

2021 STATE OF THE INDUSTRY REPORT

# Fermentation:

## Meat, seafood, eggs, and dairy



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**The Good Food Institute** (GFI) is an international network of organizations developing the roadmap for a sustainable, secure, and just protein supply. We identify the most effective solutions, mobilize resources and talent, and empower partners across the food system to make alternative proteins accessible, affordable, and delicious.

This report, as well as all of GFI's research, data, and insights, is made possible by gifts and grants from our global family of donors.

GFI's **State of the Industry Report** series dives deep into the key technologies, business developments, and scientific advances driving the alternative protein industry forward:

- Cultivated meat and seafood
- Fermentation: Meat, seafood, eggs, and dairy
- Plant-based meat, seafood, eggs, and dairy
- Industry update: Alternative seafood

*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.*

## Introduction

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Every year, we see new advancements in the alternative protein industry that are opening the door for a global shift to a far more sustainable, secure, and just food system. Like 2019 and 2020 before it, 2021 was the most active year yet for growth in the alternative protein industry, and many signs indicate that the world is on the cusp of a global race for alternative protein innovation.

By making meat from plants, through fermentation, or through cultivation of actual animal cells, we can reduce the harmful climate impacts of our food system, decrease the risk of zoonotic disease and antibiotic resistance, and feed more people with fewer resources. We can also slow biodiversity loss, reduce air and water pollution, and preserve our oceans. Indeed, alternative proteins are to meat production as renewables are to energy: the future. As the global community strives to mitigate climate risks, alternative proteins stand as an enormous opportunity that can help us reach net-zero emissions—but more investment and open-access R&D are needed.

Alternative proteins offer some of the most game-changing research opportunities with potential for global societal impact—stabilizing the climate and preserving biodiversity while eliminating food’s contribution to pandemic risk and antibiotic resistance. But to date, alternative proteins have not been appropriately prioritized. Investment in this nascent field is pennies on the dollar compared with investment in electric vehicles and renewable energy, yet livestock’s global greenhouse gas emissions are on a par with those from transportation (see [gfi.org/climate](https://www.gfi.org/climate)). Together, increased public and private investments in alternative proteins can write the next technological chapter for agriculture and spur economic growth while improving both environmental and global health outcomes.

Within the alt protein landscape, fermentation continues to gain momentum as a powerful enabling technology with applications across all platforms. Fermentation is being harnessed to improve sensory and functional attributes that can move alternative proteins closer to achieving taste parity with conventional animal products. In addition to many new companies formed in 2021, the fermentation ecosystem grew with new suppliers, business lines, manufacturing facilities, and applications, as well as record-setting investments.

While fermentation is a mature technology, its applications for alternative protein products are in the early stages of discovery. As fermentation-derived products come to market as part of a global shift away from animal-based proteins, companies are rightly touting not only improved taste, functionality, and nutrition but the sustainability of these game-changing foods.

The greatest hurdle facing alternative protein fermentation over the next decade will be building manufacturing capacity. Ensuring capacity is sufficient to meet the projected rise in demand for products will require significant investment. Such investment can have a multi-solving effect, enabling companies to scale and bring down costs while simultaneously working toward a net-zero food system.

We present this state of the industry report, *Fermentation: Meat, Seafood, Eggs, and Dairy*, to highlight the sector’s key developments in 2021 and look ahead to what’s next.



**Caroline Bushnell**

VP of corporate engagement at the Good Food Institute

# Executive summary



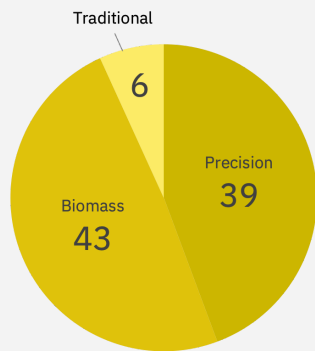
## Executive summary

Fermentation is a powerful enabling technology that is increasingly driving innovations across the alternative protein industry. In 2021, the sector continued to expand with key developments across commercial, product, investment, science and technology, and government and regulation landscapes.



### Commercial landscape

#### Number of companies by type of fermentation



**New startups.** Fifteen known startups dedicated to the use of fermentation for alternative proteins were founded in 2021, along with new suppliers focused on fermentation-enabled alternative protein ingredients.

**Precision fermentation.** Activity in precision fermentation increased, with nine of the 15 new companies focused on precision fermentation and six focused on biomass fermentation.

#### Known companies.

Eighty-eight known companies are now dedicated to fermentation-enabled alternative proteins, an increase of 20 percent from the number of known companies in 2020.

**Business lines.** At least 75 additional companies have a business line in alternative protein fermentation.



### Products

In 2021, companies advanced applications of fermentation technology to develop end products and ingredients to enhance plant-based products across categories:

- Whole-cut meat
- Seafood
- Chicken
- Beef
- Pork
- Cheese
- Eggs
- Milk
- Yogurt
- Ice cream

**Eggs.** The EVERY Company, formerly Clara Foods, **launched their first animal-free egg protein, ClearEgg**, in November 2021 in partnership with Pressed Juicery.

**Dairy.** Perfect Day's **recombinant whey proteins** became broadly commercially available in a range of products and brands.

**Fats and oils.** **Cultivated Biosciences** announced they were developing a functional fat ingredient from oleaginous yeast that can be used as a high-fat component of plant-based dairy formulations. **Mycorena unveiled a new fungi fat ingredient** that releases flavor in a similar way to animal-based fats.

## Investments

Investment in fermentation technology skyrocketed in 2021. Fermentation companies focused on the alternative protein sector raised \$1.69 billion—almost three times the amount raised in 2020—representing 60 percent of all-time sector funding and accounting for a third of 2021 alternative protein industry funding.

Category	2021	2013–2021	Highlights
<b>Total invested capital</b>	\$1.69B	\$2.81B	2021 invested capital grew 285% from 2020.
<b>Invested capital deal count</b>	54	161	2021’s largest investments were \$350 million (Nature’s Fynd and Perfect Day).
<b>Unique investors</b>	130 new	434	The number of new unique investors grew by 43% in 2021.
<b>Growth-stage fundraising (Series B and above)</b>	9	9	2021 saw the first growth-stage fundraising in the fermentation industry, including three deals >\$200 million.
<b>Liquidity events</b>	\$9.3M	\$1.50B	Quorn, the mycoprotein pioneer founded decades before most other mycoprotein companies and now owned by parent company Monde Nissin, accounts for the vast majority of fermentation liquidity events.

## Science and technology

GFI (via its [research grant program](#)) funded three projects on fermentation-derived fat solutions using oleaginous yeast, microalgae fermentation, and lipophilic yeast.

A consortium of European companies and universities launched a three-year “**Bio-purification of plant proteins**” project to explore how fermentation can improve plant-based protein ingredients.

BioFoundries and other computational tools emerged, such as Ginkgo Bioworks **Grow with Ginkgo program** and Google DeepMind’s protein-structure prediction algorithm **AlphaFold2**.

At least 11 new manufacturing facilities for fermentation were announced in 2021 across Europe, the United States, and Asia. Of these, at least eight are focused on biomass fermentation.

## Government and regulation

**Regulatory advances.** **Motif FoodWorks**, **The EVERY Company**, and **Nature’s Fynd** all received a no-questions letter from the U.S. Food and Drug Administration. Their products are generally recognized as safe (GRAS). Products include a heme protein derived from yeast, a soluble egg protein produced by yeast, and a fungi-derived protein.

**Investments and funding.** Israeli company Imagindairy, which uses precision fermentation to create milk proteins, received funding from the Israel Innovation Authority.



Section 1

# Fermentation's role in alternative proteins



## Section 1: Fermentation's role in alternative proteins

Fermentation in the alternative protein industry 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:

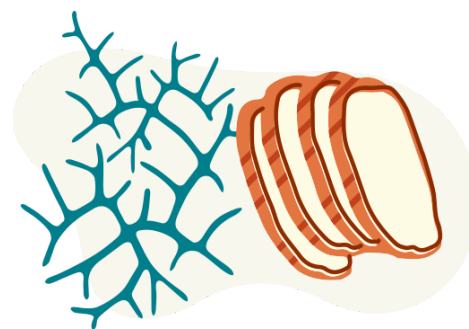
- 1) **Traditional fermentation** has been used for thousands of years to produce items such as bread and beer. It uses intact live microorganisms to modulate and process plant-derived ingredients, resulting in products with unique flavor and nutritional profiles and modified texture. Examples of this include using the fungus *Rhizopus* to ferment soybeans into tempeh and using various lactic acid bacteria to produce cheese and yogurt. A more modern version of this concept is **Mycotechnology's** fermentation of plant-based proteins with shiitake mycelium to improve flavor and functionality.



**Traditional Fermentation**

Traditional fermentation is highly relevant for alternative proteins because it can improve the sensory, functional, and nutritional attributes of many ingredients. The majority of companies using traditional fermentation, such as **Miyoko's Creamery**, which produces fermented plant-based dairy products, can be found in **GFI's 2021 plant-based meat, seafood, eggs, and dairy report**.

2) **Biomass fermentation** leverages the fast growth and high protein content of many microorganisms to efficiently produce large quantities of protein. 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 primary ingredients in a blend. Seventy percent of known biomass fermentation companies have a focus on developing ingredients and inputs for use in alternative protein end products.



**Biomass Fermentation**

A range of microorganisms are being explored for their applications in biomass fermentation, from yeast to filamentous fungi to microalgae. For example, the Israeli company **YEAP** and German company **SACCHA** are focused on using spent yeast from industrial processes to produce proteins. **Meati**, a company headquartered in Colorado, uses filamentous fungi as the base for their whole-cut steak and chicken products. An increasing number of biomass companies are also focused on microalgae that is grown without sunlight and is instead fed sugar, known as heterotrophic growth. **Sophie's Bionutrients** and **Smallfood** are two companies paving the way with microalgae innovations relevant to protein production.

3) **Precision fermentation** uses microbial hosts as “cell factories” for producing specific functional ingredients. Precision fermentation is well suited to creating high-value ingredients for plant-based foods. These ingredients typically require greater purity than the primary protein ingredients and are incorporated at much lower levels in finished products. These ingredients are powerful enablers of improved sensory characteristics and functional attributes of plant-based products or cultivated meat. Precision fermentation can produce enzymes, flavoring agents, proteins, vitamins, natural pigments, and fats.



