting or contributing to consumer research related to fermentation-derived products, please reach out to GFI directly at corporate@gfi.org.

"In the short term, the value of fermentation-based protein will be a wider variety of functionalities and organoleptic experiences for consumers and a wider range of solutions for food manufacturers. In the mid- and long-term, as the industry reaches further optimization and scale, we will reach a point where cost will finally tip the scales for good with fermentation-based ingredients becoming the first choice for food manufacturers with higher quality, a wide range of functionality, stable and accessible supply, and a stable and low cost."

– Yonatan Golan, CEO, Brevel

Are we missing something from this Commercial Landscape section? Did we get something wrong? We'd appreciate your feedback via this form.

The Good Food Institute is not a licensed investment or financial advisor, and nothing in the state of the industry report is intended or should be construed as investment advice.

Section 3

Investments

Section 3: Investments

Overview

From 2010 to 2022, alternative protein companies raised $14.2 billion, nearly doubling the amount invested on average every year, though with high variance from year to year. Following the first disclosed investment in a fermentation company in 2013, companies in the category have raised $3.7 billion, with investments on average tripling each year. This trend of rapid growth slowed in 2022, with funding for both alternative proteins as a whole and fermentation companies slowing alongside a broad global deceleration in investment across multiple sectors.

Globally, fermentation companies raised $842 million in 2022, representing a deceleration of 50 percent year-over-year (YOY) after record funding in 2021, yet also representing almost a quarter of all-time funding in the category. Funding in certain regions accelerated, rising in APAC (by 67%), Europe (37%), and the Middle East & Africa (24x). While in 2022 the sector underperformed the overall global venture funding decline of 35 percent YOY, investors shouldn't put too much stock into that comparison. Fermentation is a small market segment in which a handful of sizable raises drive most investment figures. For example, in 2021, a year of record funding for fermentation, two deals alone accounted for 41 percent of the year's total invested capital, and four deals accounted for 65 percent. Given that these four deals were raised by some of the most mature companies in this emerging market, which currently has only a handful of mature companies, this left few companies with a need to raise large rounds in 2022 (though **Meati** and **Remilk**, two other maturing companies, both raised rounds above $100 million).

This slowdown in investments took place amid challenging macroeconomic and market conditions, including falling public equity markets, steeply rising interest rates driven by elevated inflation, the ongoing pandemic, severe climate events, and the invasion of Ukraine. In fact, public equity markets fell by the most since the great financial crisis of 2008. Venture-capital-backed public companies performed especially poorly, with the PitchBook VC-backed IPO Index falling by more than 60 percent in 2022.

While this challenging market environment may continue for some time, the downturn itself and alternative proteins' status as an increasingly important environmental, social, and governance (ESG) opportunity provide potential upside for investors and the industry. Deal valuations are starting to come down, and startups are more willing to make term concessions, shifting dealmaking in investors' favor. Moreover, ESG interest remains high and private impact funds have $113 billion in dry powder (funds that have yet to be invested), creating a tailwind for alternative proteins, which are increasingly being viewed as an ESG-aligned sector.

The alternative protein industry—and the fermentation category in particular—is still in its early stages, and there are bright spots on the horizon:

- Increasing involvement of large food companies and food service providers, such as **Nestlé**, **Unilever**, and **Starbucks**, through product launches and partnerships (see the Commercial Landscape section for others) serve as de-risking events for investors who are increasingly taking notice of the category. The number of unique investors in fermentation grew by 38 percent to 713 investors in 2022.

- This investor base expansion may continue into this year. Investors who responded to GFI's 2022 Annual Investor Survey demonstrated an **elevated interest in investing in precision and biomass fermentation protein products, as well as fermentation-derived alternative fats and ingredients, in 2023.**

- Manufacturing capacity—a current bottleneck to scaling up fermentation processes and production—may start to see relief as well. Several B2B fermentation manufacturing companies, including **Liberation Labs**, **Planetary**, and **Synonym Biotechnologies**, raised seed rounds this year. In fact, Liberation Lab's seed round of $23.5 million was the second-largest seed round by a fermentation company to date.

Despite alternative proteins' clear ESG benefits, they currently face underinvestment as a climate, biodiversity, and food security solution. With just seven years until 2030—the milestone year by which global governments have committed to halving emissions—a transition toward alternative proteins must be accelerated to stay below 1.5°C of warming. In their paper What gets measured gets financed, the Rockefeller Foundation and Boston Consulting Group labeled alternative proteins as a critical climate mitigation solution and estimated that alternative proteins have an annual unmet funding need of more than $40 billion. Both private investors and governments are critical to ensure that alternative protein companies have the funding they need to alleviate the multiple crises facing the planet.

New ESG frameworks raise the bar on sustainability transparency of meat

In 2022, GFI and FAIRR developed a new, gap-filling set of ESG frameworks for the alternative protein industry that equip companies to assess and report environmental and social impacts of their business practices and their products, helping meet demand from investors, governments, and consumers for greater transparency.

The first-of-their-kind frameworks enable greater disclosures of the climate, water and land use, biodiversity, labor, and food security impacts of companies and their products, encouraging improvements in company practices and enabling comparisons between companies involved in alternative proteins and companies involved in animal protein products. The frameworks also enable investors to source high-quality ESG data from companies regarding their alternative protein offerings.

By 2025, an estimated third of global assets will be managed according to ESG principles. And while ESG reporting is currently voluntary, mandatory and globally standardized reporting is likely only a matter of time, with government-mandated climate reporting anticipated by 2025. As ESG considerations are increasingly integrated into risk mitigation and decision making, a greater need exists for standardized industry-specific assessments that enable data validation and comparability. While such frameworks exist for many other industries, the new GFI & FAIRR ESG frameworks now play that role for the alternative protein sector.

Increased visibility of the long-term environmental and social impacts of alternative proteins compared with those of conventional proteins can catalyze further investments that meet global sustainability goals and accelerate the transition to a more secure and equitable protein production system.

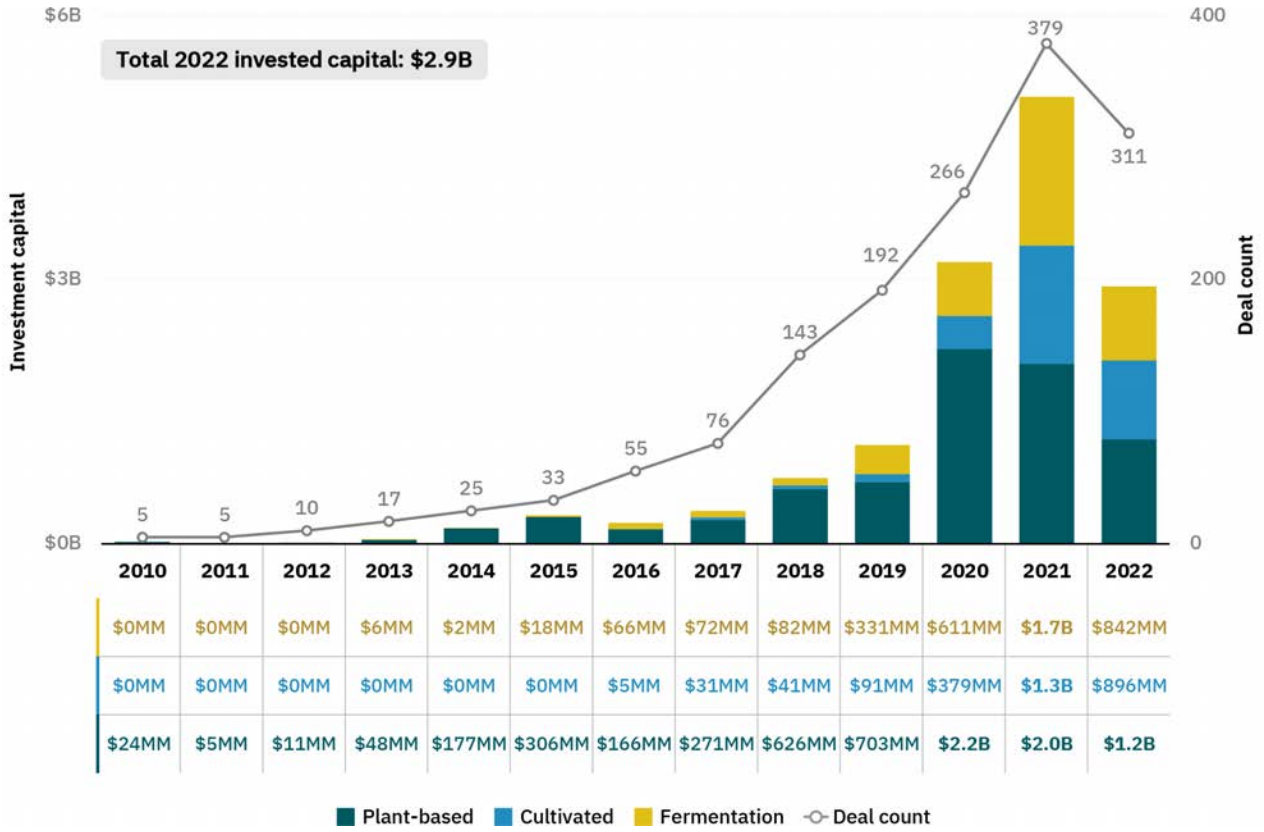
Investors and companies interested in exploring how they can adopt the GFI & FAIRR frameworks to enhance their ESG assessment and reporting practices are encouraged to reach out to GFI's Corporate Engagement team for support.

Table 7: 2022 investment overview

Total invested capital	Largest investment	Unique investors
$842MM in 2022 (23% of all-time investment) **$3.69B** total (2013–2022)	**$150MM** (Meati Foods)	**196** new in 2021 (38% growth from 2013-2021) **713** total (2013–2022)
Invested capital deals	**Growth-stage fundraising rounds (Series B and above)**	**Liquidity events**
89 in 2022 **301** total (2013–2022)	**5** in 2022 **23** total (2015–2022)	None in 2022 **$1.50B** total (2003–2022)

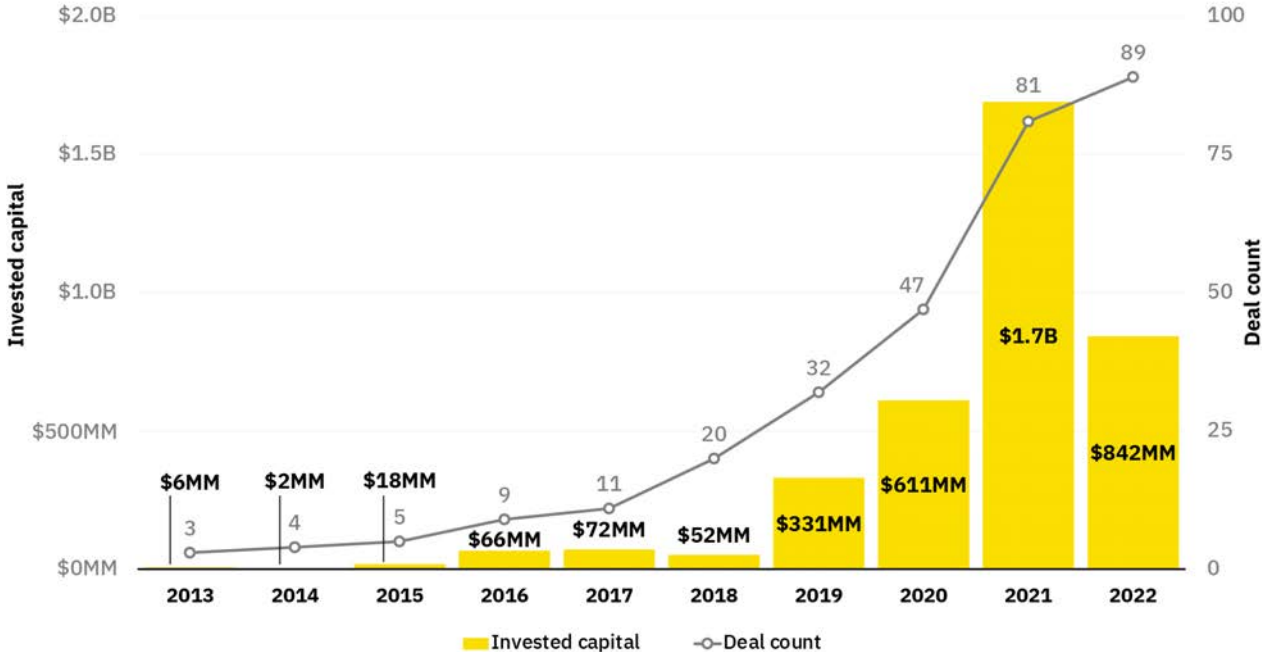
Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. See below for GFI's data collection methodology and definitions of "invested capital" and "liquidity events." The total deal count includes deals with undisclosed amounts.

Figure 10: Annual investment in alternative proteins (2010–2022)



Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. The total deal count includes deals with undisclosed amounts.

Figure 11: Annual investment in fermentation (2013–2022)



Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. The total deal count includes deals with undisclosed amounts.

"Fermented protein producers are attracting meaningful capital, which is funding an industry-wide race to deliver superior taste, texture, and nutritional profile in a cost competitive and scalable manner. Looking ahead, more investment will be needed across the space to help overcome challenges such as lowering production costs, obtaining regulatory approval, and attracting customers for large-scale commercialization."

– Caitlin Walsh, Managing Director, Thematic Investing, CPP Investments

Data collection methodology

GFI conducted an analysis of fermentation companies worldwide using data from PitchBook Data, Inc. Our analysis uses a list we custom-built in PitchBook of companies focused primarily on fermentation-enabled meat, egg, and dairy products or providing services to those who produce them.