**Precision Fermentation**

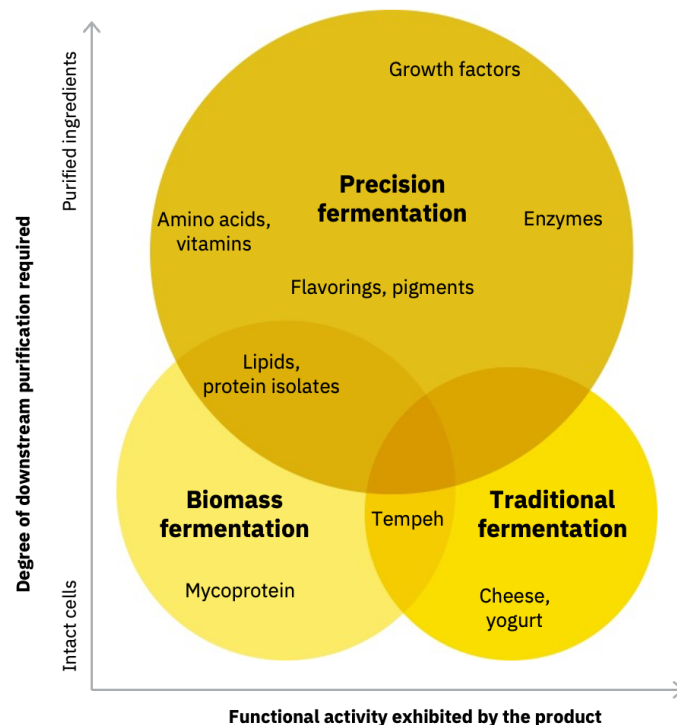
Companies using precision fermentation include **The EVERY Company**, which produces egg proteins; **Formo**, which produces dairy proteins; and **Melt&Marble**, which produces fats. Some precision fermentation companies are producing animal-free meat proteins, such as the HEMAMI™ myoglobin from **Motif FoodWorks**. 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 initiatives are generally divided into products of traditional fermentation, biomass, and functional ingredients (produced via precision fermentation), the line between biomass and functional ingredients is not always clear. 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. These proteins, as well as fats and other compounds, are best considered along a spectrum. Alternative protein end products can also incorporate ingredients created from the different production pillars (plant-based, cultivated, and fermentation-derived) to develop hybrid products with enhanced functionality, taste, and texture. The following figures highlight the range of options available for alternative protein products that use fermentation.

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

**Figure 1: A conceptual landscape of fermentation-derived and fermentation-enabled products**

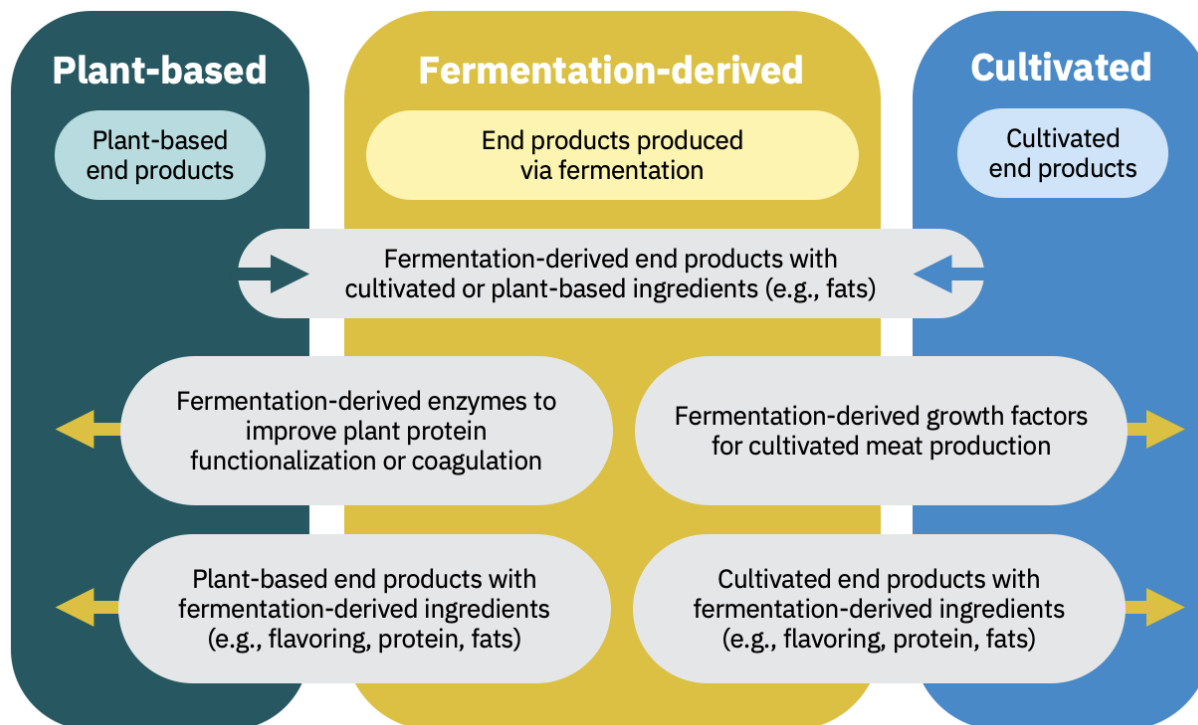


**Figure 2: Mind map of fermentation in the alternative protein industry**



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 3: 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 fermentation-enabled alternative protein 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 1: Types of companies included in report scope**

Included	Not included
<ul style="list-style-type: none"> <li>• 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 meat cultivation (such as growth factors).</li> <li>• Mycelium to produce edible biomass or functional ingredients for plant-based meat, eggs, and dairy.</li> <li>• Fermentation to produce pet food (which is highly relevant to human food applications).</li> </ul> <p>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.</p>	<ul style="list-style-type: none"> <li>• Fermentation to produce food ingredients that are not replacements for meat, eggs, or dairy (such as sweeteners and baking enzymes).</li> <li>• Fermentation to produce food items other than for humans or pets.</li> <li>• Fermentation to produce molecules for other non-food applications (such as biofertilizer, farmed animal feed, aquaculture feed, chemicals, biofuel, cosmetics, and biologics).</li> <li>• Large corporations with R&amp;D efforts in fermentation that are not publicly disclosed, as well as startup companies in “stealth mode.”</li> <li>• Nut-based and other fermented cheese and butter made from plants (such as Miyoko’s Creamery), which are covered in GFI’s <a href="#">state of the industry report on plant-based meat, eggs, and dairy</a>.</li> <li>• Tempeh and other traditional fermented foods, such as sourdough or kimchi, which are not analogues for meat, egg, or dairy products.</li> <li>• Mushrooms (the fruiting bodies of some fungi).</li> <li>• Macroalgae (such as kelp, seaweed, dulse, and sea vegetables).</li> <li>• Nonprofit organizations and academic research labs.</li> </ul> <p>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.</p>



For more background on fermentation, its definitions, and its applications, check out GFI’s [fermentation](#) page.

## Section 2

# Commercial landscape





# Section 2: Commercial landscape

In 2020, fermentation officially joined plant-based and cultivated proteins as the third production pillar of the alternative protein revolution. And in 2021, fermentation came into its own as a powerful technological platform accelerating development of the alternative protein industry. Modern fermentation technology combines the ancient wisdom of traditional food fermentation, lessons of scale learned from biofuels, precision methods pioneered by biopharmaceuticals, and the breakout success of the plant-based meat industry to take alternative protein products to the next level.

## Overview

Across the supply chain, fermentation as an enabling technology for alternative proteins is drawing increased interest.

- At least 88 companies focus primarily on fermentation for alternative protein applications.
- At least 70 other known companies, including life science, pharmaceutical, nutrition, agricultural, and big food companies, have a business line or focus area on alternative protein fermentation applications.
- Over 50 percent of companies devoted to fermentation-enabled alternative protein applications formed in the past three years, from 2019 to 2021.
- Over 80 percent of alternative protein fermentation companies have launched in the past five years.

## By the numbers

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**15** **dedicated startups launched in the fermentation-enabled alternative protein space in 2021.** At least 9 are developing dairy products, 3 are focused on seafood, and 8 are focused on ingredients and inputs to be used in alternative protein products. See Table 3 for the full list.

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**9** **of the 15 new entrants in 2021 are focused on precision fermentation.** Of these, 5 are focused on creating dairy proteins, and 4 are developing fats and oils.

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**6** **of the 15 new entrants in 2021 are focused on biomass fermentation.** Of these, 3 are developing seafood products.

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**4** **of the 7 fermentation companies developing oils and fats for use in alternative proteins were formed in 2021.**

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**88** **known companies are now dedicated to some of the newest and most promising applications for fermentation—creating proteins, lipids, and functional ingredients for plant-based products and cultivated meat.** See Table 3 for the full list.

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**70+** **known companies have a business or product line focused on fermentation-enabled alternative proteins,** including Kingdom Supercultures, Culture Biosciences, and Pow.bio. See Table 4 for the full list.

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## Fermentation for alternative protein end products

We have seen a meteoric rise over the past few years in the number of new companies applying precision and biomass fermentation technologies to alternative proteins.

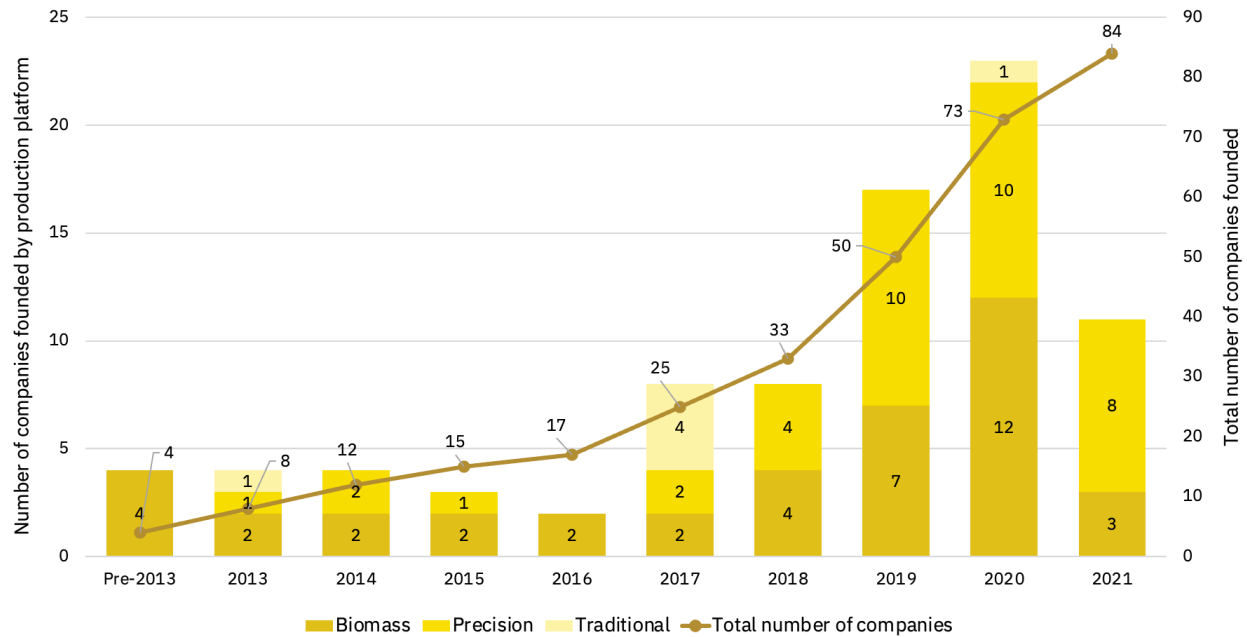
Between 2019 and 2021, an average of 10 new precision fermentation companies were established each year. Most precision fermentation companies—over 60 percent—are focused on the dairy category. About 20 percent are developing meat solutions. The remainder includes a handful of seafood and egg protein companies.

Formation of biomass fermentation companies accelerated in the past few years, with 12 new companies emerging in 2020 and six in 2021. The majority of these companies produce ingredients and inputs for use in meat-analogue products. Seafood is an emerging area, with half the new biomass companies in 2021 stating that seafood was a focus area.