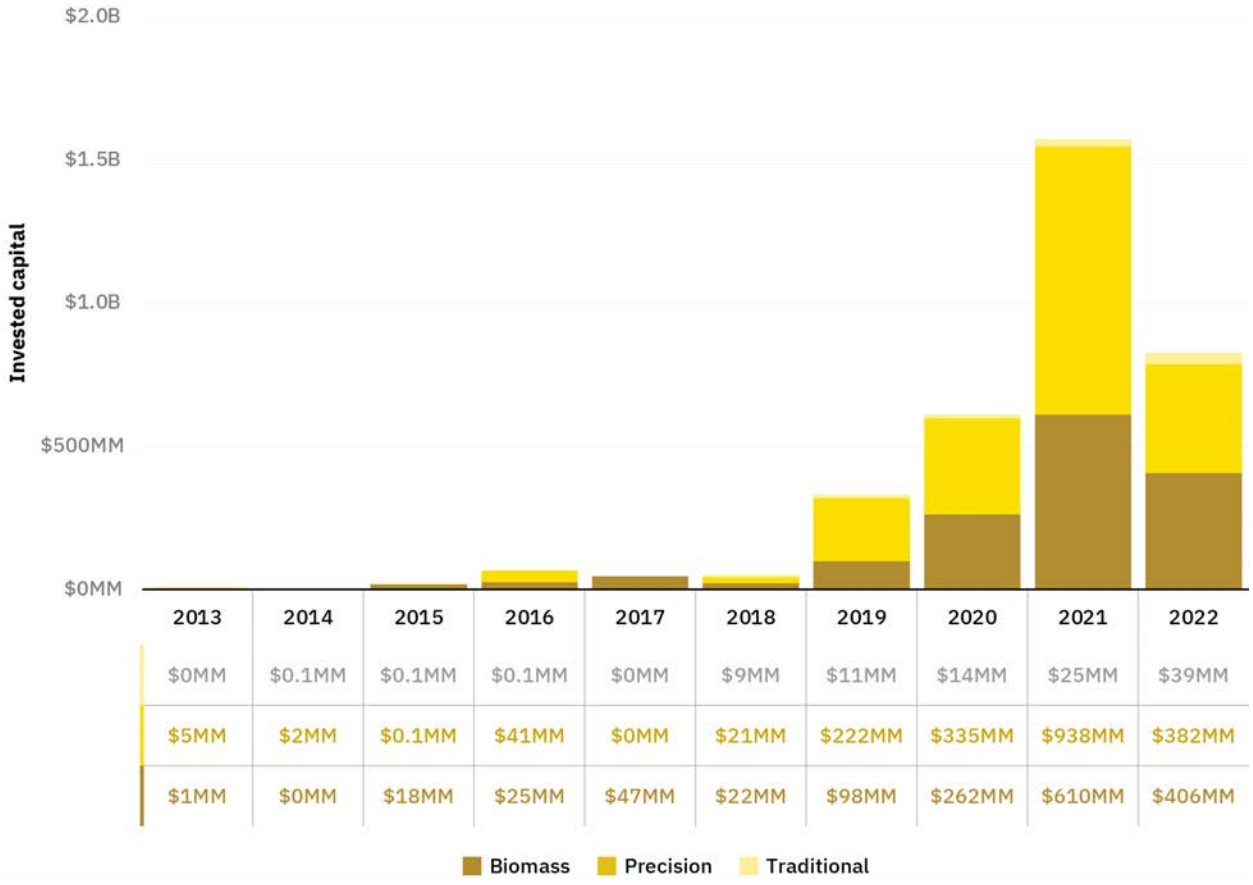
Our analysis excludes the many companies involved in fermentation but not as their core businesses, such as **Kerry**, and companies using fermentation other than to create or enable alternative meat, egg, and dairy products. Companies focused primarily on plant molecular farming—**Bright Biotech**, **Fantastic Farms**, **Moolec**, **Mozza**, **Nobell Foods**, and **Tiamat Sciences**—are included in fermentation investment totals owing to similarities in the types of ingredients they produce and in the downstream processing to obtain those ingredients from the host organisms.

PitchBook profiled 114 fermentation companies, of which 111 have disclosed deals. Of these 111 companies, 97 have deals with publicly disclosed amounts. Because these aggregate calculations include only companies with deals and deal sizes disclosed to PitchBook, they are conservative estimates.

For the purposes of this report, *invested capital/investment* comprises accelerator and incubator funding, angel funding, seed funding, equity and product crowdfunding, early-stage venture capital, late-stage venture capital, private equity growth/expansion, capitalization, corporate venture, joint venture, convertible debt, and general debt completed deals. *Liquidity events* comprise completed mergers, acquisitions, reverse mergers, buyouts, leveraged buyouts, and IPOs. We do not include capital raised through a SPAC IPO until the entity has merged with or acquired a target company.

Please note that the figures published in this report may differ from prior figures published by GFI as we and PitchBook continually improve our dataset.

Figure 12: Annual investments by type of fermentation (2013–2022)



Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. The annual totals may not match the totals in Figure 12, as companies employing plant molecular farming were excluded. The total deal count includes deals with undisclosed amounts.

Highlight

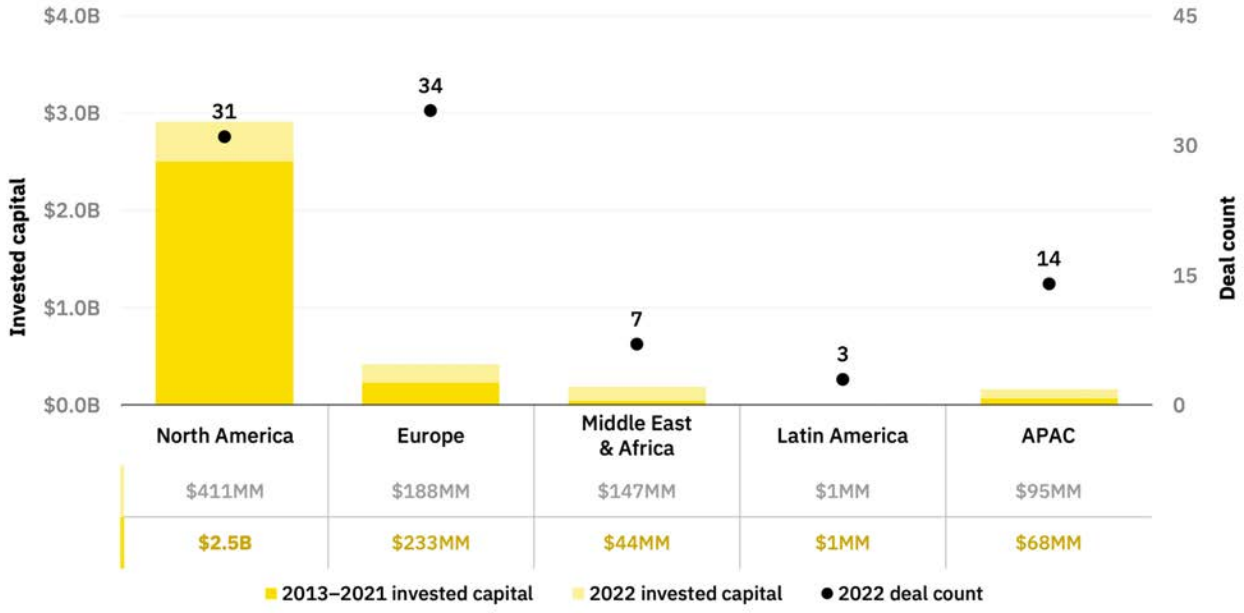
Plant molecular farming: Plants as a scalable expression platform

Plant molecular farming is a potential fourth pillar of alternative protein production that combines plant agriculture and techniques similar to those used in precision fermentation to enable the production of animal proteins in plants, like dairy or egg proteins. Read more about the plant molecular farming commercial landscape here, and the science behind this innovative process here.

Table 8: Investments in plant molecular farming (2017–2022)

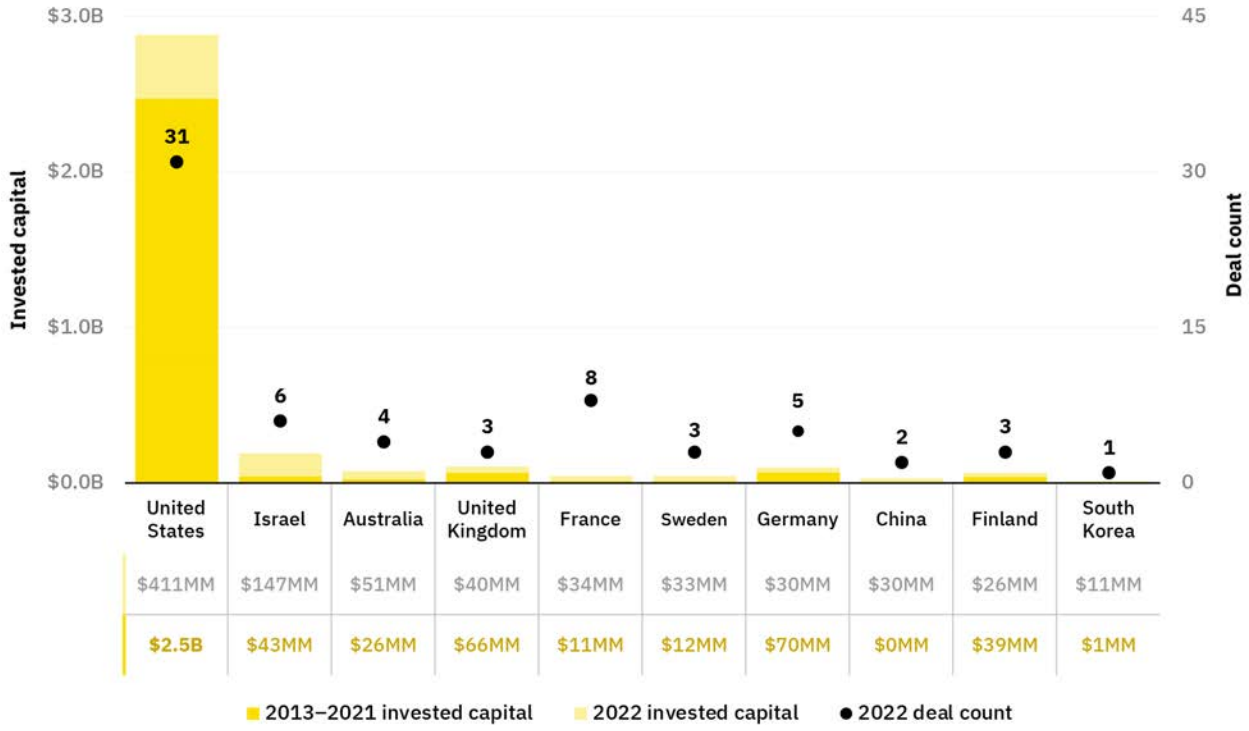
Year	Investment capital	Deal count
2017	$25 MM	1
2018	-	-
2019	-	-
2020	-	-
2021	$118 MM	8
2022	$15 MM	7

Figure 13: Investment in fermentation by region (2013–2022)



Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. North America includes Canada and the United States only. Latin America includes Mexico, South America, and Central America. The total deal count includes deals with undisclosed amounts.

Figure 14: Investments in fermentation: Top 10 countries (2013–2022)



Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. The top 10 countries were selected based on 2022 invested capital. We are aware of additional investments in these countries, including China, that are not captured by our methodology. The total deal count includes deals with undisclosed amounts.

"Investors are increasingly becoming aware of fermentation technologies as novel methods to produce a variety of proteins and specialty ingredients to spur the next innovation wave of plant-based foods. While Sustainability and ESG are overarching themes supporting interest in this sector, the attractive economics, in particular, are exciting investors. The specialty proteins produced through these novel fermentation methods are high-value, premium, functional ingredients. This, combined with lower relative input costs, excites investors and companies about the near-term potential for positive unit economics.

Funding scale-up will be the main challenge for many players. Access to capital will be driven by operational & technical milestones, procuring feedstock agreements, and long-term off-take contracts. Strategic partnerships will take increased importance in helping to drive funding needs down and unit economics up. Companies with increasingly capital-efficient business models will be well-positioned for success."

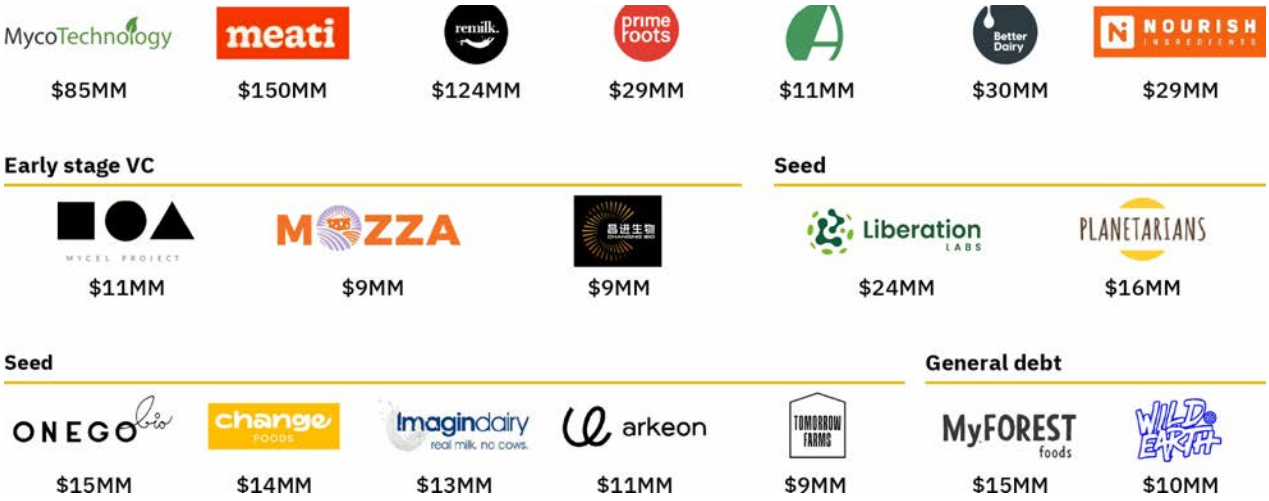
–David Verbitsky, Managing Director, Nomura

Table 9: Deal type summary statistics (2013–2022)

Deal type	Median 2007-2020	Median 2021	Median 2022	Maximum (all years)	Deal Count (all years)
Accelerator and incubator	$100K	$130K	$165K	$18.3MM	78
Seed	$2.1MM	$1.3MM	$5MM	$23.5MM	89
Series 1/2	$6.2MM	N/A	$4.8MM	$9.3MM	7
Early-stage VC (uncategorized)	$865K	$1.3MM	$4.4MM	$17MM	74
Series A/A1/A2	$11.2MM	$24.7MM	$19.8MM	$90MM	41
Series B	$30.2MM	$62.9MM	$28.8MM	$226MM	13
Series C/C1	$22MM	$263MM	$150MM	$350MM	7
Series D/D1	N/A	$199MM	N/A	$350MM	2
Series E	N/A	N/A	$85MM	$85MM	1
Late-stage VC (uncategorized)	$10MM	$14.3MM	$7.2MM	$34.8MM	38
General debt	$450K	$11.9MM	$12.5MM	$45MM	9

Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. These figures represent summary statistics of invested capital rounds with disclosed deal amounts. Deal count includes rounds with undisclosed amounts. Due to their limited number and/or size, this table excludes angel, capitalization, corporate, convertible debt, equity and product crowdfunding, private equity, and joint venture rounds. It also excludes uncategorized rounds. The total deal count includes deals with undisclosed amounts.