**Table 2: Number of companies by type of fermentation**

Type	Companies launched in 2021	Total companies	Sector share of total number of fermentation companies
Traditional	-	6	7%
Biomass	6	43	49%
Precision	9	39	44%

**Figure 4: Number of companies in fermentation-enabled alternative proteins by year founded**



Source: GFI company database.

**Table 3: Companies focused on fermentation for animal-free meat, seafood, eggs, and dairy (ordered alphabetically)**

Company	Brief Description	Year Founded	Website	Logo	Protein Category	Company Focus
Bright Biotech	U.K.-based company developing a plant-ba...	2017	https://www.brightbiotec...		Plant-based, Cultivated	Bioprocessing infrastru...
Moolec Science	Science-based ingredients company using ...	2020	www.moolecscience.com		Plant-based, Plant moleci	Meat, Eggs, Dairy
Nobell Foods	US-based company developing plant-base...	2016	https://www.nobellfoods...	nobell	Plant-based, Plant moleci	Meat, Ingredients and i
PLANETARIANS	Developer of ingredient technology system...	2017	https://www.planetarians...		Traditional fermentation	Meat
Chunk Foods	Makes clean label, plant-based whole cut p...	2020	https://www.chunkfoods...		Traditional fermentation	Meat
Prime Roots	Startup working on meat analogs made fro...	2017	https://primeroots.com/		Traditional fermentation	Meat, Seafood
The Mediterranean Food Lab	Uses raw materials of the Mediterranean Di...	2017	https://www.med-food-la...	THE MEDITERRANEAN FOOD LAB	Traditional fermentation	Dairy, Meat
Mycotechnology	Producer of pea and rice proteins fermente...	2013	http://redesign.mycotech...	Mycotechnology	Traditional fermentation	Ingredients and inputs
Wild Earth	Koji-based pet food using fermentation pla...	2017	https://www.wildearthpet...		Traditional fermentation	Other
Meati Foods	Whole muscle meats made from fungi mark...	2016	https://meati.com/	meati	Biomass fermentation	Meat
Mushlabs	Produces food from edible mushroom myc...	2018	https://www.mushlabs.co...		Biomass fermentation	Meat
More Foods	Producing beef via a high protein yeast ble...	2019	https://www.more-foods...	more	Biomass fermentation	Meat
Innomy	Company producing fungi-based meat.	2020	http://innomylabs.com/#/...	Innomy	Biomass fermentation	Meat
Sincarne, Inc.	US-based company focused on creating m...	2021	https://sincarne.com/	Sincarne	Biomass fermentation	Meat, Eggs, Dairy
Mycovation	Singapore based mycoprotein technology c...	2020	https://www.mycovation.a...		Biomass fermentation	Meat, Dairy, Ingredie
Noblegen	Noblegen produces high-value ingredients ...	2013	https://www.noblegen.com/	noblegen	Biomass fermentation	Meat, Dairy, Ingredie
Quorn	Produces f. venenatum mycoprotein-based...	1985	http://www.quorn.us/	Quorn	Biomass fermentation	Meat, Seafood
Libre Foods	Creates whole-cut products grown from fu...	2020	www.librefoods.co		Biomass fermentation	Meat, Seafood
Rethink Bio	Developing alternative protein ingredients f...	2020	https://www.rethinkbio.in/		Biomass fermentation	Meat, Seafood, Dairy
The Protein Brewery	Producer of "Fermotein" fungi based protei...	2019	https://www.theproteinbr...		Biomass fermentation	Meat, Ingredients and

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

*The list of companies above is intended to be as comprehensive as possible but should not be considered exhaustive. 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**.*



“Fermentation is an enabler of what’s possible for scaling the alternative protein industry and delivering solutions that can help meet consumers’ ever-growing demand for protein that meets their needs, from nutrition to great taste.”

—Tasha Hermes, R&D manager, Cargill

## Fermentation initiatives for animal-free meat, eggs, and dairy

More than 70 companies have some kind of commercial initiative in fermentation-enabled alternative proteins. These companies span the technology value chain, all elements of which are important to advancing fermentation as an alternative protein production platform:

- Target metabolite identification and selection
- Microbial strain development
- Feedstock discovery and optimization
- Bioprocessing design and manufacturing
- End product and ingredient commercialization

An increasing number of companies focused on other fermentation applications are beginning to expand their product offerings to include alternative proteins. For example, **Fooditive**, a sweetener company based in the Netherlands, announced in 2021 that they were expanding into alternative proteins with the launch of a casein product produced via precision fermentation. Chr. Hansen, a global bioscience company, **announced the launch of a “culture kit”** specifically designed for the fermentation of plant proteins.

Table 4 lists companies with initiatives in fermentation for alternative proteins. For a full list, please visit [this link](#).

**Table 4: Companies with fermentation initiatives for animal-free meat, eggs, and dairy**

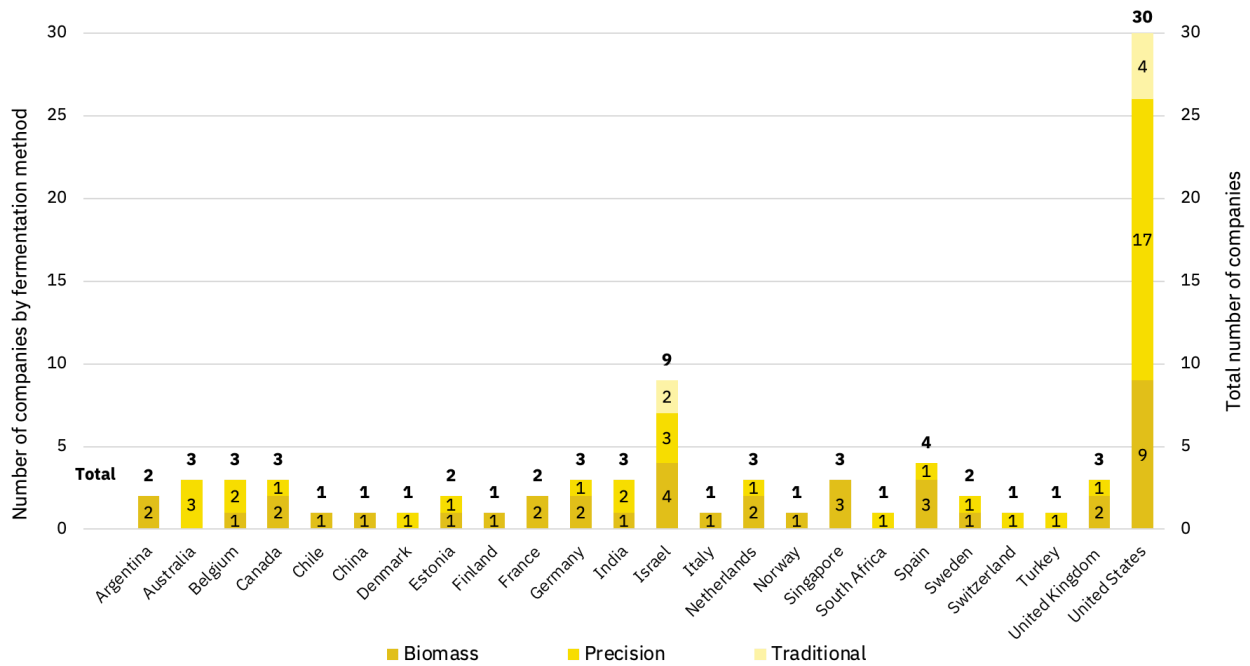
Company	Brief Description	Primary Focus Alternative	Year Founded	Website	Logo	Protein Category
CP Kelco	CP Kelco is a nature-based ingredient solut...	No	1929	www.cpkelco.com		Plant-based Cultivated
Symrise		No				Plant-based Fermentati
Biocatalysts Ltd	Global speciality enzyme development and ...	No	1983	www.biocatalysts.com		Plant-based Fermentati
KRONES AG	The Krones Group plans, develops and ma...	No	1951	https://www.krones.com/		Plant-based Fermentati
Yosin Biotechnology (Yantai) C...	China-based company that specializing in ...	No		https://www.yosinbio.com...		Plant-based Traditional
Corbion	Netherlands-based company that produce...	No		http://www.corbion.com		Plant-based Biomass fe
Geb Impact Technology Compa...	Hong Kong-based biotechnology company ...	No	2013	https://www.gebimpact.c...		Plant-based Biomass fe
Center of Food and Fermentat...	Estonia-based privately-owned contract re...	No	2004	https://tftak.eu		Plant-based Precision f
Back of the Yards Algae Scienc...	Startup working on algae-based cell cultur...	No	2018	https://www.algaescience...		Cultivated Fermentation
3D Bio-Tissues Ltd.	Research entity aimed at improving both th...	No	2019	https://www.3dbiotissues...		Cultivated Fermentation
Celltainer Biotech BV (part of a...	Startup developing single-use bioreactor u...	No	2015	http://celltainer.com/		Cultivated Fermentation
Molecular Devices	We provide our customers with innovative ...	No	1990	https://www.molecularde...		Cultivated Fermentation
Laurus Bio	Laurus Bio is an innovation-led biotechnolo...	No	2005	https://laurus.bio/about-us/		Cultivated Fermentation
ORF Genetics	Producer of plant-made recombinant growt...	No	2001	https://orfgenetics.com/p...		Cultivated Fermentation
Biostream International	Netherlands-based company that produce...	No	2013	https://www.biostream-in...		Cultivated Biomass fern
INFORS HT	Switzerland-based company that develop...	No	1965	https://www.infors-ht.co...		Cultivated Precision fer
Core Biogenesis	Core Biogenesis uses plants as biofactori...	No		https://corebiogenesis.co...		Cultivated Plant molecu
BioBetter	BioBetter Ltd. is the developer behind a tru...	No	2015			Cultivated Plant molecu
UCDI		No		https://www.co2.co.jp/en/...		Fermentation-derived
IMenz Bioengineering	R&D partner for fermentation solutions (pa...	No	1998	http://www.imenz.com/		Fermentation-derived

*This list of companies is intended to be as comprehensive as possible but should not be considered exhaustive. 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**.*

## Geographic expansion

The fermentation industry spans the globe. Companies involved in fermentation for alternative protein applications operate in at least 24 countries. The largest concentration of companies is in the United States with 31, followed by Israel with nine and Spain and Germany with four each. Of the 15 companies formed in 2021, three are in the United States, two are in Estonia, and the rest are in Australia, Austria, France, India, Israel, South Africa, Sweden, Switzerland, and Turkey.

**Figure 5: Geographic distribution of fermentation-enabled alternative protein companies by headquarters**



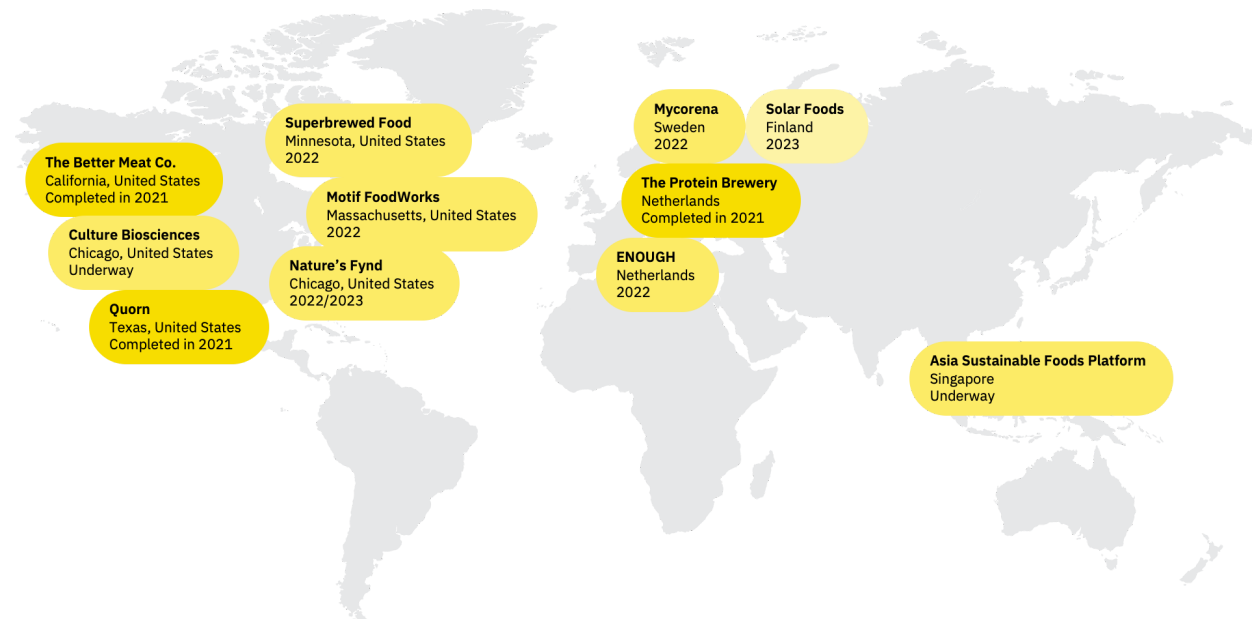
## Manufacturing and scaling up production

Manufacturing capacity is a major bottleneck in scaling fermentation companies. For precision fermentation companies, the lack of capacity is particularly pressing. More precision fermentation capacity was reportedly **lost in 2021 than was added**. Many of the facilities that exist today are old and configured for pharmaceutical or ethanol production, not food production, leading to inefficiencies as precision fermentation companies scale up their production for food purposes. There is little public or private capital for companies to develop their first scale-up facilities. To address this funding gap, The Breakthrough Institute, an environmental research center, called for **public investment in fermentation to transform protein production**.

Despite these challenges, 2021 saw several companies announce new facilities to scale production of their fermentation-derived products. Notably, the majority of facilities announced are designed to scale biomass fermentation production. These facilities will increase the ability of those companies to meet demand for their products and ingredients, though they are not sufficient to meet the overall need for increased fermentation infrastructure in the coming years. For fermentation to realize its full potential, additional manufacturing infrastructure must be developed.

Figure 6 highlights several facilities announced or completed in 2021 that will be focused on producing alternative proteins.

## Figure 6: New fermentation production facilities



### **The Protein Brewery | Netherlands | Completed in 2021**

The Protein Brewery completed construction of their pilot plant, designed to produce 100 kg per day of Fermotein, their proprietary protein-rich, fibrous fungi that can be used as an ingredient in alternative meat and seafood products.

### **The Better Meat Co. | California, United States | Completed in 2021**

The Better Meat Co. finished construction on a 13,000 sq. ft. facility to produce Rhiza, their proprietary mycoprotein ingredient with a meat-like texture.

### **Nature's Fynd | Chicago, United States | Underway, expected completion in 2022 or 2023**

Nature's Fynd announced plans to build a new 200,000 sq. ft. manufacturing facility in Chicago to produce Fy, an alternative protein sourced from fungi and produced through fermentation that has applications in meat and dairy products.

### **Mycorena | Sweden | Underway, expected completion in 2022**

Mycorena established a joint venture with property management company Falkenberggruppen to establish a facility for large-scale production of their fungi-based protein called Promyc. The new facility is expected to produce several thousand tons each year. Promyc can be used as an ingredient in whole cuts, patties, balls, mince, and nuggets.

### **Solar Foods | Finland | Underway, expected completion in 2023**

Solar Foods announced plans to begin building its first industrial-scale production facility this year for Solein, a protein created from air.

### **ENOUGH | Netherlands | Underway, expected completion in 2022**

ENOUGH announced plans to build a large fermented-protein facility to produce their mycoprotein ingredient ABUNDA. Capacity will start at 10,000 tons per year and increase to 50,000 tons per year by 2027. The facility is co-located with a Cargill commodity-processing site.

### **Culture Biosciences | California, United States | Underway**

Culture Biosciences secured \$80 million to ramp up production of five-liter and 250-liter cloud bioreactors so their clients can begin sensory and regulatory testing of larger quantities of novel fermentation-enabled or cell-based products on their path to market. Importantly, this facility will enable fermentation companies to gather crucial scaling data to accelerate their transition into a true commercial-scale facility or co-manufacturing relationship.

### **Superbrewed Food | Minnesota, United States | Underway, expected completion in 2022**

Superbrewed Food is retrofitting a large-scale ethanol production facility to produce up to 20,000 tons per year of their “brewed” protein. They will use the facility to make alternative dairy products like cheese.

### **Motif FoodWorks | Massachusetts, United States | Underway, expected completion in 2022**

Motif FoodWorks announced they would open a new 65,000 sq. ft. R&D and pilot-scale production facility to scale up HEMAMI™ and APPETEX™ (their plant-based texture ingredient that’s not made through fermentation). The facility will feature three pilot production lines for fermentation, ingredient, and finished-product production. HEMAMI™, an animal-free myoglobin protein that lends authentic meat flavors and aroma to plant-based products, promises to be a game changer.

### **Quorn | Texas, United States | Completed in 2021**

Quorn announced the opening of an R&D center in Dallas, Texas. This is part of the company’s U.S. expansion strategy, and the culinary development hub will focus on product innovations for the North American market.

### **Asia Sustainable Foods Platform | Singapore | Underway**

Temasek and the Agency for Science, Technology and Research (A\*STAR) have committed \$30 million to launch the Asia Sustainable Foods Platform, which will provide R&D advisory and pilot-scale manufacturing facilities (the Food Tech Innovation Centre) to help food-tech companies in Asia scale up production and accelerate the growth of alternative protein foods in the region.



## Products

Culinarians, ingredient companies, and food manufacturers increasingly recognize the potential of targeted fermentation to endow foods with unique flavor, texture, and nutritional attributes. Along with advances in biotechnology, data analysis, and industrial design, this potential has established fermentation as an indispensable platform for innovations in both ingredients and primary protein production. 2021 saw the development and launch of more alternative protein products created with this technology, including several noteworthy industry firsts.

### Consumer product categories: Fermentation allows for a huge diversity of products

In 2021, companies advanced applications of fermentation technology to produce ground meat products, whole-cut meats, eggs, milk, cheese, ice cream, seafood, fats, oils, honey, infant formula, collagen, gelatin, pet food, and more. Fermentation is also enhancing plant-based products across these categories. As these products come to market, companies are touting not only the taste, functionality, and nutrition of their products but the sustainability of their manufacturing processes.

### Ground meat

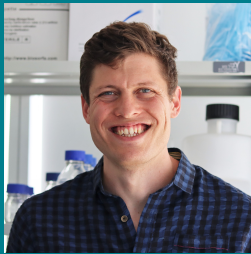
Ground products are a common format for alternative products because the texture of conventional ground meat is often easier to replicate with existing technology. Several fungi-based ground meat products launched in 2021:

- The Chicago-based company Nature's Fynd announced **the sale of their Breakfast Bundle**, which contains cream cheese and breakfast patties both made out of their signature Fy protein. They also released the results of a life-cycle assessment, which found that their Fy protein requires **99 percent less land and 87 percent less water than beef**. The company also **raised \$350 million in a Series C round** to scale production.
- KFC Singapore rolled out their mycoprotein-based **Zero Chicken Burger** at nearly all KFC Singapore locations.

### Whole-cut meats

Whole-cut products are often considered the holy grail of alternative proteins because of the challenges in replicating the texture of fillets, steaks, and other pieces of intact meat tissue. Fermentation presents opportunities for fibrous texture in whole-cut meats without the extrusion processes on which plant-based products have traditionally depended:

- Colorado-based Meati Foods **raised \$50 million in an oversubscribed Series B** to scale production of their whole-cut mycelium-based steak and chicken products. The company also **tested their products at a restaurant** in Boulder, Colorado.
- **The Better Meat Co.** debuted their mycelium-based steak at a high-end Sacramento steakhouse in August 2021.
- **Israel-based More Foods** produces beef strips made from a high-protein yeast blend. The use of yeast over other traditional proteins enables the company to create a texture that more closely resembles whole cuts.
- Chunk Foods is creating **whole cuts of steak** using solid-state fermentation. The Israeli company raised \$2 million in seed funding to further develop their products.



“Chunk’s technology combines plant ingredients and food-grade microorganisms to create a variety of whole muscle cut alternative products. This approach benefits from the cost-effectiveness of plant-based products, combined with the excellent flavor, texture, and production efficiency of fermented foods. The process offers opportunities in scaleup and manufacturing as it is mostly based on readily available raw materials such as soy, while still allowing for very fine control of product properties such as texture and flavor, at competitive unit economics compared to meat. The process results in a short and clear ingredient list and requires a fraction of the CAPEX of a classic biomass fermentation facility.”

—Amos Golan, founder, **Chunk Foods**

## Eggs and egg replacements

Fermentation holds the potential to impact the **\$227 billion global egg industry**. In 2021, several new fermentation-enabled egg products and ingredients became available on the market for the first time:

- EVERY **launched their first animal-free egg protein** in November 2021 in partnership with Pressed Juicery.
- OsomeFood, a Singapore-based startup, debuted a **hard-boiled egg** made from fungal mycoprotein.
- SACCHA, a German startup, announced that their alternative protein, derived from fermenting spent brewer's yeast, had the functionality of egg protein. According to the company, **the soluble protein uses 250 times less water than beef and generates 13 times fewer CO2 emissions than pea protein**.
- Nanyang Technological University in Singapore announced the development of an **emulsifier created from fermented brewers' spent grain**. The product can be used as a replacement for eggs and dairy in foods such as mayonnaise and whipped cream.

### Fermentation-enabled egg proteins come to market

Precision fermentation had a significant market advancement in 2021 with the launch of EVERY's ClearEgg and EggWhite products. The first company to bring a genuine animal-free egg protein to market, EVERY, formerly known as Clara Foods, was formed in 2014 by Isha Datar of New Harvest and New Harvest community members David Anchel and Arturo Elizondo. The company's fermentation-derived egg proteins are produced using microbes. EVERY ClearEgg is an animal-free, soluble, virtually tasteless and odorless egg protein that can be used to enhance a range of beverages and foods. In late 2021, ClearEgg **made its commercial debut** through EVERY's partnership with cold-pressed-juice brand Pressed, which puts the product in smoothies. EVERY EggWhite is an animal-free protein that can replace egg whites but is not yet commercially available.



“Precision fermentation as a biological technology is an incredibly powerful one—capable of producing the exact molecules and compounds out in the world today with laser-like precision, all while using far less water, land, and energy. The proteins made using this technology can possess the exact same amino acid profile, taste, and functional properties of the animal-derived animal protein. That means companies and consumers can use them in the exact same way without any behavior or experience changes.”