Figure 15: 2022 key funding rounds



Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. "2022 key funding rounds" includes investments in the 75th percentile or higher for each funding round category that includes more than three deals. For funding round categories that include three deals or fewer, all deals are included.

Table 10: Most active investors in 2022

Investor	Logo	Investor type	Headquarters	2022 deal count	Total deal count
SOSV / IndieBio	SOSV	Venture capital	Princeton, USA	12	40
Big Idea Ventures	BIG IDEA VENTURES	Venture capital	New York, USA	10	23
Blue Horizon Corporation	blue horizon	Impact Investing	Zurich, Switzerland	8	15
FoodHack	FOOD HACK	Corporation	Lausanne, Switzerland	5	5
Plug and Play Tech Center	PLUGANDPLAY	Accelerator / Incubator	Sunnyvale, USA	5	7
Good Startup	Good Startup	Venture Capital	Singapore, Singapore	4	9

Happiness Capital	Corporate Venture Capital	Hong Kong, China	4	10
Sustainable Food Ventures	Venture Capital	Raleigh, USA	4	10
Thia Ventures	Venture Capital	Geneva, Switzerland	4	4
Agronomics	Venture Capital	Douglas, UK	3	8
Astanor Ventures	Impact Investing	Brussels, Belgium	3	3
Atlantic Food Labs	Venture Capital	Berlin, Germany	3	7
Better Bite Ventures	Venture Capital	Christchurch, New Zealand	3	3
EIT Food	Accelerator / Incubator	Leuven, Belgium	3	7
GERBER-RAUTH	Family Office	Milan, Italy	3	4
Lever VC	Venture Capital	Brooklyn, USA	3	10
S2G Ventures	Venture Capital	Chicago, USA	3	10
Siddhi Capital	Venture Capital	Cherry Hill, USA	3	6

Source: GFI analysis of data from PitchBook Data, Inc.
Note: Data has not been reviewed by PitchBook analysts. "Most active investors in 2022" includes any organization that made three or more publicly disclosed investments in a cultivated meat company during the calendar year 2022.

Liquidity events

While no fermentation company liquidity events—also known as exits, representing the sale of an equity owner's interest in a company typically through a merger, acquisition, buyout, or IPO—took place in 2022, we have already begun to see activity very early in 2023. **Moolec Science**, a plant molecular farming company, acquired **LightJump Acquisition Corporation**, a publicly traded special purpose acquisition company (or SPAC), through a reverse merger for $138 million. This resulted in the combined entity trading on the NASDAQ under the ticker symbol MLEC and MLECW beginning on January 3, 2023. As part of the transaction, the company received $10 million of development capital from undisclosed investors on the same date via a private placement. This liquidity event adds Moolec to the still small, but growing, list of alternative protein companies that are publicly traded.

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Are we missing something from this Investment section?
Did we get something wrong? We'd appreciate your feedback via this form.

Section 4

Science and technology

Section 4: Science and technology

Overview

Humans have harnessed fermentation technology for millennia to improve taste, nutrition, texture, and flavor, and it's just now entering an entirely new chapter. Like other realms of science, we've barely scratched the surface of fermentation's potential not only to feed and heal people but also to aid ecosystem restoration by enabling a shift away from more resource-intensive ways of making food.

Early precision fermentation involved the development of microbes to obtain chemicals and enzymes for food processing (e.g., citric acid, pectinases, amylases). This laid the groundwork for the commercialization of other natural enzymes, recombinant enzymes (e.g., chymosin for cheese production), and natural microbial products. Advancements in genomics over the past 20 to 30 years have enabled the microbial production of chemicals, vitamins, enzymes, hormones, and more. In this time, bioproducts have been dominated by high-value, low-commodity pharmaceuticals like insulin or by low-commodity, high-volume bio-industrials like ethanol and citric acid. For alternative proteins, solutions may exist in both areas—high-value flavor ingredients or high-volume ingredients for end products.

Today, microbe-derived ingredients can be produced from biomass as a single-cell protein or via precision fermentation to produce specific target molecules, such as proteins, vitamins, flavors, and fats. While these technologies are well understood and commercially established, fermentation-derived food products have exceptional potential. As many as one trillion species of microorganisms are estimated to exist on earth, exceedingly few of which have ever been commercialized for use in food. With greater investments in R&D to explore this enormous new frontier, fermentation innovation could produce the animal proteins people want to eat but without the negative impacts of conventional animal agriculture.

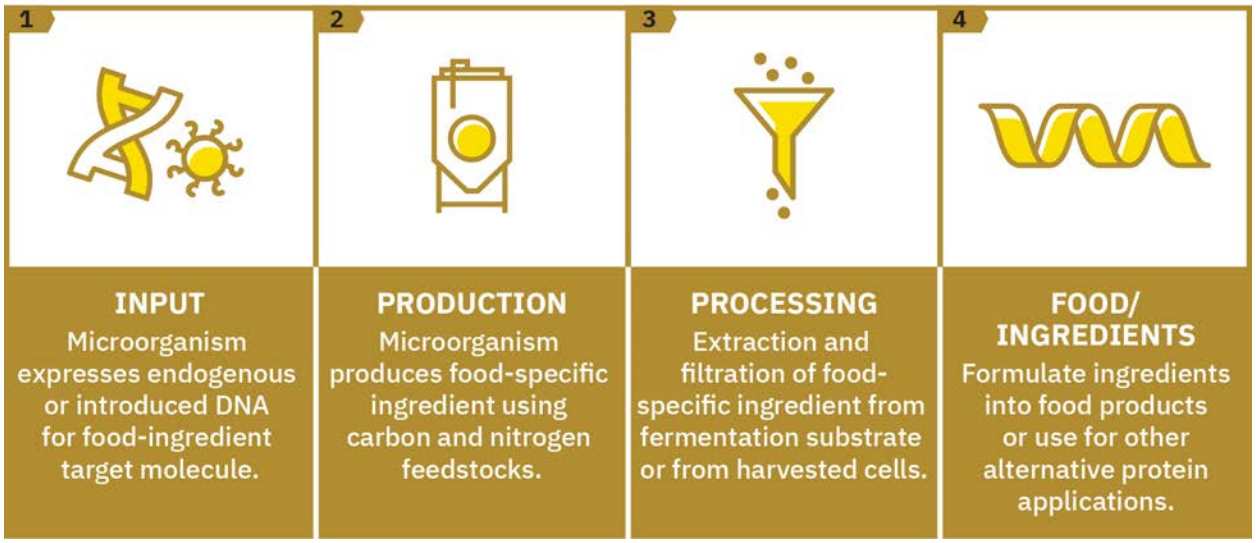
The bioeconomy era is upon us. Proteins and ingredients produced by microbes are already used across the sector, yet there are untapped applications of this technology in alternative proteins. Technological innovation opportunities in this area include target selection, strain development, feedstock optimization, bioprocess design, and end-product formulation.

For a comprehensive introduction to the current state of the science in fermentation, visit GFI's science of fermentation page.

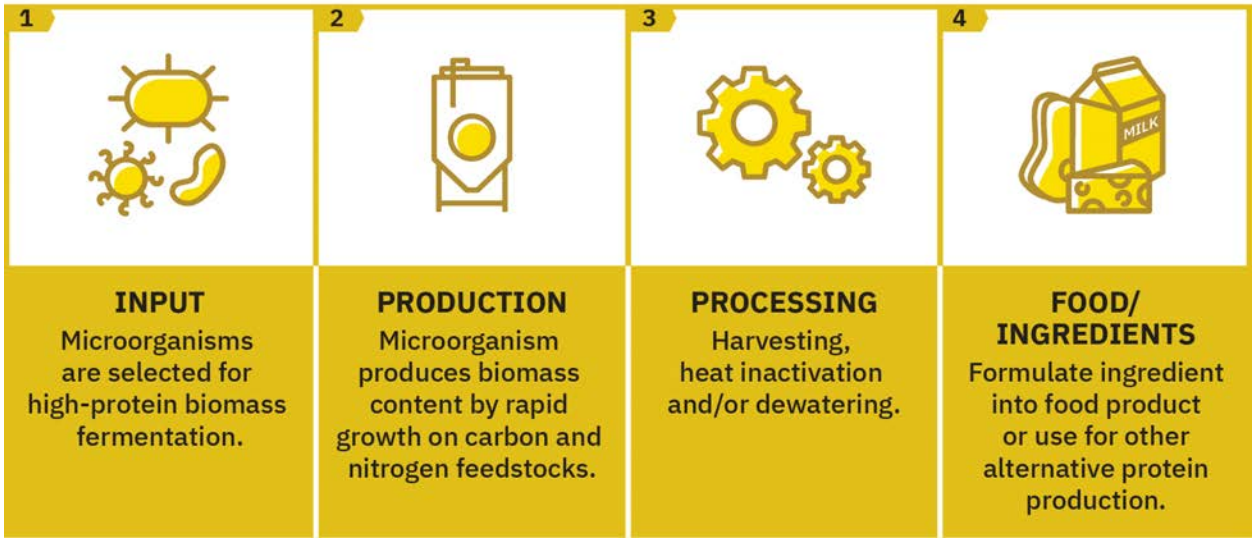
Research across the technology stack

Figure 16: Fermentation in the alt protein industry

Precision fermentation process



Biomass fermentation process



Target selection

Definition: A central mantra of target selection is to begin with the end in mind. The product target could be a biomass single-cell protein, a natural product extract, or a precision-engineered product. When microorganisms are used as production hosts to create specific high-value ingredients, it's crucial to identify and design the right target molecules to manufacture.

Success in target selection and design is often defined by biological, technological, economic, and market factors. Considerations include the target molecule end function, potential applications, degree of similarity to other products, regulatory approval pathways, price points, time to market, market demand, and intellectual property protection. Once the target product has been selected, research is undertaken to design the production pathway through bioinformatic target screening, microbial host selection, and metabolic pathway design.

Initial target selection depends on a thorough knowledge of the state of the science as well as the use of bioinformatics for target design. A review paper published in 2022 provides a detailed understanding of the development needs to produce recombinant milk proteins. There is also a growing use of a multi-omics approach in conjunction with machine learning to drive target selection and strain development. This perspective paper outlines the steps used in a multi-omics, machine-learning approach for applications of high-protein microalgae development.

2022 research highlights:

Use of bioinformatics AI and machine learning

Companies and researchers across the space are harnessing the power of machine learning and artificial intelligence (AI) to aid in target selection prediction. Bioinformatics tools like AlphaFold AI can predict protein structure to a high degree of accuracy within a matter of days, which can help rapidly predict the structure and function of different protein sequences to determine end-product functionality. This Nature paper includes a great example of using bioinformatics and AlphaFold protein structure to identify linalool synthase genes that could enable higher productivity (the amount of product produced per hour in fermentation).

- The startup Shiru is pioneering the use of AI and protein function prediction using AlphaFold. They also announced a new partnership with **Puratos**, a baked goods company, to develop functional animal-free egg prototypes using their target selection platform called Flourish. The system uses bioinformatics with machine learning (ML) to search

through millions of natural proteins for desired functional food properties, like texture, emulsion, or gelling, based on the protein sequence and predicted structure.

- **ICL Food Specialties** and **Protera Biosciences** have partnered to develop sustainable proteins via precision fermentation using an AI-backed technology platform. Protera uses their deep-learning platform called Madi to predict the structure and function of proteins, and then produce the proteins with the desired functionality by precision fermentation. The company looks to target proteins that could provide nutritional and functional properties to reduce the number of chemically derived functional ingredients.

End-product considerations

For many companies, end-product function dictates target selection and design. Food formulations often call for enhanced protein content without a strong flavor or aroma profile. Thus, fermentation can provide protein with neutral organoleptic properties or with specific functionalities.

- With end-production formulation in mind, startup Eggmented Reality leverages bioinformatics to identify proteins that can deliver specific functionality like gelation. Their first product target is a functional binder ingredient alternative to egg or methylcellulose (there are negative perceptions of methylcellulose despite being safe for consumption).

- Brevel is developing ingredients (such as a microalgal protein) that have mild flavors and neutral colors to enhance an end product's nutritional profile while not affecting taste, a critical driver in consumer acceptance.

Applications beyond alternative proteins

Advances in fermentation technology have broad applications beyond the production of alternative protein meat, seafood, eggs, and dairy. In 2022, fermentation science benefitted sweeteners, palm oil, and pet food:

- Israel-based food tech startup Amai Proteins utilized a computational protein design process to develop novel redesigned proteins based on natural protein structures. Amai's go-to-market strategy for target selection is to deliver a protein-based sweetener as a replacement for other sugar substitutes. Their precision fermentation-derived sweet protein Sweelin is produced in ways that reduce downstream processing.

- Companies like **C16 Biosciences**, Clean Food Group**, No Palm Ingredients**, and **Yali Bio** have focused their target selection on alternatives to palm oil, like oils derived from oleaginous yeast. This is driven by the high environmental impact of palm oil and the market potential of microbe-derived fats/oil alternatives. In 2022, the German ingredient supplier Doehler invested in UK-based startup Clean Food Group to develop a

bio-equivalent alternative palm oil from oleaginous yeast. Food industry innovations in fat can also have applications for replacing animal fats.

- Pet food is a market with enormous potential for alternative proteins and products, and may have a faster path to market through consumer adoption. Wild Earth dog food expanded their fermentation-derived protein availability in 2022. Aside from the sustainability of fermentation-based proteins, fermented pet food has the promise to reduce allergens and pathogens in pet food products. In 2022, Bond Pet Foods closed a funding round to develop their precision fermentation proteins for pet food.

Strain development

Definition: Strain development focuses on bringing out the best features of a particular microbial strain and minimizing undesirable qualities.

When selecting a strain, researchers account for metabolism, protein trafficking, cell morphology, cell proliferation, and potential for genetic improvements. Research is ongoing to improve gene expression and protein production systems in workhorse organisms. In addition, improving microbes' ability to be a chassis for productivity involves many cellular pathways and mechanism enhancements. Finally, bioprospecting for novel organisms can result in the identification of novel compounds and host organisms to further increase productivity.

2022 research highlights:

Research on workhorse organisms for precision fermentation

Yeasts like *Saccharomyces sp.* and *Pichia sp.,* and filamentous fungi like *Trichoderma reesei* and *Aspergillus niger* are workhorse strains in precision fermentation research. Several advances made in 2022 added to our knowledge of the potential of yeasts and fungi for producing end products and ingredients for alt protein products:

- Researchers at **VTT** (a research institution owned by the Finnish state) developed strains of *T. reesei* to produce hen egg ovalbumin and bovine beta-lactoglobulin. The functional properties of the non-animal TrOVA and TrBLG exhibited comparable properties to the matching animal-derived proteins.