—Arturo Elizondo, founder and CEO, EVERY

## Dairy

Fermentation-powered proteins are poised to be hugely transformative to the dairy category owing to the amount of innovation in product functionality and taste. Nearly 65 percent of precision fermentation companies (24 of the 39 known companies) are focused on creating proteins or fats found in dairy, and several biomass fermentation companies are creating products for use in dairy applications:

- In 2021, Perfect Day’s recombinant whey proteins became broadly commercially available in a range of products and brands.
  - Starbucks **began trialing Perfect Day’s milk** at select locations.
  - Perfect Day’s subsidiary, The Urgent Company, **launched Modern Kitchen**, a brand making animal- and lactose-free cream cheese, and **California Performance**, a brand producing animal-free whey protein powder. California Performance whey protein is available in Singapore and Hong Kong, making this the company’s first expansion outside the United States.
  - **Hong Kong’s Igloo Dessert Bar** launched Asia’s first-ever animal-free ice cream, using Perfect Day’s dairy proteins.
  - The Urgent Company also **acquired the Coolhaus ice cream brand** with plans to transition their products to animal-free versions using Perfect Day’s animal-free dairy proteins in the formulations.
  - Perfect Day **released the results of a life-cycle assessment** (LCA) of its animal-free whey protein. According to the LCA, Perfect Day’s protein production reduces blue water consumption by at least 96 percent and nonrenewable energy use by at least 29 percent, compared with conventional production methods for whey protein. These findings add to prior ones revealing that the company’s production method reduces greenhouse gas emissions up to 97 percent.

- Sophie’s Bionutrients partnered with Ingredion Idea Labs to **create microalgae-based cheese** from their microalgae milk (made from microalgae protein powder mixed with water). The cheese is reportedly reminiscent of cheddar, and its application could be in the form of a spread or a block.
- Nature’s Fynd **debuted cream cheese** made with their signature Fy protein in breakfast bundles alongside the company’s breakfast sausages with a retail launch in California.
- Superbrewed Food (formerly White Dog Labs) announced they would **produce dairy products**, including a range of dairy-free cheeses, from their novel microbial protein.

## Seafood

Seafood is a significant white space in the alternative protein sector. To date, there are at least 11 companies producing alternative seafood using fermentation-enabled technology. In 2021, the industry welcomed at least one new company, along with several other exciting milestones:

- Estonia-based B2B startup **Meet Future** began developing fish and chicken alternatives using mycoprotein.
- Chicago-based Aqua Cultured Foods **debuted** a whole-muscle seafood alternative produced through biomass fermentation. Their first product will be frozen popcorn shrimp, but the company plans to launch a number of whole-cut analogues, including calamari, ahi tuna, and fish fillets. After **closing** a \$2.1 million oversubscribed pre-seed round in October, the company **signed a proof of concept** agreement with Migros, Switzerland’s largest retailer, to speed up product development.
- French startup Algama was **awarded** a €2 million grant from the European Commission to help bring its microalgal fermentation-derived seafood products to market.



See GFI’s **state of the alternative seafood** industry report to learn more.



“By using fermentation, we are able to produce products that are intrinsically flavorless and work well as a canvas for any and all flavors our team comes up with. The flavor combinations are remarkably similar to the seafood analogs that they claim to be. ...One thing that excites me about this method is that it completely decouples the demand of seafood from proximity to a body of water. How many landlocked states and countries burdened with food insecurity could benefit from this type of technology?”

—Anne Palermo, co-founder and CEO, Aqua Cultured Foods

## Fats and oils

Fat is a key contributor to the sensory experience of eating meat, eggs, and dairy. By using microbial fermentation, companies can produce a wide array of fats and oils that are essential for replicating both the flavor and the mouthfeel of animal products. Applications for these fats and oils include making plant-based milk creamier, improving the flavor and texture of plant-based meat, and being incorporated into cultivated meat products. 2021 was a breakout year for fat-focused fermentation companies, with four new companies launching to create fats and oils. At least seven fermentation companies are now dedicated to producing fats used in alternative protein production. Of these, six are leveraging precision fermentation:

- **Cultivated Biosciences** announced they were leveraging fermentation to develop a functional fat ingredient from oleaginous yeast that can be used as a high-fat component of plant-based dairy formulations.
- **Nourish Ingredients raised \$11 million** to scale development of their fermentation process that recreates the molecular structure of animal fats in order to mimic proteins such as seafood, pork, beef, and chicken products.
- Swedish startup **Mycorena unveiled a new fungi fat ingredient** that releases flavor in a similar way to animal-based fats during the cooking process and eating experience. Their new fat could replace coconut or other vegetable-based oils currently used in alternative meat products.
- **Yali Bio**, which recently came out of stealth mode, is creating fats tailored to the specific formulation needs of the end product, whether meat, eggs, or dairy.
- **Melt&Marble** raised \$750,000 in seed funding to create bioidentical fats via precision fermentation. They plan to create an entire range of fats for use in alternative proteins.



“From smell and texture to appearance and function, fats are absolutely critical to our experience of food. Precision fermentation is a technology that can help tailor animal-free fats to mimic the flavor profiles of the familiar—meat, fish, and dairy—and create brand new taste experiences for the consumer. Precision fermentation-derived fats can combine with plant-based technology to make food of the future—food that tastes as good, if not better, than the real thing. And if we can unlock the potential of alternative proteins to appeal to everyone, including dairy-lovers and carnivores, we can make a planet-changing impact on our food system.”

—James Petrie, founder, Nourish Ingredients

## Other products produced with fermentation

Fermentation holds disruptive power for other products made from animals, beyond meat, eggs, dairy, and seafood. The following product areas saw significant fermentation innovation in 2021:

### Infant nutrition

Infant nutrition was a rapidly growing area of investor interest in 2021. Traditional infant formula relies on dairy milk to meet babies' nutritional needs. However, precision fermentation has the potential to produce functional, immunologically active proteins similar to those found in breast milk.

- Helaina, which uses precision fermentation to produce human infant formula, **raised \$20 million in Series A funding** to begin its manufacturing and commercializing process.



“Fermentation has the potential to go far beyond sensory profiles. Using this well-established technology allows for a targeted approach to making bio-active and functional ingredients; we can program and train microbes to make components (otherwise derived from conventional agriculture) that are known to promote improved health outcomes. For example, Helaina is making proteins with the aim of immune-equivalency to the proteins in breast milk as well as bio-active properties that span benefits beyond immunity. The result is food ingredients with tangible value for our immunity and overall health.”

—**Laura Katz, founder and CEO, Helaina**

## Pet food

Pet food is a growing product category within alternative proteins. Human-food producers can also leverage research and technology developed for pet food applications. In 2021, Bond Pet Foods **announced a partnership** with Hill's Pet Nutrition to use Bond's microbially derived proteins in their traditional meat formulations.



### Honey\*

MeliBio **held a tasting of the world's first honey** produced via microbial fermentation that is bioidentical to honey produced by bees. The company received special mention in *TIME's* list of the best inventions of 2021 and has raised \$1.5 million in pre-seed funding.

### Collagen and gelatin\*

Collagen is a protein found in connective tissue that is typically derived from the bones, hooves, and other byproducts of farmed animals and fish. Gelatin is a partially degraded form of collagen protein with unique gelling properties that make it appealing for use in a variety of food products. The traditional global collagen market is valued at more than \$8 billion, with the food and beverage industry generating much of the demand.

- Geltor debuted **an animal-free collagen product** called PrimaColl that is bioidentical to poultry collagen but made via precision fermentation. Geltor plans to market this new product for use in the food and beverage industry.
- **Jellatech** raised a \$2 million pre-seed round to continue developing their animal-free collagen and gelatin products.

\*These product areas and companies have not been included in investment totals or counts of alternative-protein-focused companies.

## B2B fermentation companies as suppliers and service providers for the alternative protein industry

Because fermentation is an enabling technology, proteins derived from it are found across a range of products to enhance their flavor, texture, and nutritional profile. The majority of B2B companies using fermentation for alternative protein products position themselves as ingredient suppliers that empower B2C companies to improve their branded products. Scale, cost, and functionality are these companies' core drivers for differentiation and adding value to the alternative protein ecosystem. 2021 saw several developments in the B2B supplier and service subsector:



- Motif FoodWorks announced the **commercial release of their myoglobin, HEMAMI™**, a yeast-based heme protein that is identical to bovine myoglobin. The ingredient is available to plant-based meat manufacturers to give their products the flavor and aroma of conventional meat.
- Novozymes announced the **launch of a mycoprotein innovation platform** designed to help scale up promising technologies for using fungi as a source of protein.
- The Better Meat Co. signed deals with meat industry incumbent **Hormel Foods** and **The Plant-Based Seafood Co.** to create products with Better Meat's mycoprotein, Rhiza.
- Nourish Ingredients, a startup producing fat through precision fermentation, **formed a partnership** with Australian cultivated meat startup Vow to develop cultivated meat with fermentation-derived fat.
- **General Mills** launched Bold Cultr cream cheese made with Perfect Day's animal-free dairy proteins.
- MycoTechnology entered into a **collaboration agreement** with Planterra, the U.S. plant-based subsidiary of global meat giant JBS. This agreement formalizes an R&D partnership to create fermentation-derived ingredients for Planterra's plant-based meat brand, Ozo.
- **ENOUGH partnered with Unilever's plant-based meat brand, The Vegetarian Butcher**, to supply the company with ENOUGH's sustainable meat-like mycoprotein called ABUNDA. According to data from ENOUGH, ABUNDA mycoprotein **uses 97 percent less water than beef production and generates 82 percent fewer carbon emissions.**
- ENOUGH broke ground on a new production facility, which is **co-located with a Cargill site** in order for Cargill to supply the company with efficient feedstocks.
- **CK Ingredients signed an MOU with The Protein Brewery** to commercialize its Fermotein ingredient in North America. According to The Protein Brewery, **Fermotein uses only 1 percent of the land and 5 percent of the water and generates 3 percent of the carbon emissions of traditional beef.**
- **Anheuser-Busch InBev partnered with EverGrain** to use spent grain from the beer-making process to create alternative protein products. Upcycled brewing products like this can be used to create plant-based milk and egg products.
- Kingdom Supercultures announced a **biobank of microbial "supercultures"** to make plant-based milk and cheeses that taste like their conventional counterparts, available for use by plant-based companies in their product development.
- **VTT Technical Research Centre of Finland** partnered with Finnish dairy company Valio to research which raw materials for the food industry could be produced using cellular agriculture and fermentation.



“It’s one thing to know how to make a food technology using precision fermentation. It’s a whole other ballgame when it comes to understanding how to best use food-tech in food. The companies that will stand out in this space will be the ones who have a real understanding and love of food, who are able to combine food science with the culinary arts.”

**—Jonathan McIntyre, CEO, Motif FoodWorks**

*Are we missing something? 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

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### Overview

2021 was the year that fermentation cemented its position in the alternative protein investment landscape. Fermentation companies raised \$1.7 billion, accounting for one-third of all investments in alternative proteins, up from less than a 20 percent share in 2020. Fermentation investments in 2021 also represented a nearly threefold increase from 2020 as investors flocked to the industry, which was even featured on a *60 Minutes* segment with Bill Gates.