- Similarly, the **Protein Brewery** published a patent application demonstrating ovalbumin production in the filamentous fungal strain *A. niger*. And, **the EVERY Company** has also demonstrated precision egg white protein production in yeast cells like *Pichia pastoris.*

- *P. pastoris* is also the host organism used by **Impossible Foods**, who had patents granted this year regarding methods for genetically engineering yeast cell hosts. The patents cover the utilization of methanol expression transcriptional activator and of alcohol oxidase promoter, which natively induces expression in the presence of methanol. The second patent covers the use of different mutated alcohol oxidase promoters for native or heterologous protein expression, which allows for improved expression and/or expression in the absence of methanol.
- **Impossible Foods** pioneered the use of fermentation-derived leghemoglobin in their plant-based burgers. Building upon this, **Zhejiang University** researchers reported the development of a P. pastoris strain with increased leghemoglobin secretion and expression up to 3.5 g L^{-1}, representing the highest secreted production reported in the literature thus far.
- Researchers at **Fujian Normal University** have screened an initial set of small peptides to determine the best secretory pathway activation signals in *P. pastoris,* screening both P. pastoris and other budding yeast alpha-mating factor proteins. These results will help with the development of increased secretory pathway activation in *P. pastoris,* **which has the potential to improve downstream processing yield.**
- In *S. cerevisiae*, researchers at **Delft University of Technology** demonstrated strain engineering for anaerobic co-fermentation of glucose and sorbitol which can increase the range of feedstock sources. Researchers are also using CRISPR technology to iterate and analyze large numbers of genome edits simultaneously. Kalsec partnered with Infinome Biosciences to develop precision fermentation products using Infinome's CRISPR platform. Elsewhere, research at the University of Manchester has demonstrated increased protein secretion, which can improve downstream purification in S. cerevisiae when specific non-coding RNAs are deleted.
- In the bacteria kingdom, GFI grantee Dr. Peter Stagios at the **University of Toronto** demonstrated microbial production of growth factors as a **serum replacement in cultivated meat medium.** And **Danisco** had a patent application published related to recombinant *Bacillus* strains comprising enhanced protein productivity phenotypes, compositions, and methods for constructing recombinant *Bacillus* cells.

Applications of machine learning

An undercurrent of strain engineering is the application of machine learning for improved strain design. Without the use of AI ML, the strain development design-build-test-learn process can be cumbersome, time-intensive, and narrowly scoped. Application of ML tools can improve strain design and accelerate R&D cycles, such as with the automated recommendation tool developed by scientists at the US DOE's **Joint BioEnergy Institute.** In 2022, startups leaned into ML:

- Startup **Eden Bio** raised an initial seed round to advance their platform, which uses ML predictions for strain improvements. Their ML strategy allows them to use literature- and lab-based expression data to direct strain engineering for amplified secretion.
- Israel-based startup Imagindairy, a developer of animal-free dairy proteins, is utilizing ML models to amplify protein expression to improve operational expense targets.

Strain development in the alternative fats and oils

Alternative fat innovation is crucial for the success of the alternative meat industry. Fermentation-derived fats and oils can improve flavor, texture, nutrition, cookability, and more. Several advances happened on this front in 2022:

- **Corbion** had a patent published for oleaginous microalgae engineering for the production of structuring fats. The process uses recombinant DNA techniques to produce triglyceride oils with desired fatty acid profiles. The oil produced can be used as frying oil, roll-in shortening, tempering fat, or cocoa butter replacement.
- Researchers at **Technical University of Munich** evaluated oleaginous yeasts for lipid productivity across a range of substrates, providing foundational knowledge of multiple host organisms.
- GFI grantee Dr. Kyria Boundy-Mills is identifying wild (non-GMO) oleaginous yeast strains which accumulate fat at high yields and with compositions and properties similar to animal fats.
- A knowledge base was established via review papers on the engineering of Yarrowia lipolytica for fatty acid production and recent advances in the genetic engineering of oleaginous yeasts. Further development in Y. lipolytica included the discovery of a unique four-member protein family involved in extracellular fatty-acid binding.

Novel strain discovery

The process of collecting, isolating, and evaluating novel microorganisms is an intensive endeavor with great potential for future applications given the diversity and untapped potential of the microbiome.

- In 2022, researchers sought to identify novel marine yeasts that could be used to produce various molecules of interest.
- Similarly, researchers from Brazil biosprospected novel lipid-producing yeasts and algae as alternatives to animal and vegetable oils. Also, the Leibniz Institute **DSMZ culture collection** published Mediadive, an open-source, expert-curated cultivation media database that can help researchers find common medium recipes to facilitate microbial fermentation. Publicly available and well-curated databases on growth media can enable screening and discovery of food-producing microbes.

Feedstock optimization

Definition: Optimizing feedstocks for microbes can cut costs, reduce waste, and improve the sustainability of alternative protein production. Currently, much of biomanufacturing, including alternative protein production, relies on processed fermentable sugars from crops (e.g., maize, sugarcane) and energy-intensive Haber-process-derived nitrogen (e.g., ammonium) to grow microbes. Research is underway to make more efficient use of these standard feedstocks and drive the development of alternative feedstocks.

Research highlights:

Optimizing and diversifying feedstocks

As the bioeconomy grows, the demand for sugar sources will greatly increase as will the need for alternative carbon sources, such as lignocellulosic biomass for saccharification into C5/C6 sugar feedstocks. Single-cell protein and precision fermentation products from lignocellulose side streams have potential as a next-gen sugar source for protein production. In 2022, a techno-economic model was published for lignocellulosic sugar production from municipal solid waste pulp, which may provide a more sustainable sugar feedstock at competitive costs.

For many lignocellulosic feedstocks, the processing cost of cellulase is a key limiting factor for economic viability. In 2022, researchers at the Brazilian Biorenewables National Laboratory published results for their Trichoderma-based enzyme production platform for on-site cellulase production. Their cellulase cocktail production shows similar efficiency to a common commercial cellulase with a target price lower than assumed in the National Renewable Energy Laboratory's TEA for lignocellulosic saccharification. Cellulase cost reduction and improved efficiency can reduce next-generation lignocellulosic sugar feedstock costs.

Coproduction and valorization of side streams as feedstocks

Single-cell protein (SCP) can be produced on a variety of industrial side streams and food waste, like potato processing waste. Fungal biomass production can also utilize many different organic carbon feedstock sources, including lignocellulosic waste streams. In 2022, several researchers focused on ways to valorize side streams as feedstocks:

- Researchers in China and Australia assessed the production of SCP from a consortium of yeasts grown on potato starch processing water. Similarly, researchers in Sweden evaluated multiple fungal strains for edible biomass production at demonstration-scale using potato liquor side stream feedstocks.
- GFI grantee Dr. Naazneen Sofeo is evolving oleaginous yeast strains to grow on cheaper food waste streams (compared to pure carbohydrates). This work aims to sustainably produce yeast lipid profiles similar to the triacylglycerols found in chicken and sheep fats.
- Researchers in Spain demonstrated an accumulation of lipids in *Y. lipolytica* when grown on volatile fatty acids, which can be obtained from industrial wastes.
- Researchers in Sweden assessed olive oil as a novel feedstock to grow Aspergillus, Neurospora, and Rhizopus and evaluated the biomass's nutritional profile.
- A patent application was published from **MycoTechnology** demonstrating the production of edible mycelial biomass from date extract syrup as a primary carbon source.
- Similarly, researchers at **King Saud University** evaluated biomass and oil production in the alga strain Aurantiochytrium sp. on low-cost feedstocks like date fruit and molasses.
- Researchers in India demonstrated side stream valorization of jackfruit seed through bioconversion into an SCP using five GRAS (generally recognized as safe) filamentous fungi by submerged fermentation.

Locating fermentation facilities alongside critical inputs

Colocating fermentation facilities with feedstocks and transportation hubs can be key for sustainability outcomes for alternative protein commercialization. In 2022:

- **ENOUGH** (formerly 3F BIO) opened their mycoprotein production facility with a 10,000-ton production capacity in Sas van Gent, Netherlands. To ensure a consistent feedstock supply and support a zero-waste design, the facility is co-located with Cargill's facility on the Gent-Terneuzen canal.
- **Arbiom** received €12 million ($13 million) to build their first commercial plant for the production of their SylPro product. **Arbiom's** feedstock strategy aims to use underutilized lignocellulosic biomass to develop high-protein, sustainable, nutritional ingredients. Their plant is planned to be co-located with a pulp and paper mill for improved logistics and cost.

Diversifying feedstocks

Microbial production from gas feedstocks like CO_2 can have lower land use impacts due to not needing glucose from crop plants. In 2022:

- **Solar Foods** published a patent describing their feedstock strategy of creating SCP from gas rather than organic carbon. The method uses chemoautotrophic hydrogen oxidizing bacteria to create microbial biomass from CO_2, oxygen, and hydrogen gas. The company recently received €10 million ($10.8 million) investment to build a commercial production facility.
- **Air Protein**, a California-based company who also utilizes chemoautotrophic microorganisms, had a patent application published for the protein hydrolysate composition derived from these microorganisms via gas fermentation. The protein hydrolysate could supplement media for serum-free culturing of animal cells as well as other microorganisms.
- Similarly, Arkeon, an Austria-based ingredients company who has raised $10 million in funding to date, utilizes autotrophic archaea that can grow on CO_2 and hydrogen to produce and secrete all 20 amino acids to the fermentation broth.

Conversely, a growing trend in the microalgae sector is the shift to heterotrophic growth (sugar or mixotrophic growth strategies using glucose) as a substitute for strictly photoautotrophic growth (sunlight and CO_2). While the sugar source is not usually cheaper or more sustainable than for photoautotrophic growth, this approach often reduces operating expenses by increasing yield and titer, and reducing cultivation time. In 2022:

- **Corbion** was granted a patent for high-protein microalgae (*Chlorella sp*.) production under heterotrophic conditions.
- Researchers in Taiwan published findings of heterotrophic growth of a high-protein Chlorella sp. strain.
- Israel start-up **Brevel** utilized a mixotrophic growth strategy to grow their microalgae product.

Acetate can be used as the sole carbon source for a range of food-producing microorganisms, including microalgae, yeast, and fungal mycelium. Scientists at **Lawrence Berkeley National Laboratory (Berkeley Lab)** published a new biomimicry technique in Nature Food, modeled after a metabolic process found in some bacteria, to convert carbon dioxide (CO_2) into liquid acetate, a key ingredient in producing "liquid sunlight" or solar fuels through artificial photosynthesis. Research demonstrated the production of acetate via a two-step electrocatalytic process using CO_2, electricity, and water. This work could prevent fermentation feedstocks from having to compete with food source plants as the demand for fermentation substrates increases.

Bioprocess design

Definition: The bioprocess for fermentation-derived ingredients involves upstream (USP) cultivation of the microorganism in large-scale bioreactors followed by downstream purification (DSP) of the target product. Whether through improvements to downstream yield, upstream medium recycling, improved system control, or novel growth strategies, innovations in bioprocess design can unlock opportunities for cost reduction, scale-up, and environmental sustainability for fermentation's use within alternative proteins.

Research highlights:

A collaborative bioprocess review was published by **King's College London**, **Quorn**, and **Calysta**, which provides excellent insights on strain selection, feedstock, bioprocess development, and commercial landscape for microbial protein and precision fermentation. Another collaborative review paper discusses the feedstock, bioprocess, and commercial landscape of mycelial production in depth.

Bioprocess development across pillars

Production-scale fermentation puts unique stresses on microbes. Nutrient mixing, temperature, and pressure are all examples of challenges to fermentation that increase as reactor size increases. Keeping production-relevant conditions in mind during scaled-down fermentation testing is key to efficient bioprocess development, a critical context for R&D as highlighted in the BioMRL framework published this year. Novel microplates and bench scale reactors, like the Biolector and Ambr250 systems, can enable high throughput strain screening and assessment of strains in scaled-down commercially relevant conditions with fewer resources to speed up bioprocess development.

In large fermentation bioreactors containing a complex blend of liquid media, biomass, and dissolved gas the distribution of material can be very different from smaller vessels used early in bioprocess development. Therefore, it is important to understand the hydrodynamics inside industrial bioreactors, as this can improve bioreactor design and inform control parameters for successful fermentations.

- This year, scientists at **Novozymes** and researchers in Denmark and Australia published a detailed hydrodynamic characterization of industrial bioreactors through computational fluid dynamics that model mixing, temperature, and mass transfer.

- Researchers at **Nanjing Tech University** developed and modeled performance in a novel rectangular airlift reactor to improve upstream productivity relative to a conventional airlift reactor.

Improvements to media usage can also greatly improve bioprocess expenses.

- Researchers at the **Vienna University of Technology** evaluated multiple filtration membranes and methods for fermentation effluent medium recycling.

- **Researchers in Japan demonstrated the possibility of creating a circular, closed-loop bioprocess using microalgae and mammalian myoblast. Their process showed how microalgae can treat cell culture waste, provide nitrogen-rich hydrolysate in-house, and reduce operating expenses in cultivated meat.**

Bioprocess developments in precision fermentation

Filamentous fungi are powerful fungal cell factories for the production of different enzymes, proteins, and other ingredients. However, they typically form hyphal pellets in liquid-submerged culture, which impacts mixing and prevents accurate real-time monitoring of biomass density.

- Researchers in Japan developed a filamentous fungi cell line more suited for submerged fermentation, with a more dispersive morphology in liquid culture. This enabled quantitative monitoring of biomass, which can improve upstream productivity.
- Microparticle-enhanced cultivation is another novel approach to control the size and structure of mycelial clumps in submerged fermentation.

ML approaches in bioreactor monitoring and control can be powerful tools when coupled with advanced process controls. This year, **The EVERY Company** had a patent application published for an AI/ML system for optimization of USP precision fermentation of animal proteins, which helps improve fermentation titer, glucose utilization, and productivity.

Bioprocess developments in biomass fermentation

A review paper published in 2022 focused on SCP production by different microorganisms, including heterotrophic microbial species, fungi, phototrophs, methanotrophs, and autotrophic hydrogen oxidizers.

Microbe-derived SCP is typically grown in traditional submerged fermentation, while mycelial biomass can be generated through submerged fermentation or through low moisture solid-state fermentation (SSF). In 2022:

- **Ecovative Design** had a patent application published for environmental control systems for SSF production, which is important for improved productivity.
- Start-up **Esencia**, backed by **Big Idea Ventures**, is building fish and seafood alternatives like scallops by leveraging SSF to mimic the mouthfeel of seafood.
- **Aqua Cultured Foods** are using microbial fermentation techniques to grow whole-muscle seafood alternatives, and say they have doubled their production output through process development improvements. They utilize solid organic matter plus a nutrient-rich solution in their fungi cultivation while controlling environmental conditions to produce their whole protein biomass.

While SSF has gained a lot of attention for its potential to deliver whole-cut meat alternatives, submerged fermentation is a more mature technology. Since 1985, **Quorn** has used submerged fermentation to grow their *Fusarium venenatum* mycoprotein. In 2022:

- **MycoTechnology** had a patent granted for methods of myceliated high-protein food production using fermentation to improve the organoleptic properties of plant proteins.
- **Better Meat Co.** developed a process for biomass protein from the filamentous fungi *Neurospora crassa*, which has been used in traditional fermented foods in Indonesia, and is a model system for fungal study. Neurospora is a fast-growing fungi that can be used in biomass protein fermentation with the ability to increase the nutrient value of grains and legumes by increasing the protein content and soluble prebiotic polysaccharides. Better Meat Co. also had their patent granted in 2022 for their enhanced aerobic fermentation methods for producing an edible mycelium meat analogue, Rhiza, from filamentous fungi.
- **Superbrewed Foods** had several patents granted, including a mixotrophic bioprocess and fermentation feedstock production patent. They also had a patent published regarding compositions and methods to produce a protein hydrolysate from their anaerobic *Clostridium tyrobutyricum* production system. Their hydrolysate would provide a more complete amino acid profile and consistent final product, which could be used in a variety of microbial fermentation or cultivated meat media recipes.
- **Noblegen**, a Canadian-based digital biology company, is developing an egg replacement using Euglena-derived components and reported a method for improved cryopreservation of Euglena, which can improve industrial strain control. Strain control and seed train stability are notable areas of opportunity. Noblegen also had a patent application published regarding downstream processing and protein extraction from their *Euglena* biomass.
- **Solar Foods** published a patent application describing a continuous culture bioprocess for their single-cell protein biomass grown from gas feedstocks.
- The **Protein Brewery** published a method for the pasteurization of fungal biomass that optimizes downstream processing for improved end-product formulation.

- Alternative seafood startup, Koralo Foods**,** developed a novel alternative seafood product through the cultivation of fungal mycelium and microalgae that imparts the taste and texture of seafood while also providing the nutritional benefits of both the fungal protein and microalgae omega-3-fatty acids in a single process.

Bioprocess developments in microbial oils

If microbes could make more lipids in the most nutritious, well-digested, and flavorful forms, then fermentation-derived fats could replace fats and oils from a variety of conventional animal sources. In 2022, several researchers advanced the science of making oils/fats using microbial fermentation:

- Researchers from China, Egypt, Saudi Arabia, and Malaysia demonstrated that coculturing *Mucor plumbeus*, an oleaginous fungus, with *Bacillus subtilis* bacteria led to significant yield increases in fungal biomass, lipids, and total fatty acids. **Coculturing can unlock the full potential of microbes, as the process often mimics their natural environment, which can induce the production of high-value fats, proteins, and other food ingredients.**

- Researchers at the **University of Bath** published a bioprocess study for pilot-scale semi-continuous cultivation of an oleaginous yeast on a potato starch hydrolysate for microbial oil production. **Evaluations such as this provide crucial insight into cultivation strategies and productivity at larger scales using commercially relevant feedstocks, which helps the field determine technical feasibility and refine techno-economic models for microbe-derived oils.**

- A team of scientists led by **Nanyang Technological University, Singapore** developed a method to produce and extract plant-based oils from microalgae (*Chromochloris zofingiensis*) that could replace palm oil.

- Several companies have developed algal and fungi-derived oils and omega-3s for use in food products. This year, **ATK Biotech** was granted GRAS status for their DHA algal oil extracted from Aurantiochytrium limacinum, which is a common alga used for DHA production. And researchers from Khon Kaen University optimized DHA production in the same alga through fed-batch bioreactor optimization on a number of feedstocks including cassava pulp hydrolysate. Similarly, GFI grantee Dr. Salma Yusop is developing improved bioprocesses to cultivate microalgae for DHA omega-3 production.

With all the developments in microbial oil production, more research and development are needed for food-grade lipid downstream processing to improve economic viability. Downstream processing costs are a major obstacle for the commercialization of microbial lipids since the lipids/oils (fats) are typically stored within the cell and require intensive separation from other cell components (e.g., proteins, polysaccharides). In 2022:

- **C16 Biosciences** had their patent application published regarding microbially produced palm oil substitutes. Their patent demonstrates microbial-produced oil with characteristics of palm oil. The oil is extracted from oleaginous microbes through oil refining, degumming, bleaching, and/or deodorization, which are typical oil extraction processes.
- Whereas, **Corbion Biotech** has published a patent demonstrating a microbial oil extraction method using a high-pressure expeller press to improve cost and efficiency.
- The UK-based company Holiferm continued commercializing their gravimetric lipid processing technology that could improve lipid molecule separation for alternative fats/oils for food applications.

Check out our research grants page to explore grant opportunities and meet the scientists leading open-access fermentation research for applications in meat, eggs, and dairy.

"The science is clear. We cannot continue to rely on animal agriculture to feed the growing global population and meet our sustainability goals. In fact, we need to rewild and reforest large parts of our planet to restore biodiversity and reduce pressure on natural ecosystems. In order to do so, we must scale back the animal agriculture footprint and create a new robust sustainable food ecosystem. Precision fermentation allows us to do just that by replacing key food ingredients like proteins, fats, and flavors, made through fermentation, at a fraction of the environmental footprint of animal analogues. Further, fermentation infrastructure can be built in places where traditional animal agriculture is not possible or is under stress due to climate change, thus increasing the overall resilience of the system and enabling better food security of nations around the world."

– Irina Gerry, Chief Marketing Officer, Change Foods

Research on environmental and social impact

While fermentation has been used for many years to produce drugs and food additives, its applications for alternative proteins can support progress in food system sustainability. In 2022, researchers around the world focused on lower energy-intensive processes for fermentation facilities to reduce costs, create jobs, and lower environmental impacts.

A 2022 report by Boston Consulting Group and Blue Horizon pointed to the maturation of the alt protein fermentation sector, emphasizing innovations in infrastructure, data-driven advances, and novel fermentation. The buildout of new biomanufacturing facilities also adds completely new career pathways in the food industry. Importantly, research is being performed to identify products and processes that can deliver the greatest environmental benefits, while highlighting ongoing opportunities for improvement. While the sector is still emerging, life cycle assessments (LCAs) show that these foods tend to have lower carbon and land use footprints than conventional animal products do, while energy use can vary by technology.

Researchers from **Potsdam Institute for Climate Impact Research** analyzed the environmental land use impacts of substituting fermentation-derived microbial protein for ruminant meat. Replacing just 20 percent of per-capita beef consumption with microbial protein from sugar-fed fermentation by 2050 would be sufficient to reduce deforestation and related land-use change emissions by 50 percent. A group of researchers in Finland found that microbial protein obtained from hydrogen-oxidizing bacteria results in environmental impacts 53-to-100-percent lower environmental impacts than conventional meat.

For precision fermentation-derived ingredients, several LCAs were published in 2022 by researchers at VTT Technical Research Centre of Finland, focused on the dairy protein beta-lactoglobulin and the egg white protein ovalbumin (microbially produced by *T. reesei*). The beta-lactoglobulin LCA found that the environmental impacts were of the same magnitude as pasture-based dairy proteins with the main contributions from sugar and electricity. The ovalbumin LCA found decreased emissions and land use compared to conventional egg white protein. This study also highlighted the high contribution of industrial inputs, such as electricity and sugar source, to the total environmental impact.

As seen from the VTT LCA evaluations in 2022, opportunities exist for sustainability improvements via the use of more sustainable carbon sources and renewable energy. Input sources can contribute significantly to a product's impact. Utilization of novel side stream feedstocks, such as potato wastewater, as an alternative carbon or nitrogen source improves environmental impact and helps reduce process costs. Fermentation can help valorize food waste streams like surplus bread or surplus dates. This approach not only generates food but also reduces landfill disposal and emissions.

There is a growing interest in microalgae as a sustainable product platform. In 2022, the EU approved microalgae-derived omega-3s

for human consumption. LCAs were published for the industrial production of heterotrophic microalgal oil, as well as heterotrophic microalgal omega-3s compared to fish oil. Both studies showed potential sustainability benefits even in glucose-fed heterotrophic conditions. Autotrophic microalgal production systems typically have a lower environmental impact compared to animal protein production, as documented in this evaluation of large-scale spirulina production. The environmental impact of microalgal-based products is not uniform, however, and opportunities for improvement exist as outlined in this LCA of autotrophic microalgae products.

"Long-term, the fermentation industry has the potential to be impactful across all types of food, from proteins to fats to other ingredients. In addition, its potential across a huge range of industries is only just starting to be explored. Over the next ten years we are excited to observe how the fermentation industry develops, especially when we start considering other sector disruptions happening in parallel, such as localized, distributed energy production and storage, which will have positive impacts for food production through fermentation. This goes hand in hand with fully understanding the climate, environmental and social impacts of fermentation, and we would like the fermentation industry to embrace and lead that going forward."

– Catherine Tubb, PhD, Director of Research, Synthesis Capital

Research on health and nutrition

Fermentation can generate the macro- and micronutrients needed for human diets. (And, in fact, in austere environments such as long-duration space travel, fermentation becomes an attractive method to produce nutrients in the most resource- and energy-efficient manner possible.) There is exciting research being performed on the nutritional profiles of fermentation-derived proteins.

In a study on human consumption of mycoprotein after exercise, a mycoprotein matrix of fiber and protein was shown to be just as effective a protein source as mycoprotein isolate. Many nutritional standards and digestibility benchmarks for protein do not take into account mycoprotein's unique nutrient profile, which has contributed to calls for considering mycoprotein its own category for digestion studies and nutritional guidelines. Still, in line with current standards for nutrition, research

published in 2022 showed both Superbrewed Food's single-cell protein and Nature's Fynd's Fy mycelial product to be high in protein with essential amino acids and favorable digestion profiles. Overall, current reviews of fungal protein have found it to be a healthy and well-established food source. Mycelial protein can also increase the protein content of legumes and grain products. Israeli startup **Kinoko** won the Hebrew University of Jerusalem's 2022 Asper Prize to develop their method of growing mycelial on grains and legumes to create **a high-protein hybrid product that includes both the mycelium and the legume or grain base.**

Typically, infant formulas contain fats derived from plants that provide energy and nutrients but are not exact replacements for human milk fats. Scientists are harnessing the oleaginous yeast Y. lipolytica to produce nutritional fats that match the unique structure of the human milk fat triacylglycerol.

Precision fermentation-derived ingredients like milk fat and lactoferrin have the potential to improve the nutritional profile of infant formula and provide new supply chains in an industry rife with shortages and manufacturing challenges.

As perceptions of foods change and consumers are better informed of the advantages of new products, it's likely that precision fermentation-derived protein will attract new consumers. One advantage? **Precision fermentation-derived proteins can sweeten our foods while reducing sugar consumption.** Sweet proteins are hundreds or thousands of times sweeter than sugar, and are digested as proteins. While some plants produce these proteins via fruit, they are typically in low concentrations. These proteins are prime candidates for precision fermentation. In 2022, **Oobli** began selling chocolate bars sweetened with P. pastoris-produced brazzein, a sweet protein isolated from the Oubli plant. Conagen has also announced their production of two sweet proteins via precision fermentation, thaumatin I and II. We expect protein sweeteners to become more common in the coming years.

Scientific ecosystem growth

Progress toward price parity

As companies begin to scale their technology and assess commercial readiness, having a framework for bioprocess development (BioMRL) can help identify and mitigate risks in scaling biomanufacturing from R&D to commercialization. Furthermore, the use of techno-economic models and access to pilot-scale testing can help assess the commercial readiness of bioproducts.

In fermentation, there are many areas for optimizing cost efficiency, including increasing scale, decreasing feedstock cost, and improving strain productivity and downstream yield. Techno-economic analyses (TEAs) can provide a fundamental understanding of the technological and economic bottlenecks that limit the cost reduction and scalability of alternative protein products.

Upstream and downstream pilot assessments, like those offered by ABPDU and Pilots4U, help bridge the process development gap and inform techno-economic feasibility. In 2022, **ABPDU** collaborated with Joywell Foods (now Oobli) to upscale their sweet protein technology. In Europe, Pilots4U offers a network of open-access multipurpose pilot and demonstration facilities for the European bioeconomy. It is coordinated by the Bio Base Europe Plant, a unique pilot facility for process development and scale-up that has helped several companies scale, including **Arbiom**, **ENOUGH**, and **Inbiose**. **Arbiom** collaborated with a consortium of partners to assess SylFeed.

In 2022, Boston Bioprocess launched with the goal of working with fermentation companies on improvements in strain, process, and scale-up to drive down costs. Startup New Wave Biotech is developing a virtual platform for pre-pilot-scale assessments of downstream processing costs.

Sourcing the appropriate equipment and facilities needed for precision fermentation, which is subject to FDA food safety requirements in the United States, is also challenging and expensive. Currently, not many companies have sufficient expertise. In 2022, **Perfect Day** announced the launch of an enterprise scale-up service, **Nth Bio**, to offer expertise in USP and DSP development for commercialization.

Progress toward taste parity

Fermentation has the potential to add flavors and ingredients, reduce or remove unwanted flavors or aromas, and enhance the organoleptic experience of alternative protein products. This work on improving taste and aroma leads to increased consumer appeal.

Some plant-based protein sources can contain compounds that produce undesirable flavors in foods. This is why traditional fermented foods have long had a role in modifying and improving the flavor profiles of plant-based proteins.

- In a hybrid traditional and biomass fermentation approach, **MycoTechnology** had a patent published regarding the production of fungal mycelium grown on plant proteins like pea, rice, and chickpea, that results in an improved taste profile with more meaty, savory, and umami flavors. In fact, researchers at MycoTechnology found that shiitake fungi mycelial fermentation metabolizes and removes galbazine and other compounds to improve the organoleptic properties of pea protein. Fungi are thus capable of metabolizing a wide range of compounds to enhance the taste of alternative protein products.

Texture plays an important role in the organoleptic experience of eating meat. Many companies are developing fungal mycelium-based products to mimic the texture of meat.

- **Ecovative Designs**, the original parent company of **MyForest Foods** (formerly Atlast), had a patent published for methods of producing a mycelium biomass with a texture analogous to a whole-muscle meat product like bacon. The whole-cut mycelium is then formulated with fats and flavoring aromatic ingredients to complement the whole-cut texture. Their MyBacon product has been well received by consumers.
- **Mycorena** has had a patent application published for a dried filamentous fungi biomass product that has a meat-like texture and neutral taste, which enables easier formulation into an appealing alternative meat product.
- Conversely, **New School Foods** developed a directional freezing method to create fibrous meat analogs using any number of microbe- or plant-derived proteins with edible hydrocolloids such as gelatin, starch, seaweed extracts, or methylcellulose.