The industry gained notice among mainstream investors. In its report *2022 Emerging Technology Outlook*, PitchBook highlighted fermentation as an exciting emerging technology and predicted that record venture capital funding would “fuel significant widespread adoption gains in fermented protein in 2022.” Four rounds that together accounted for \$1.1 billion (65 percent) of the 2021 investment capital in fermentation-derived alternative proteins were led by several well-known investors:

- Biomass fermentation company **Nature’s Fynd** raised \$350 million in a Series C round led by SoftBank’s Vision Fund 2.
- Precision fermentation company **Perfect Day** raised **\$350 million** in a Series D round co-led by two government-related investors: Temasek, one of Singapore’s sovereign wealth funds, and CPP Investments, which invests assets of the Canada Pension Plan.
- **Motif FoodWorks**, which uses a variety of technologies to create their food breakthroughs, including precision fermentation, raised \$226 million in a Series B round co-led by major investors Ontario Teachers’ Pension Plan Board and BlackRock.
- A third precision fermentation company, **EVERY**, raised \$175 million in a Series C round co-led by new investor McWin and existing investor Rage Capital.

Meanwhile, nondilutive financing was nearly absent from fermentation company financing. Only \$39 million of publicly disclosed debt was raised by such companies in 2021, with Meati, Solar Foods, and EVERY raising general debt. While this may be partially due to less frequent disclosure of debt financing, as well as the relative nascency of the industry’s life cycle, nondilutive capital is a critical type of financing that companies will need to turn to in coming years. As companies shift to commercial-scale production by building or leasing manufacturing facilities and equipment, nondilutive capital—including various forms of debt, project financing, and infrastructure and equipment leasing—may offer benefits over dilutive equity financing.

While investment capital in fermentation and other alternative protein industries has grown at an impressive rate, it remains a small fraction of the trillions of dollars that have been invested in climate technology companies. In fact, \$47 billion of private capital flowed to the climate

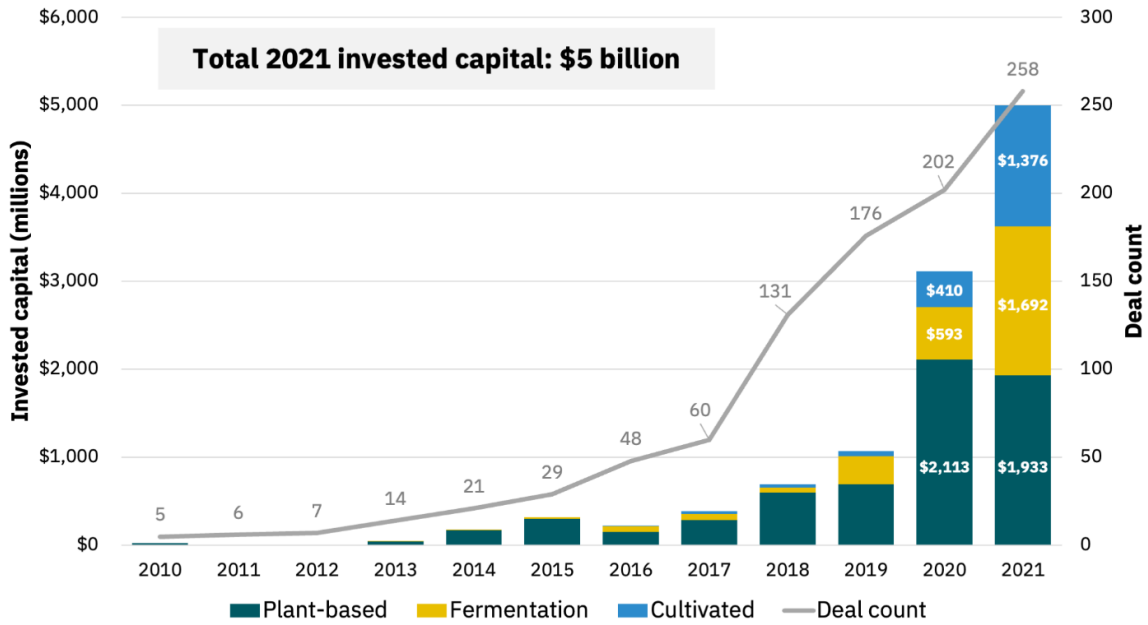
tech sector in 2021 alone. Given that alternative proteins offer a scalable solution for mitigating the 15 to 20 percent of global greenhouse gas emissions resulting from animal agriculture, it is clear that much more investment will be needed to help reach public and private net-zero commitments. Such investments will also enable companies to continue critical R&D, scale production, and bring down costs to better compete with conventionally produced animal protein.

**Table 5: 2021 investment overview**

Total invested capital	Largest investment	Unique investors
<p><b>\$1.69 billion</b> in 2021 (60% of all-time investment, up 285% from 2020)</p> <p><b>\$2.81 billion</b> total (2013–2021)</p>	<p><b>\$350 million</b> (Nature’s Fynd and Perfect Day each raised \$350 million)</p>	<p><b>130</b> new in 2021 (43% growth from 2020)</p> <p><b>434</b> total (2016–2021)</p>
Invested capital deals	Growth-stage fundraising rounds (Series B and above)	Liquidity events
<p><b>54</b> in 2021</p> <p><b>161</b> total (2013–2021)</p>	<p><b>9</b> in 2021</p> <p><b>9</b> total (2016–2021)</p>	<p><b>\$9.3 million</b> in 2021</p> <p><b>\$1.50 billion</b> total (2013–2021)</p>

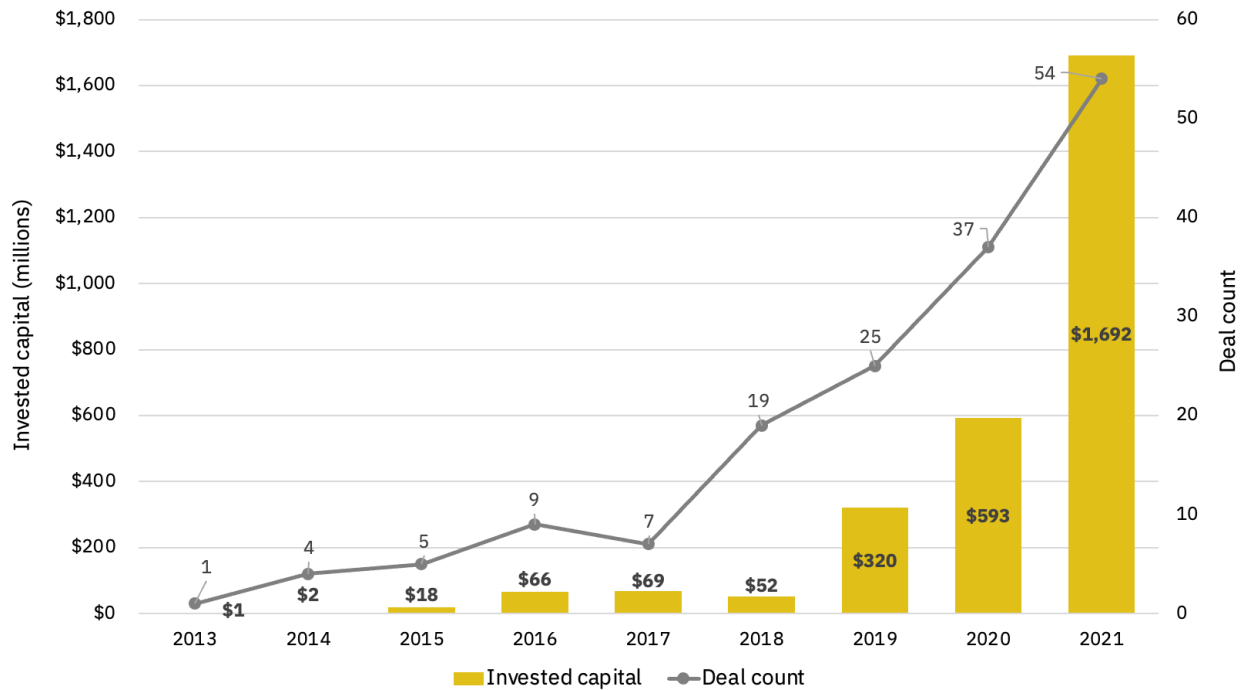
Source: GFI analysis of data from PitchBook.  
 Note: Data has not been reviewed by PitchBook analysts. See below for GFI’s data collection methodology and definitions of “invested capital” and “liquidity events.”

**Figure 9: Annual alternative protein investment trend (2010–2021)**



Source: GFI analysis of data from PitchBook.  
 Note: Data has not been reviewed by PitchBook analysts.

**Figure 8: Annual investment in fermentation companies (2013–2021)**



Source: GFI analysis of data from PitchBook.  
 Note: Data has not been reviewed by PitchBook analysts.



“2021 definitely has been the year of precision fermentation. Investment into this segment of cellular agriculture has been growing to an all time high over the last 4 years. We are now seeing that also the sector agnostic, late-stage investors are convinced by the existing proof of concept. Now that industry pioneers have shown that precision fermentation is a viable solution to recreate the dairy products we all know and love, the fundraising process and vetting has become a lot more sophisticated. Investors are no longer just looking for the biggest visionaries, but for the most competent teams to scale their operations globally and to bring their costs to a competitive level to enter the mass market.”

—Raffael Wohlgensinger, CEO and co-founder, Formo

## Data collection methodology

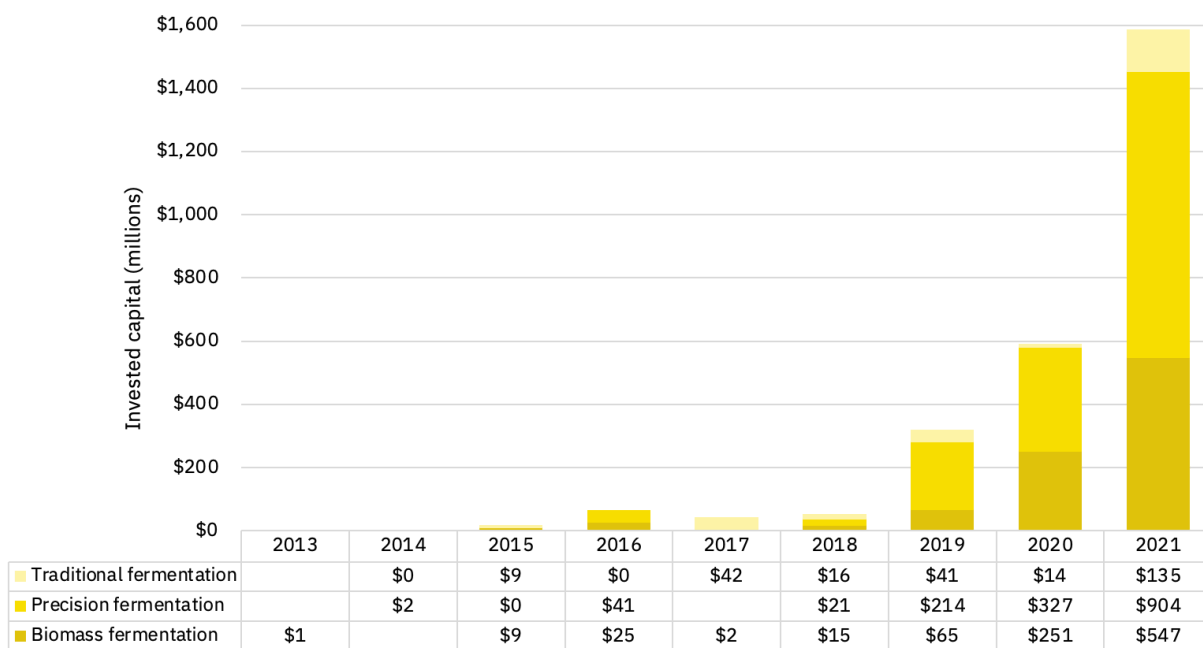
GFI conducted an analysis of fermentation companies worldwide using data from PitchBook. Our analysis uses a list we custom-built in PitchBook of companies focused primarily on fermentation-enabled meat, egg, or dairy products or providing services to those who produce them. Our analysis excludes the many companies involved in fermentation but not as their core businesses (Table 4) 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 owing to similarities in the types of ingredients they produce and in the downstream processing to obtain those ingredients from the host expression organisms.

PitchBook profiled 84 fermentation companies, of which 65 have disclosed deals. Of these 65 companies, 52 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* comprises 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 continually improve our dataset.

**Figure 9: Investments by type of fermentation (2013–2021)**



Source: GFI analysis of data from PitchBook.

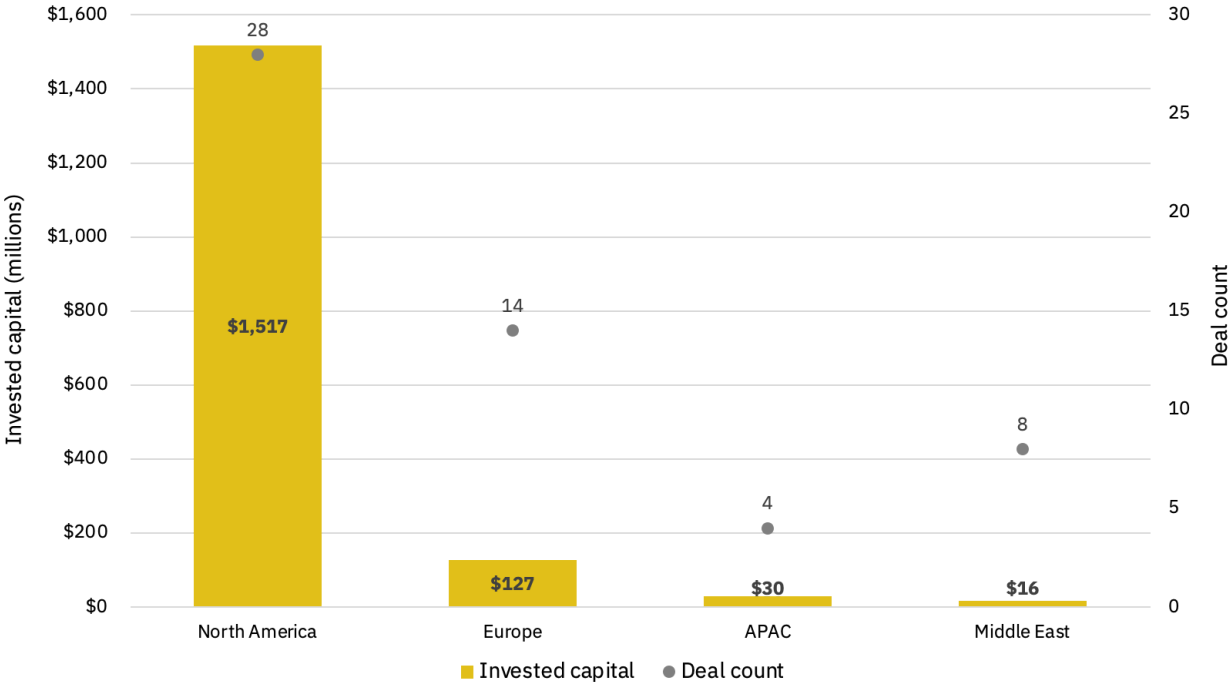
Note: Data has not been reviewed by PitchBook analysts. The annual totals may not match the totals in Figure 8, as companies employing plant molecular farming were excluded.

All growth-stage funding rounds that have ever been raised by fermentation companies occurred in 2021. Among the three types of fermentation, precision fermentation companies raised the most capital, over half of all fermentation investments secured in 2021. Meanwhile, biomass fermentation companies raised about one-third, and traditional fermentation raised a minority of the \$1.7 billion in investment. This aligns with the relative cost of the various technologies, as precision fermentation typically requires the most specialized and expensive



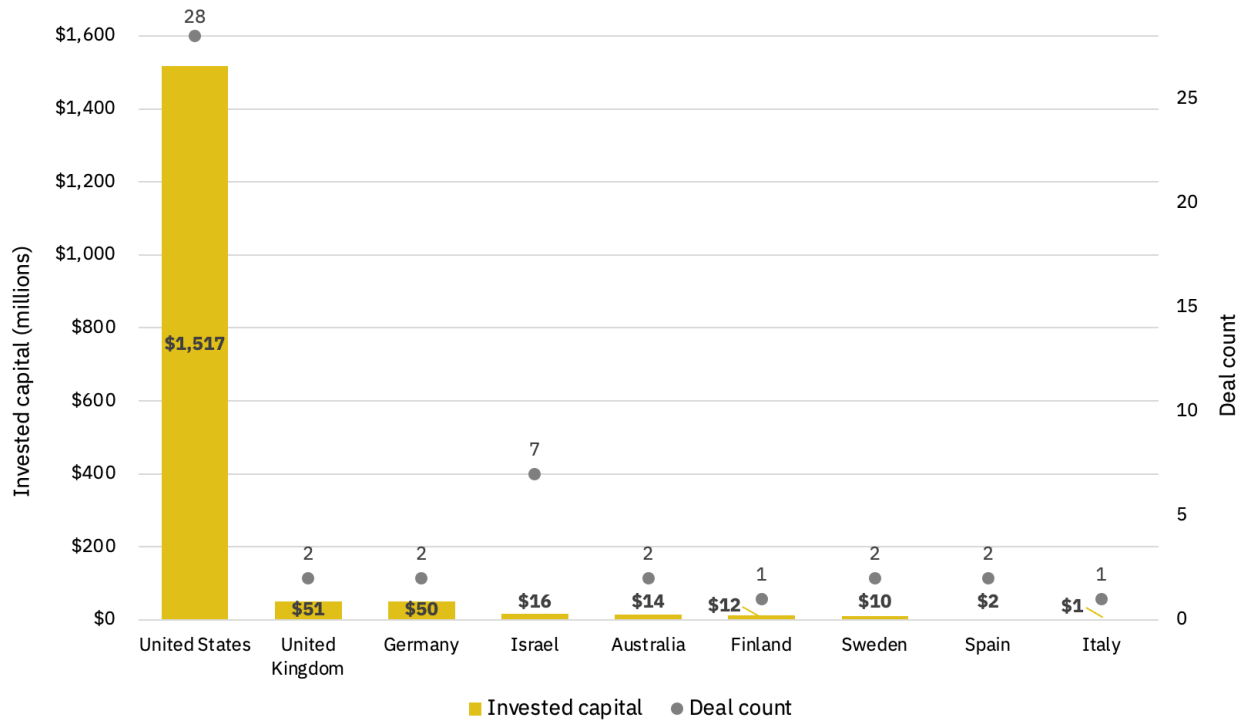
equipment, as well as higher R&D expenditures for strain development and for optimizing downstream purification steps. Many companies that employ traditional fermentation in their product lines are categorized as plant-based in our analysis, which partially accounts for the category’s relatively low investments as captured here. Companies based in the United States raised the vast majority (90 percent) of investments. We expect the geographic distribution to broaden in future years.

**Figure 10: Investments in fermentation by region (2021)**



Source: GFI analysis of data from PitchBook.  
 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.

**Figure 11: Investments in fermentation: Country highlights (2021)**



Source: GFI analysis of data from PitchBook.  
 Note: Data has not been reviewed by PitchBook analysts.



“Investors have become increasingly interested in fermented protein technologies given the large total addressable market driven by the variety of protein types that can be produced and the numerous product applications. Investors are further inspired by the economic profile of these businesses as they scale.”

—Rob Steele, managing director, Bank of America Merrill Lynch

**Table 6: Deal type summary statistics (2013–2021)**

Deal type	Median	Minimum	Maximum	Count
Accelerator and incubator	\$125K	\$10K	\$330K	39
Seed	\$2.1M	\$200K	\$11.5M	38
Early-stage VC (uncategorized)	\$1.3M	\$60K	\$34.8M	14
Series A/A1/A2	\$2.1M	\$1.0M	\$9.0M	29
Series B	\$2.8M	\$0.2M	\$226.0M	10
Series C/C1	\$4.7M	\$7.0M	\$350.0M	5
Series D/D1	\$9.3M	\$48.2M	\$350.0M	2
Series E	\$61.8M	\$61.8M	\$61.8M	1
Late-stage VC (uncategorized)	\$5.6M	\$560K	\$4.5M	6
General debt	\$11.9M	\$450K	\$18M	6

Source: GFI analysis of data from PitchBook.

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 size, this table excludes angel and Series 1 rounds. It also excludes uncategorized rounds.

**Figure 12: 2021 key funding rounds**

**Seed**

						
\$16M	\$11.5M	\$11M	\$3M	\$2.1M	\$2.1M	\$2M

**Early-stage VC**

**Series A**

						
\$3M	\$50M	\$40M	\$26.5M	\$20M	\$17M	\$9.2M

**Series B**

**Series C**

					
\$226M	\$75M	\$50.7M	\$50M	\$350M	\$175M

**Series D**

**Series E**

**General debt**

					
\$48.2	\$350M	\$61.8M	\$8M	\$12M	\$18M

Source: GFI analysis of data from PitchBook.

Note: Data has not been reviewed by PitchBook analysts.

**Table 7: Most active investors in 2021**

Investor	Investor type	Headquarters	2021 deal count	Total deal count
Big Idea Ventures*	Venture capital	New York, USA	10	10
SOSV / IndieBio	Venture capital	Princeton, USA	7	20
CPT Capital	Venture capital	London, UK	6	19
S2G Ventures	Venture capital	Chicago, USA	4	8
Sustainable Food Ventures	Venture capital	Raleigh, USA	4	4
Rage Capital	Venture capital	New York, London, Singapore	3	4
Aera VC	Venture capital	Auckland, New Zealand	2	4
AgFunder	Venture capital	San Francisco, USA	2	3
Agronomics (LON: ANIC)	Venture capital	Douglas, UK	2	5
AiiM Partners	Impact investing	Palo Alto, USA	2	3
Breakthrough Energy Ventures	Impact investing	Kirkland, USA	2	5
Entrée Capital*	Venture capital	London, UK	2	2
FootPrint Coalition*	Venture capital		2	2
Gaingels*	Venture capital	New York, USA	2	2
Good Seed Ventures	Venture capital	Rheine, Germany	2	3
Happiness Capital	Corporate venture capital	Hong Kong	2	7
Hillhouse Capital Group*	PE/buyout	Beijing, China	2	2
IndieBio	Accelerator/incubator	San Francisco, USA	2	5
Main Sequence Ventures	Venture capital	North Ryde, Australia	2	3
Prosus Ventures*	Corporate venture capital	Hoofddorp, Netherlands	2	2
Purple Orange Ventures	Venture capital	Berlin, Germany	2	3
Rich Products Ventures*	Corporate venture capital	Buffalo, USA	2	2
Sand Hill Angels*	Angel group	Mountain View, USA	2	2
SoftBank Investment Advisers*	Venture capital	London, UK	2	2
Stray Dog Capital	Venture capital	Leawood, USA	2	5
Temasek Holdings	Sovereign wealth fund	Singapore	2	6
The Kitchen FoodTech Hub*	Accelerator/incubator	Ashdod, Israel	2	2
Viking Global Investors	Hedge fund	Greenwich, USA	2	3
Walter Robb	Angel (individual)	Chicago, USA	2	3

Source: GFI analysis of data from PitchBook.