Fats hold the key to bridging the taste gap between plant-based and animal-based meats. This is why many fermentation companies are developing microbial-sourced fats, as a better alternative to coconut and palm oil ingredients.

- **Melt&Marble** is developing oleaginous yeast strains that produce fat profiles similar to beef fat. In 2022, they debuted their non-animal fat prototype with a beef-like fat melting profile, enabling progress toward taste parity with conventional products.

Microbe-derived biomass can also enable an improved flavor profile of meat alternatives:

- To proactively improve sensory characteristics, researchers in Belgium and the Netherlands have evaluated the potential of microalgae as a flavor enhancer for alternative seafood products.
- Conversely, others are developing a high-protein microbial biomass that has little to no flavor profile making it an easier protein source to formulate with flavor molecules. As mentioned previously, **Brevel** has developed a sugar-based fermentation of high-protein microalgae that has a neutral taste compared to soy and pea protein. And similarly, gas-fermented biomass produced by **Solar Foods** has a slight umami flavor and does not have a bean off-flavor, which should enable easier product formulation.

Fermentation-derived ingredients like aminos (e.g., glutamate) and yeast extracts are already widely used as food ingredients to improve taste. And, precision fermentation is beginning to produce tailored flavor ingredients like heme proteins to provide a more meat-like taste and appearance.

- Companies like **Motif Foodworks** produce myoglobin via precision fermentation as a flavor ingredient. This year researchers at **KU Leuven** and precision fermentation company **Paleo** demonstrated that fermentation-derived myoglobin can improve the aromatic profile of plant-based meat products.
- Similarly, **Triton Algae Innovations** has developed strains of the microalgae *Chlamydomonas* to produce iron-complexed proteins like hemoglobin, myoglobin, and leghemoglobin to impart meat-like taste, texture, and appearance. They have also developed strains of *Chlamydomonas* with color-fast red pigment to improve meat substitute product formulation with their pigmented algal cells.
- In addition to their non-heme iron binding protein development, **Cargill is also developing a natural thermolabile red pigment that provides a pink/red color to a meat substitute product and transitions to a brown color after cooking. Both ingredients could be formulated with any number of plant-based (e.g., soy, pea) or microbial-based protein sources (e.g., mycoprotein) to improve taste and visual appeal.**

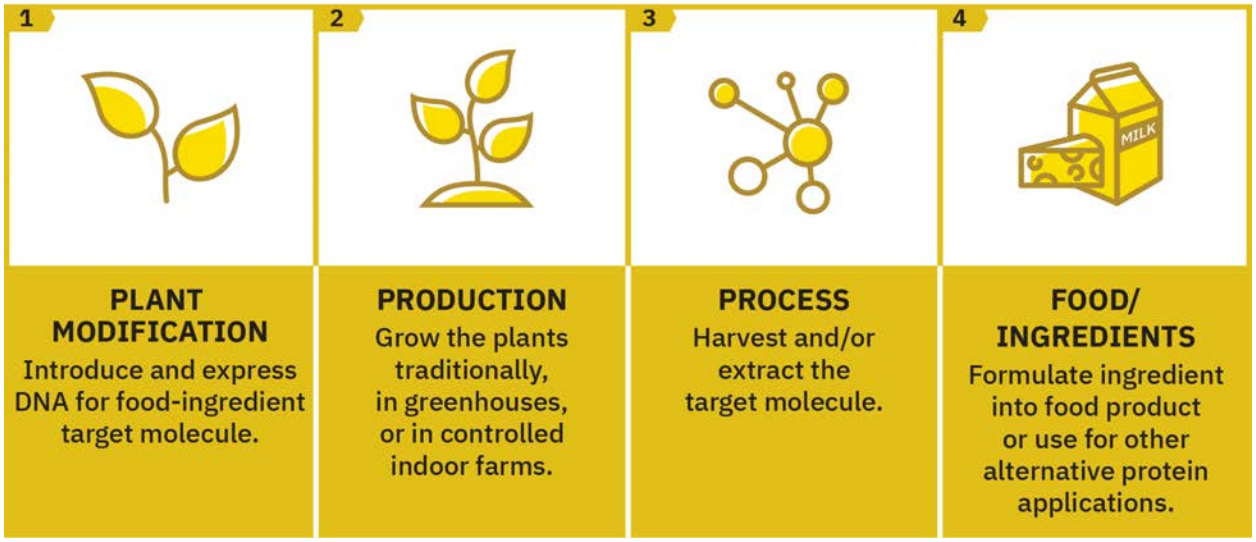
Highlight

Plant molecular farming: Plants as a scalable expression platform

Plants use energy from the sun and nutrients from their surroundings to build biomass and make the proteins, starches, pigments, and biomolecules that they need to grow and thrive. Recent advances in plant genetics and crop engineering are enabling the production of novel food ingredients in plants, like dairy or egg proteins. Plant molecular farming is an approach that allows plants to produce alternative proteins inside of a plant using photosynthesis and well-established farming techniques.

This approach continues to garner attention as a platform for protein production. In many ways, it is positioned similarly to precision fermentation as a method of production in that many species and cultivars exist that are capable of producing proteins. A clear research interest in this area is the potential to unlock photosynthesis to fix the carbon (and perhaps nitrogen-fixing by the rhizobiome and endosymbiotic microbes) required for plant growth and the energy for protein synthesis. Work is underway to understand the physiological limits for protein yield, greenhouse costs compared to field-growth costs, and the unique downstream processing requirements of plant tissues.

Figure 17: Plant molecular farming process



The promise of plant molecular farming

Leveraging plants as recombinant protein hosts could offer a number of benefits, including the following:

1 **Plant molecular farming could occur on farms in open fields where allowed, and does not face the scaling challenges associated with large bioreactors.**

This process could lead to lower inputs, increased production scale, and allow for harvest and process protocols similar to those established for plant-based protein ingredients. In 2022, **IngredientWerks** announced their spinout from AgriVida and plans to develop protein expression in row crops like *Zea mays* (corn). The idea is to leverage the mature processing infrastructure for crop starch and protein separation from row crops.

2 **Plant bioprocessing technology is mature and companies using this approach are taking advantage of that maturity to produce recombinant proteins in novel ways.**

In 2022, **Nobell Foods** (formerly Alpine Roads) submitted a patent application for transgenic plant production of recombinant casein/lactoglobulin (whey). Within that application, they demonstrate the fusion expression of casein and lactoglobulin that can then be cleaved after isolation. These technologies take advantage of plant expression systems to simultaneously make two major components of dairy protein—casein and whey.

3 **Gene expression regulation in plants is similarly complex to that in other multicellular eukaryotes.**

Plant genes can have enhancer elements, promoters, and terminators. All of these elements afford the opportunity to tune and control gene expression that leads to protein production. In 2022, **Leaf Expression Systems LTD** applied for patent protection on their plant molecular farming expression vectors that include upstream and downstream elements designed to enhance protein yield. As plant transgenic approaches and gene expression systems improve, protein yields and plant molecular farming applications will become more widespread.

4 Plants have a variety of tissues for protein expression.

Recombinant proteins could be produced in leaf, root, or seed cells. In 2022, **Core Biogenesis** applied for patent protection and raised $10.5 million to develop their system to express proteins in oilseeds to allow for a **unique approach to downstream processing and protein purification to reduce costs and improve efficiency.**

5 These approaches are broadly applicable to crop improvement.

Carrot callus tissue can be fermented to produce protein such as brazzein using airlift vessels. Related, an LCA analysis published in 2022 showed that the environmental impact of plant cell culture is comparable to that of greenhouse agriculture. This technology can also be used for nutrition improvement in plants, for example, by introducing **the vitamin D_3 biosynthesis pathway to tomatoes to biofortify fruit and leaf tissue with vitamin D_3.**

A note on nomenclature: Plant molecular farming is a rapidly evolving and growing field. "Plant molecular farming" is a phrase used by many in the industry, but to date, no consensus has emerged on the preferred terminology for this alternative protein production technology. Nomenclature considerations should include differentiation with existing production methods, descriptiveness and accuracy, brevity, and appeal to consumers.

Are we missing something from the Science and Technology section? Did we get something wrong? We'd appreciate your feedback via this form.

Section 5

Government and regulation

Section 5: Government and regulation

Overview

Around the world, governments are investing in the development and expansion of fermentation capabilities to increase domestic food production, streamline and reduce waste from agricultural systems, and produce food more sustainably and with fewer greenhouse gas emissions. In an unpredictable, trying year for global food security and the climate crisis, policymakers have leveraged fermentation technologies' flexible platform and low-input production processes to make possible a secure, sustainable food supply.

In 2022, governments around the world supported new and existing research on fermentation and its commercialization. Nations such as the United Arab Emirates, with growing demand for dairy products and little ability to produce them domestically, have invested in local precision fermentation capacity. Nations like Finland and Singapore have supported the development of scalable biomass fermentation to guard against food system vulnerability. Across the board, cellular agriculture has become a priority as greenhouse gas emissions from agriculture increasingly figure in countries' Nationally Determined Contributions (NDCs) toward preventing climate change.

Global public funding

Europe

In 2022, Europe led the world in funding cellular agriculture research and commercialization, prompted not only by climate concerns but also by the disruption to food systems caused by Russia's invasion of Ukraine—both key suppliers of staple crops and animal feed.

The European Union established a budget of €13.1 million ($14 million) for HealthFerm, a research collaboration of 22 partners from across Europe that will focus on the health and sustainability of plant-based fermented foods (GFI Europe serves on the HealthFerm advisory board). Finland announced a €34 million ($36.5 million) grant to **Solar Foods**, who make a low-input biomass-fermented protein powder called Solein—"protein from thin air." The grant will accelerate progress on one production facility currently under construction and allow for the construction of a second.

In a bid to increase food self-sufficiency, Norway's research council announced a five-year, €10 million ($10.8 million) program to develop cellular agriculture and precision fermentation capacity and solve problems like cost and scalability. The United Kingdom's Biotechnology and Biological Sciences Research Council set aside £20 million ($24.65 million) toward capacity building, research, innovation, and business-led commercialization in the

alternative protein industry, including for biomass and precision fermentation.

The Netherlands, Europe's leading agricultural exporter, announced a world-record-breaking €60 million ($64.4 million) investment toward building a full cellular agriculture ecosystem, including R&D, commercialization, workforce transition programs, and education, claiming the investment will generate billions per year in earning capacity for the Netherlands by 2050. Not long after, the country celebrated the completion of construction for one of the world's largest protein facilities, built by UK mycoprotein startup ENOUGH with €16.9 million ($17.9 million) in EU funding through the Bio-based Industries Joint Undertaking. **Intended to reduce waste and improve food system resilience by creating edible protein from agricultural side streams, the plant will upcycle waste products from a nearby starch plant operated by Cargill.**

The European Union also provided €2.4 million in commercialization funds to Mushlabs, a German company pioneering a fermented mycelial mushroom product, through the European Innovation Council's highly competitive EIC Accelerator program. The EIC stated that "[t]he jury believes that the European Union needs to support companies with unique and strategic technology to produce sustainable alternative protein."

Middle East

Governments in the Middle East also tackled global food insecurity with investments in precision fermentation capabilities, especially in the light of growing domestic demand for meat and dairy products. The United Arab Emirates supported construction plans for a 1.2 million-liter (327,000-gallon) precision fermentation facility in Abu Dhabi to be operated by U.S. company **Change Foods** through the UAE's NextGenFDI program. **The facility will create casein, the key protein in cheese, using 1/10th of the water and 1/5th of the energy compared to conventional dairy farming.**

> ***"This is about creating dairy in the desert."***
>
> **– David Bucca, CEO and founder of Change Foods, on building a new precision fermentation facility in Abu Dhabi**

In Oman, which produces about twice as many dates as they can consume or export, the nation's sovereign wealth fund partnered with **MycoTechnology**, a Colorado-based mycelium fermentation company, to develop a production facility that will use dates as a feedstock for protein-rich biomass fermentation.

And Israel, one of the world's leading proponents of alternative protein technology, launched a NIS 50 million ($14.4 million) request for proposals for precision fermentation infrastructure, citing the importance of diversifying food sources. The Israel Innovation Authority claimed in the RFP that fermentation technology has the highest market growth potential and the greatest ability for multiple companies to take advantage of shared R&D facilities.

North America

The United States, an agricultural powerhouse and the world's leading agricultural exporter, increased its public support for cellular agriculture at both the federal and state level in 2022. In September, the Biden Administration released the Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy, in which the president directed the heads of relevant agencies to create reports on the American biotechnology sector, including one from the United States Department of Agriculture (USDA) on cultivating alternative food sources. At the end of 2022, a bipartisan group of lawmakers approved a $5.5 million appropriation for alternative protein research, potentially including fermentation, through the USDA's Agricultural Research Service—a $1 million increase over FY22. At the state level, the Utah Governor's Office of Economic Opportunity provided U.S. precision fermentation company **Perfect Day** with a tax credit to build a production facility in Salt Lake City, with the mayor citing the growing life sciences ecosystem as a valuable asset. Perfect Day plans to add 60 permanent jobs at the location over the next four years.

In the area of fermentation specifically, the U.S. government made a futuristic move by funding research in an inhospitable environment: outer space. With a contract from NASA in partnership with Montana State University, biomass fermentation company Nature's Fynd launched a bioreactor up to the International Space Station aboard a SpaceX rocket to test the capabilities of producing edible protein in zero gravity.

Canada invested in precision fermentation development and commercialization through Ontario Genomics, a government-funded nonprofit, which collaborated with German bioengineering company **The Cultivated B.** to develop a 130,000-square-foot bioreactor manufacturing facility. The company will provide a domestic supply of bioreactors for both cell cultivation and precision fermentation and set aside 20,000 square feet of the facility for an innovation hub as a term of the collaboration. Ontario Genomics also collaborated with the **Canadian Food Innovation Network** in administering AcCELLerate-ON, a CAD$900,000 competition for cellular agriculture-focused food and beverage projects. One of the 2022 winning projects seeks to achieve pilot-scale precision fermentation capabilities for heme, an alternative meat ingredient.

Asia

China's first-ever bioeconomy five-year plan supports alternative proteins research and development for novel foods, while its 2022 agricultural five-year plan includes cultivated meat and other "future foods" for the first time. At the "Two Sessions" in March 2022, China's most important annual political conference, President Xi Jinping explicitly called for protein diversification—including from plant-based and microorganism sources.

In Southeast Asia, **Nurasa**—a wholly owned company of Singapore's sovereign wealth fund Temasek—entered into a joint venture with food distribution giant **ADM** to launch food tech company ScaleUp Bio, who will operate Singapore's first facility to offer

end-to-end contract development and manufacturing organization services in microbial fermentation from lab to pilot scale. ScaleUp Bio has also forged a multi-year partnership with the Singapore Institute of Food and Biotechnology Innovation, a division of the Agency for Science, Technology, and Research (A*STAR). ScaleUp Bio's first lab facility is scheduled to open in mid-2023, with a 100-liter capacity. A second facility, geared toward co-manufacturing services, will open in late 2023 and have a capacity of 10,000 liters.

Australia

In Australia, precision fermentation start-up Change Foods was awarded two grants from the Trailblazer Universities Food and Beverage Accelerator, which is funded by the Australian Government, for a research partnership with Queensland University of Technology to develop precision fermentation facilities that use inedible sugarcane fibers as feedstock for producing dairy proteins.

Regulation

The food industry has long used microbial fermentation as a processing method and to create ingredients derived from microbial cultures. The technology is also used to create natural flavorings and sweeteners found in many foods and beverages. Given this history, most governments have well-established regulatory systems to ensure the safety of innovations in this platform. Some countries evaluate new fermentation products under novel food regulations, which usually require premarket authorization, while others like the United States apply a more nuanced regulatory framework.

Premarket authorization around the globe

In the European Union, companies must secure premarket authorization for many new fermentation-derived ingredients. When produced without genetic modification, those ingredients are reviewed under the European Union's novel food regulation. The procedure includes a risk assessment conducted by the European Food Safety Authority. Premarket authorization is handled centrally at the EU level, meaning that once the European Commission and representatives from EU member states approve a product, the approval applies across all 27 EU countries.

- In early 2023, the European Commission authorized **MycoTechnology**'s pea and rice protein fermented by shiitake mushroom mycelia, which the company calls FermentIQ.
- **Nature's Fynd**, **Solar Foods**, and **The Protein Brewery** have also submitted novel food applications to the European Union.
- Additionally, the European Union has been assessing **Impossible Foods**' soy leghemoglobin both as a genetically modified food and as a food additive.

While the United Kingdom is no longer a member of the European Union, it has retained its novel food regulation. A fermentation company seeking to sell their products in the United Kingdom must apply for authorization from the UK Food Standards Agency (FSA). The FSA provides general guidance on how to submit a novel food application. Notably, in December 2022, the FSA launched a regulatory review to identify and evaluate a range of potential regulatory models for novel foods. This may result in a new system for evaluating future novel fermentation-enabled products.

Singapore also treats fermentation-enabled foods as novel foods subject to premarket authorization. In September 2022, the Singapore Food Agency (SFA) updated the nation's guidance for novel food safety assessments. The guidance sets forth categories of information that must be provided to SFA for product approval and links to helpful resources. The updated document contains specific guidance for foods produced by biomass fermentation and functional ingredients produced through precision fermentation. SFA strongly encourages companies interested in selling alternative protein products in Singapore to contact the agency early in the R&D and commercialization planning process.

Food Standards Australia New Zealand (FSANZ) has regulatory authority over precision-enabled foods in Australia and New Zealand.

- In February 2021, **Impossible Foods** received final approval from FSANZ to sell their heme product in both countries.

In India, the Food Safety and Standards Authority (FSSAI) has the authority to approve novel foods, including products of fermentation. Notably, in November 2022, FSSAI proposed new regulations for foods derived from genetically modified organisms. The proposed regulations address both premarket approval and labeling.

- In 2022, **Perfect Day** received regulatory approval for their animal-free milk proteins.

United States

The U.S. Food and Drug Administration (FDA) has regulatory authority over fermentation-enabled foods. There are two potential regulatory pathways that companies can follow to ensure their novel fermentation-derived ingredients and foods can be sold in the United States. The first is a food additive petition, which is a lengthy process involving consultation with FDA and a petition to the agency requesting the issuance of a regulation that would allow specific uses of the ingredient or additive. The second pathway is a GRAS notice, which is used for ingredients that the food producer believes are already "generally recognized as safe" among qualified experts under their conditions of intended use.

In recent years, multiple fermentation companies have obtained "no questions" letters from FDA for their ingredients, meaning FDA does not object to the companies' view that their ingredients are GRAS:

- In April 2022, **ENOUGH** (formerly 3F BIO Ltd.) received a no questions letter from FDA regarding their ABUNDA® mycoprotein.
- In December 2021, **Motif FoodWorks** received a no questions letter from FDA in response to their GRAS notice for a heme protein derived from yeast, which the company calls HEMAMI™.
- In September 2021, **EVERY** received a no questions letter from FDA in response to their GRAS notice for a soluble egg-white protein produced by yeast.
- In March 2021, **Nature's Fynd** (formerly Sustainable Bioproducts) received a no questions letter from FDA in response to their GRAS notice for a fungi-derived protein.
- In March 2020, **Perfect Day** received a no questions letter from FDA in response to their GRAS notice for beta-lactoglobulin, the major protein in whey.

Singapore

In October 2022, Singapore became the first nation on Earth to grant approval for microbe-based protein ingredient Solein, created by Finnish startup **Solar Foods**. The Singapore Food Agency (SFA) assessed Solein on three levels: safety of the individual ingredients, production process, and that it met standards under Singapore's food regulations. SFA will sample and test the food products containing Solein when the products are ready to be imported into Singapore. Solar Foods' first commercial facility is currently being built in the southern Finnish city of Vantaa and will be up and running in 2024.

Labeling and nomenclature

Labeling of fermentation-enabled and plant-based products remains contentious in some markets. In October 2020, the European Parliament rejected a bill that would have prohibited the use of meat terminology like "sausage" or "burger" on labels for products not derived from an animal carcass. While dairy terms such as "milk" and "yoghurt" are banned under EU law, the European Parliament rejected a proposed amendment that would have banned any "evocation" of the concept of dairy, even when used with a clear modifier such as "alternative" or "style." The amendment would have banned terms such as "creamy," imagery that "evokes" dairy, and packaging forms that resemble conventional dairy packaging.

Companies using fermentation to produce animal-free dairy, eggs, and other novel proteins have not fully aligned on terminology for products or ingredients derived from precision fermentation. In 2022, German fermentation company **Formo** worked with **Fordham University** and **Mercy for Animals** to conduct a study of consumer attitudes toward fermentation-enabled dairy, surveying consumers in Germany, Singapore, the United Kingdom, and the United States. The majority of those surveyed preferred the term "animal-free dairy." Consumers noted that this nomenclature was "direct, simple, and clear." Several companies in the precision fermentation sector are already using this nomenclature or closely related terms, whereas producers using biomass fermentation tend to use unique identifiers for their proteins.

For ingredients (primarily B2B communications):

- The ingredients disclosure on labels for products made with ingredients from **Perfect Day**, use "non-animal whey protein." This parallels "non-animal rennet," a widely accepted term used by cheese manufacturers to refer to rennet made via precision fermentation.
- **The EVERY Company**, a food technology company making eggs and other animal-based proteins using precision fermentation, describes their products as "animal-free." Food technology company Motif FoodWorks also refers to HEMAMI™—the company's fermentation-derived natural flavor product—as "animal- free."

For product labels (primarily consumer-facing communications):

- **Brave Robot** and Graeter's, who also use ingredients from Perfect Day, describe their respective ice cream products as "animal-free dairy." Starbucks described milk that was trialed with Perfect Day dairy proteins as "animal-free milk."
- Change Foods, a company making dairy products enabled by precision fermentation, also describes their products as "animal-free dairy."

In the biomass fermentation sector, companies use various terms to describe products and ingredients, although the category is still emerging and other terms may work equally well or better:

- **Quorn** coined the term mycoprotein to describe their fungi-derived protein ingredient.
- Other biomass companies have developed unique, branded names for their proteins. Examples include Fermotein produced by **The Protein Brewery**, Rhiza produced by The **Better Meat Co.**, Fy produced by **Nature's Fynd**, Promyc produced by Mycorena, Solein produced by Solar Foods, and ABUNDA produced by **ENOUGH**.
- MycoTechnology and other companies that use mycelium from species such as *Lentinula edodes*, whose fruiting bodies are consumed as shiitake mushrooms, may be able to use "mushroom protein," "mushroom extract," or similar terms.

Are we missing something from this Government and Regulation section? Did we get something wrong? We'd appreciate your feedback via this form.

Section 6

Forecast

Section 6: Forecast

Fermentation forecasts

The fermentation pillar represents something of a contradiction: Fermentation as a technology has existed for thousands of years, but some forms of fermentation are relatively new to the alternative protein sector. The pillar's overall nascency means market forecasts are few and far between and can limit the reliability of existing estimates.

The broad definition of "fermentation-derived" alternative proteins—along with the varying stages of the technological development of traditional, biomass, and precision fermentation—can make it difficult to form one cohesive market forecast. In fact, most organizations avoid fermentation-specific forecasts altogether, instead opting for ancillary references to fermentation as part of broader alternative protein industry outlooks. EY, for example, references fermentation in their alternative protein market projection by saying, "As the technologies scale, cultivated proteins and protein via fermentation could be substantially less expensive than conventional proteins between 2030 and 2035," while Blue Horizon points to increased investment as a reason for the likely growth of fermentation's market share. But both organizations stop short of specific market share projections for the sector.

The hesitance to stake out a specific path toward increased market share likely stems from the difficulty of defining the exact target market for each fermentation technology. Traditional, biomass, and precision fermentation as well as plant molecular farming all occupy unique roles in the alternative protein ecosystem and often aim for distinct end-use applications. In fact, the two fermentation sub-pillars most frequently associated with alternative proteins—whole biomass and precision fermentation—don't necessarily share addressable markets. By and large, biomass fermentation aims to replace the meat (or eggs or milk) on the dinner plate by producing vast quantities of high-protein products that mirror the sensory and nutritional experiences of traditional center-of-the-plate items. Alternatively, precision fermentation uses microbes to create specific animal-free yet bioidentical proteins and fats, making for ingredient-friendly applications. These technologies can work in concert to create alternative protein products, but they rarely compete directly in the same product categories.

In other words, the answer to the question of "What share of the market will fermentation-derived products comprise by year X?" involves more caveats than expected at first glance. Each sub-pillar faces its own set of supportive and impeding factors to growth:

- Traditional fermentation benefits from widespread public knowledge and acceptance of the technology but is limited in its ability to, on its own, achieve the taste and texture of a variety of animal products.
- Whole biomass fermentation benefits from its positive consumer perceptions, taste and texture functionality, and excellent sustainability credentials but the introduction of new products is currently impeded by regulatory hurdles, especially in Europe. Scaling also remains a challenge. **Enough**'s new facility in the Netherlands adds capacity, but much more is needed to match the growing opportunity.
- Finally, precision fermentation is supported by its ability to create animal-free animal fats and proteins but also faces its own set of cost hurdles and distributional challenges before the technology can grow to a much larger scale.

So, where are the fermentation markets headed? Fueled by progress made in the past year, consumers around the world will grow increasingly familiar with foods made possible by fermentation's applications to the alternative protein sector. Regulatory clarity around mycelium's novel food status in Europe could help de-risk investments in the space, and precision fermentation will continue to chart new frontiers in dairy, egg, and meat technology. As technologies advance, hybrid plant-based, fermentation-derived, and cultivated products will grow increasingly common in the marketplace as key methods for improving taste and sensory experiences. Investment in the category will likely remain strong, driven by the fast-growth environments of Asia Pacific and the Middle East, and sales of precision and whole biomass fermented products will likely increase as distribution expands.

A global shift to fermentation-derived protein production is not inevitable, though. It can happen with advances in science, significant investments in infrastructure and manufacturing capacities, and delicious, nutritious, affordable products that win over more and more consumers. In 2022, a number of companies, investors, researchers, universities, and governments leaned into fermentation technologies in new and notable ways. This growing momentum, and the increased recognition of the global stakes, is making possible an "animal-free animal protein" future. The next few years are critical, with giant strides needed by all sectors—public, private, academic, and philanthropic—to create an industry capable of transforming how animal protein is made around the world.

A deeper dive into alternative protein market forecasts

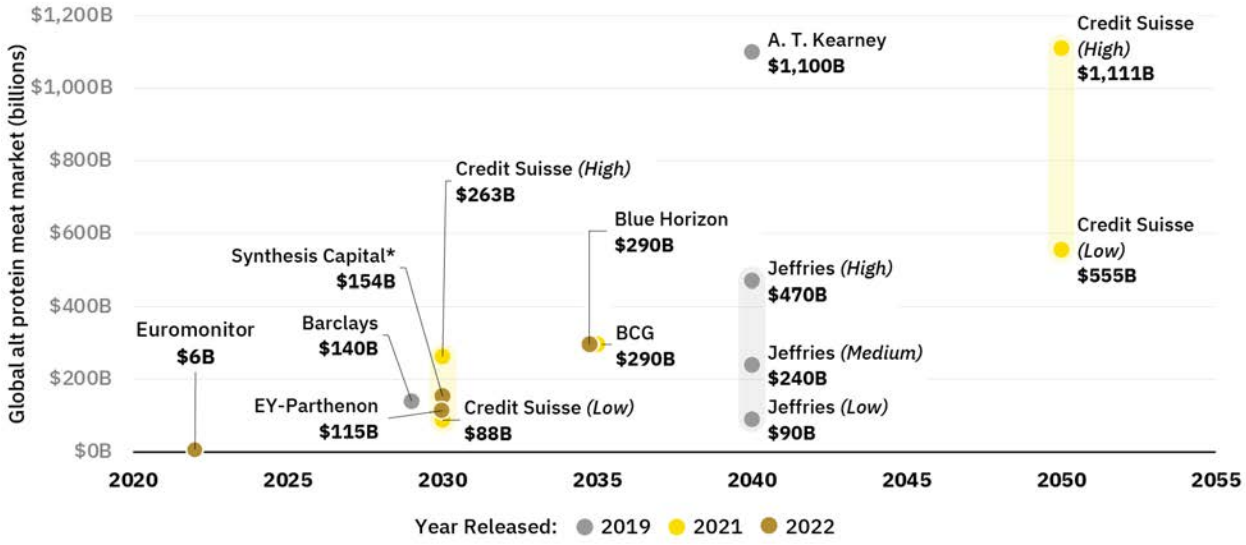
The FAO projects that the global meat market will grow from 360 million metric tons (in 2022) to 455 million metric tons by 2050. Cultivated, plant-based, and fermentation-derived proteins represent an opportunity to significantly reduce risks and improve the efficiency of meat production while offering consumers the meat-eating experience they crave.

Over the past decade, the promise of alternative proteins spurred billions of dollars in investment, led to rapid growth in the plant-based meat market, and increased funding and activity in cultivated meat and fermentation-derived proteins. From 2017 to 2022, the global plant-based meat and seafood market grew 118 percent from $2.8 billion to $6.1 billion, according to Euromonitor data. All-time investments in cultivated, fermentation-derived, and plant-based proteins approached $3 billion, $4 billion, and $8 billion, respectively, by the end of 2022.

Despite the relative newness of the alternative protein sector, industry forecasts followed the trend of rapid growth, with estimates for a 2040 total market size ranging widely from $90 billion to $1.1 trillion. Reasons these forecasts vary are manifold, but they include large variances in key drivers such as customer adoption rates and policy environments. What these forecasts tend to share is mapping out growth paths built on relatively rapid compound annual growth rates.

But in 2022, the short-term outlook for alternative proteins shifted from the rapid growth expectations of prior years. Global overall venture funding fell in response to changing macroeconomic conditions, and alternative protein companies were not immune to this decline. The alternative protein sector with the largest market presence—plant-based proteins—didn't receive investment capital that reached the highs of recent years. On average, alternative protein forecasts limited their upside relative to those published in years prior (see figure 18), as the market landscape tempered expectations for consistently high double-digit year-over-year growth rates. This change was most pronounced in forecasts specific to the plant-based market, but total alternative protein projections also took a more modest approach.

Figure 18: Total alternative protein industry forecasts by year released



Source: GFI synthesis of multiple reports.
**Some forecasts projected share of the total meat market rather than the industry size in dollars. For those forecasts, we estimated the dollar size of the alternative protein sector using EY's forecast for the total 2030 meat market.*

The fact that 2022 forecasts had lower ceilings than those published in earlier years—even though multi-decade outlooks should be relatively impervious to short-term market conditions—raises questions about the benefits of examining the specific outcomes of any single projection. With methods, scope, and publication date varying widely by forecast, it may be more useful to focus on the assumptions, growth factors, and roadblocks shaping projections rather than the topline numbers frequently pulled for headlines, which we do below.

Examining the structure of alternative protein market forecasts

In many cases, the assumptions and inputs of a projection can be more informative than the output itself in navigating the potential impacts of technological developments and policy changes in emerging industries. Often, the key question facing forecasters is less "How will this market develop?" and more "In what type of world will this market develop?" The decisions made on the front end of the forecasting process—about how industry participants will respond to changes in the market, what will drive growth or impede progress, and how market expansion will occur—are the focus of this section.

So, what are the most common assumptions found in alternative protein market forecasts?

Common forecast assumption:

Taste and price parity are essential.

Nearly every forecast implies that improved product features such as taste and price parity with conventional meat will drive the adoption of alternative proteins. Blue Horizon Ventures, for example, affirmed that health, taste, and price are key to boosting demand, while Synthesis Capital discussed a tipping point at which rational consumers switch to alternative proteins based on product cost and quality. These assumptions are backed by research: Multiple studies show that taste and price are essential drivers of alternative protein demand. Achieving taste and price parity for alternative proteins is at the heart of GFI's theory of change—give people the meat they love, made in far more sustainable ways, that costs the same (or less) and tastes the same (or better) than conventional meat. But it's important to remember that product improvements don't occur in a vacuum. In reality, taste and price improvements are likely necessary but perhaps not sufficient on their own for market growth. Factors like product variety, availability, and consumer acceptance are also needed to manifest the more robust visions for the future of alternative protein market share. To compete with conventional meat, alternative proteins must reach taste and price parity, but they also need to encompass the entire selection of conventional meat products, be available wherever conventional meat is sold, and be coveted by consumers.

Common forecast assumption:

Consumer adoption is a limiting factor to market growth.

Most alternative protein market forecasts see growth as dependent on consumers wanting and buying alternative protein products, with market penetration naturally following. Jefferies, for example, identifies consumer tastes and adoption as key drivers of market growth, and Boston Consulting Group states that growth relies on consumers being convinced of taste, texture, and price competitiveness in relation to conventional meat. These views complement the commentary above on the importance of consumer preferences. While taste parity, price parity, and consumer adoption are all necessary, they aren't alone sufficient for achieving market growth—companies must also be able to adequately meet increased market demands for the industry to see growth. While some projections identify manufacturing capacity as a bottleneck, consumer adoption remains the key metric in most overall estimates. This may not be surprising, given how large a share the plant-based category represents in several of these models, and how today, consumer adoption is a central bottleneck to the plant-based industry. Indeed, many plant-based companies with products on the market today elected to cut costs

in 2022 and lower their near-term growth expectations—as such, consumer adoption and manufacturing capacity are fitting leading considerations in this economic environment. The scope of manufacturing capacity scale-up needed is sizeable—$27 billion in capital expenditure by 2030—for plant-based meat to reach even a six percent share of the global meat market.

Common forecast assumption:

Innovation brings more innovation, investment brings more investment.

Alternative protein forecasts generally assume the direction of the alternative protein market is up and to the right: Investment leads to better, more affordable products and technological breakthroughs that continue this cycle, spurring growth and leading to more investment. EY identifies an ever-increasing need for technological innovation in protein production, and Kearney states that it is all but inevitable that alternative proteins will capture substantial market share. The common practice of using compound annual growth rates as forecasts only adds to the sense of a predestined march toward 100-percent market share. While the general assumption of steady growth largely matches overall historical precedents, the growth depicted in many models doesn't tell the full story. Firstly, rapid double-digit growth rates year over year can make sense for an emerging category where bringing one or two facilities online or launching a handful of new products can double revenue. Additionally—and particularly in times of macroeconomic upheaval—it's important to understand that inconsistent growth patterns can be common to emerging industries. When seeking to project realistic long-term outcomes, it's critical to acknowledge that outcomes can take hard turns in either direction with even the smallest of perturbations affecting a market. Take renewable energy and electric vehicles: Just a few short years ago, these technologies struggled to compete in the market. At the time, both were written off as unlikely to ever compete with fossil fuels and gas-powered cars. But as governments continued to expand market access, prices fell faster than most experts expected. Sales of solar energy reached one percent penetration in 2015. Sales of electric vehicles reached that same percent in 2017. Today, the biggest automobile manufacturers in the world are pledging to produce 100 percent electric vehicles by 2035, and according to the International Energy Agency, renewable energy will be the backbone of a carbon-free energy system of the future.

Industry drivers

Next, what are the most common industry-supportive factors identified in existing forecasts?

Supportive factor identified across forecasts:

Consumer acceptance will increase as products improve.

Many consumers already recognize the climate, health, and animal welfare benefits of alternative proteins, but for those products currently available in the marketplace, taste and price metrics often still fall short compared to conventional products. Industry stakeholders recognize additional opportunities for progress, and alternative protein market outlooks point to product innovation as a driver of future growth.

Supportive factor identified across forecasts:

Public and private investment will help lower costs, improve products, and raise awareness of alternative proteins' role at the center of the plate.

While investment dollars in 2022 slowed from record spending in 2020 and 2021, the multiyear trajectory still points upward. Key partners remain committed to alternative proteins' potential—and fermentation specifically, as evidenced by **Meati Foods**' $150 million Series C raise, **Remilk**'s $124 million Series B funding round, and Finland's $36.5 million grant to **Solar Foods**. In addition, public support grew, with governments around the world increasing support for alternative proteins overall in notable ways, from an uptick in public policymaking and R&D funding to the European Commission granting novel food status to **MycoTechnology**'s FermentIQ products. Investment to date is no guarantee of future growth, but sustained support for new technologies and ventures bodes well for the future of the industry.

Industry roadblocks

Finally, what do alternative protein market projections frequently identify as limiting factors to market growth?

Roadblock identified across forecasts:

Current price premiums and a general lack of taste parity with animal products hamper alternative protein brands' abilities to attract new consumers to the space.

Most products on the market today are plant-based, sold at a premium, and don't fully recapitulate the experience of eating conventional meat. Fermentation-derived products can help close the taste gap for alternative proteins, but their markets currently remain small. Inflationary pressures only add to the barriers of high prices, as many consumers look for opportunities to cut costs in their grocery and restaurant budgets. Plus, complex manufacturing processes, limited availability of key ingredients, and cost to scale certain products exacerbate the current price premium and act as speed bumps to the development of the alternative protein market. That said, a clear path remains for reducing prices and improving product quality, and cultivated and fermentation-derived products may ultimately play a key role in closing these gaps.

Roadblock identified across forecasts:

Regulation for some alternative protein product categories is new, and it's possible that regulatory hurdles could slow industry growth.

Immense progress has been made on the path toward a fair and open regulatory environment for alternative proteins. In 2022, the U.S. FDA gave the "green light" to UPSIDE's cultivated chicken, paving the way for the first cultivated meat product to be sold in the United States. A U.S. court ruled that Louisiana's label censorship law targeting plant-based proteins was unconstitutional. But with nearly any new product or technology, the risk of challenging the status quo almost always skews toward more reactive rules and regulations, not fewer.

Since this section largely synthesizes the findings of external forecasts, the three distinct alternative protein pillars are occasionally grouped under the larger alternative protein umbrella. But in reality, each pillar exists in a different stage of development and faces its own unique set of opportunities and challenges for growth.

Fermentation-derived products are on the upswing. Foods made via biomass fermentation hold the potential to provide consumers with healthy, affordable protein that effectively mirrors the meat-eating experience. Precision fermentation and plant molecular farming can generate animal-free animal proteins and fats and have the potential to significantly enhance the taste and functionality of alternative protein products, and traditional fermentation remains a key component of improving the sensory qualities of alternative proteins across the product spectrum. But these technologies and their corresponding infrastructures are in varying stages of development, and many consumers around the world have yet to try alternative proteins made via biomass fermentation, precision fermentation, or plant molecular farming. Continued investments in research and development, capacity build-up, and distribution infrastructure remain key to unlocking the potential of these markets. With significant progress made in these areas in 2022, these markets are likely to see steady growth in the coming years.

Expert predictions

Looking to the year ahead, a group of industry experts weigh in with their predictions of what's next in fermentation for alternative proteins.

"Over the last few years we have seen the industry go from proof-of-concept to tangible progress on scaling production for use in the food sector. This is immense progress in a short space of time – we can now buy animal-free whey protein in multiple products across the US, for example. We are strongly optimistic considering this progress, and the potential for how far we can go – the developments over the last few years are just the start!"

– Catherine Tubb, Ph.D., Director of Research, Synthesis Capital

"To really achieve widespread marketplace success, precision fermentation companies need to overcome a couple of key challenges. Processes need to be further and more efficiently optimized. Costs can then come down so products will become more affordable and accessible for more consumers. This way, early successes in alternative proteins can expand and diversify into more categories, such as fats, colorants and other ingredients. We are hopeful in the coming years our industry will see more facilities, capabilities and opportunities come online."

– Francisco M. Codoner, CEO, ScaleUp Bio

"In the past year fermentation has become the forefront of the industry, mainly due to the food tech sphere shifting strongly towards the climate tech space with more investors coming into the picture and a deeper understanding of the significant role food can play in mitigating climate change. This shift also drives the focus further upstream to ingredients and manufacturing rather than consumer brands and plant based applications. In the next 1-3 years I believe we will see more and more pilot scale and small commercial scale facilities shifting gears into commercial manufacturing, alongside a rise in consumer applications containing microorganism-based ingredients."

– Yonatan Golan, CEO, Brevel

"To me, this is the time for the new generation of plant molecular farming to thrive. With the climate crisis, markets are now ready and a lot of big companies in different markets are looking for new solutions to face the uncertainty of supply in the next 10 years. The main challenges will be scale and time. We need to be careful not to harm the environment when we scale these technologies, and we need to accept that scaling takes time."

– France-Emmanuelle Adil - Co-founder & CEO, Tiamat Sciences

"Cross-industry collaboration will be key to accelerating the success of the fermentation sector. New industry alliances like the Fungi Protein Association and the Precision Fermentation Alliance will facilitate new consumer research, regulatory engagement, and strategic partnerships that will allow the industry to better understand their consumers, unlock public funding, and solve important bottlenecks, like manufacturing capacity."

– Audrey Gyr, Startup Innovation Specialist, The Good Food Institute

Conclusion

Conclusion

Exciting developments propelled the alternative protein field, including microbial fermentation, forward in 2022. The sector still has miles to go, however, to reach full potential. We offer three summary reflections to take into the year ahead:

1
Keep the long view in sight.

Conventional meat consumption is vast and growing, and fermentation-derived products—for now—comprise only a small segment of the total meat, egg, and dairy markets. At this moment, it's promising to see increasing recognition among both the public and private sectors of the potential of microbial fermentation and alternative proteins writ large to meet long-term global goals in the areas of climate, public health, biodiversity, and food security. Advances in alt protein science and technologies are happening fast, as more researchers and funding flow into the field. The policy and regulatory landscape is just starting to take shape. Consumers want sustainable options, but they don't want to compromise on taste, price, or convenience. Navigating and building the path to scale and adoption will take years. Staying on this path while overcoming obstacles and headwinds will be critical to success.

2
A global protein transformation will require strong, system-wide participation.

Companies can lead by delivering tasty, affordable alternative protein products to mainstream consumers, representing a significant market opportunity given growing consumer interest in sustainable foods. The research community can lead by encouraging more scientists, from diverse disciplines and at different points in their careers, to jump into the alt protein field. The world's governments can lead by funding critical R&D to advance alt protein science, manufacturing incentives to help scale-up, and policies that level the playing field to allow alternatives to compete on taste, price, and convenience. Doing so can address the industry's biggest technical challenges, inspire additional research, create new opportunities for growth, and ensure these sustainable foods can benefit everyone.

3

Believe change is possible.

At GFI, we bring determination and informed optimism to our work because we know a better food future is achievable. We see these same traits in those who pushed the field forward this year, many of them highlighted in this report. Across sectors and regions, there is a growing understanding of the importance of finding viable alternatives to industrial animal agriculture, and huge opportunities for companies who get involved in this space. Just as the world is changing how energy is produced, we need to change how meat is made. Alternative proteins can satisfy growing demand, reduce pressure on the planet, and enable a more sustainable, secure, and just food future. Alongside other advances and innovations, alternative proteins—including foods made possible via microbial fermentation—can help write the next chapter for food and agriculture around the world.

To those who are in this work already, we hope this report gives you a more detailed look at this rapidly evolving sector. For thus new to the field, welcome. Stay a while, grow with us, and change the world.

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About GFI

The Good Food Institute is a nonprofit think tank working to make the global food system better for the planet, people, and animals. Alongside scientists, businesses, and policymakers, GFI's teams focus on making plant-based and cultivated meat delicious, affordable, and accessible. Powered by philanthropy, GFI is an international network of organizations advancing alternative proteins as an essential solution needed to meet the world's climate, global health, food security, and biodiversity goals. To learn more, please visit www.gfi.org.

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