Note: Data has not been reviewed by PitchBook analysts. "Most active investors" includes those who made two or more investments during the calendar year.

\*Indicates funders that made disclosed investments in fermentation-enabled meat, eggs, and dairy for the first time in 2021.

## Liquidity events

As the vast majority of alternative protein fermentation companies were founded in 2013 or later, the industry is too young for us to expect many liquidity events, such as IPOs or acquisitions. Quorn, the mycoprotein pioneer founded decades before most other mycoprotein companies, is an exception. Rank Hovis McDougall (RHM), a UK-based food company, began research and the regulatory approval process for their products in the 1960s. But not until 1985 was the brand Quorn (named after a British village) first marketed via a joint venture between RHM and Imperial Chemical Industries (ICI).

Quorn first sold at Sainsbury's in the United Kingdom in the form of savory pies. Other parts of Europe followed, and finally North America in 2002. As one of the first alternative protein market entrants, Quorn enjoyed market dominance and commercial success. In 1993, Quorn was spun off by ICI, which had acquired all of RHM's shares, to AstraZeneca. In 2003, Montagu Private Equity bought Quorn for \$116 million before selling it two years later to Premier Foods for \$315 million. In 2011, other private equity investors acquired Quorn before Monde Nissin, a Philippines-based food company, ultimately acquired it for \$726 million in 2017. Notably, Quorn has also successfully secured large tranches of debt financing, including a \$147 million debt refinancing, a £113 million note, and a £10 million revolving credit line from CitiGroup Global Markets and HSBC Bank in March 2019 per PitchBook. In 2021, Monde Nissin filed for the Philippines' **first-ever billion-dollar IPO in 2021**. We expect other fermentation companies to undergo liquidity events in the coming years.

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## Section 4

# Science and technology



## Section 4: Science and technology

Fermentation is a mature technology, with roots in traditional food preservation and more recently in the production of natural products and pharmaceuticals. Despite these solid foundations, opportunities abound for new applications in the alternative protein arena. In the past few decades, biotechnologists have applied scientific strategies to discover new functionalities for foods and to create entirely new types of food. These innovations include the design of specialty cultures for fermented products, the production of new types of dietary supplements and microbial protein, and the large-scale manufacture of food additives. The vast physiological diversity of microorganisms suggests that these innovations have only scratched the surface of what fermentation can offer as a platform, especially during the fast-approaching era of a transition away from animal-based proteins.



For a comprehensive introduction to the current state of the science in fermentation, visit GFI's [science of fermentation](#) page.

### Key areas for science and technology development

In 2021, notable progress was made toward several prioritized solutions listed in the **Advancing Solutions** repository. This repository was created to provide technical background and orient priorities for research, investment, and funding of fermentation efforts in alternative protein.

#### **Comprehensive microbial screening to identify new protein-production candidate strains:**

- Most commercial biomass fermentation platforms currently use a species of *Fusarium* fungus, perhaps owing to established bioprocess scalability, **GRAS status**, or favorable **intellectual-property landscape for the genus**. **Recent research and commercial development suggest considerable untapped potential in using other fungal genera for biomass production. Opportunities remain for comprehensive assessment of non-*Fusarium* fungal species with regard to bioprocess scalability, nutritional composition, and sensory characteristics.**
- Biomass fermentation using bacteria presents massive **potential** from the perspective of efficiency (e.g., leveraging anaerobic bioprocesses) and yield (achieving upwards of 50 percent conversion of feedstock to biomass or co-products). Development of bacterial strains for edible protein offers considerable process and nutritional advantages (no mycotoxins) but unique requirements, such as to remove nucleic acids. Taking a page from the probiotics industry that cultivates strains **found in food or in nature**, bioprospecting has **proved** to be a powerful tool to identify wild-type **strains** that produce high-quality protein or novel **compounds of value**.
- For precision fermentation, the use of new strains other than yeast or *E. coli* workhorse strains may offer advantages such as **high expression levels** of recombinant proteins,



greater **stress tolerance**, and the unique ability to synthesize **novel natural products**. Nonmodel strains demonstrate remarkable **metabolic versatility** that suggests their potential for use with nonstandard medium inputs, such as co-products or side streams from food-processing industries. Perhaps the greatest untapped metabolic versatility, however, is exhibited by microbial consortia, the design and application of which for fermentation has been **developed** by several **companies** in order to generate unique types of protein that may not be achievable using single-strain fermentations. For more ideas of how microbial communities may advance alternative proteins, see **Engineering Biology Research Consortium’s microbiomes roadmap**.



For more information on this topic, see the **concept note on the GFI website**.

### **Biosynthetic pathway discovery for fermentation-produced molecules:**

- Given the volume and diversity of genetic information within microbes, there remains much to discover. Only relatively recently have **powerful “omics” and bioinformatics tools** allowed researchers to catalog microbial nucleic acids and proteins and organize them in terms of **metabolic pathways and functions**. Strategies for **genome mining** and **molecular manipulation** developed by scientists investigating natural products for pharmaceutical candidates could be adapted directly to identify microbial sequences that could produce molecules that mimic animal molecules.
- In addition to finding animal-free analogues, mining microbial sequence space can also lead to entirely new food ingredients. Mining microbial sequences for novel biosynthetic capabilities is part of bioprospecting, a mature field of **computational biology** that has demonstrated success in various biotechnological applications, such as **drug discovery** and the development of **industrial enzymes**. For alternative proteins, if the desired functionality is known but a molecular species or structure is not, **computational strategies established by natural product bioprospectors** can help identify candidate molecules that achieve that functionality. A similar approach is currently taken by food ingredient companies **Shiru** and **Motif**.



For more information on this topic, see the **concept note on the GFI website**.

### **Producing animal-like fats through microbial fermentation:**

- Several companies reported breakthroughs in production of animal fats by precision fermentation in 2021, including C16 Biosciences, Farmsow, **Melt&Marble**, and Nourish Ingredients. The latter recently announced a **collaboration** with Vow to provide animal-like fats for cultivated meat products. Using fats chemically similar or identical to those found in animal tissues as a food ingredient for plant-based and cultivated meats will boost overall sensory appeal by better replicating the flavors and mouthfeel of animal-based meat.

- Inclusion of animal-based fats will also help generate the unique aromas derived from the Maillard reactions that occur between fats, sugars, and proteins on the surface of animal-based meat during cooking. Molecular tools to **tune lipid metabolism** in lipid-accumulating strains will be useful to optimize production of **custom lipids** and lipid-derived **specialty ingredients**. In a possible major scientific and commercial breakthrough, Mycorena announced the production of **fungal lipids** that behave similarly to animal fats.



For more information on this topic, see the [concept note on the GFI website](#).

### Fat production and encapsulation within oleaginous yeast:

- Oleaginous yeasts like *Y. lipolytica* are known for their natural ability to synthesize, accumulate, and **store lipids**. GFI's most recent research grant program funded two proposals that screen oleaginous yeast strains for the ability to accumulate lipids similar in structure to lipids found in animal tissue.
- Food-friendly scalable methods for downstream **extraction**, recovery, and storage of lipids from oleaginous yeast biomass will be an important factor for food applications. One option is **microencapsulation**, in which lipids are retained inside yeast cells, protecting them from degradation by light, oxygen, and heat during storage. Lipids may then be extracted from the yeast cells when required, or the whole dried, lipid-containing yeast cells may be added directly to foods as an ingredient.
- Although yeast lipid encapsulation is a **well-established** bioprocessing technique, reports of its applications to alternative proteins so far have been limited. An exception is Cultivated Biosciences, a new company that feeds food-waste side streams to non-GMO oleaginous yeast to produce a **dairy cream-like product**.



For more information on this topic, see the [concept note on the GFI website](#).

### Biological and enzymatic processing methods for animal-free proteins:

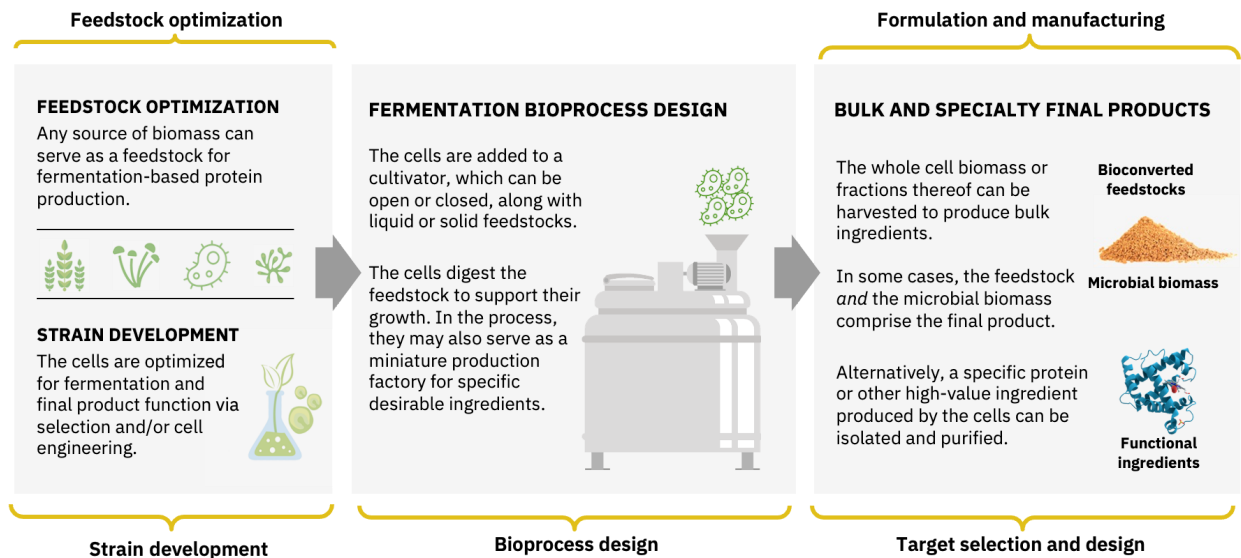
- Another application of fermentation as a technology is as a pretreatment of proteins from other sources. A preliminary fermentation step can increase proteins' solubility and bioavailability, as well as remove off-flavors or aromas. In 2021, a European consortium of food manufacturers and researchers announced a three-year collaboration on "**bio-purification**" of **plant proteins** to improve sensory characteristics. Similarly, Novozymes' **MycoProtein Innovation Call** grant program included a section on improvement of nutritional value of plant proteins using fungal fermentation. Bio-transformation pioneers **Afineur** and **Mycotechnology** unveiled cultured protein products with enhanced nutritional features derived from fermentation.
- Strictly enzymatic pretreatment methods received a boost in 2021 when Amano announced non-GMO enzymes that release umami and kokumi flavors in plant-based

**meat** and **beverages**. From a research perspective, major breakthroughs in enzyme design reported in 2021 included a **method** to screen thousands of enzymes in a microfluidic device and a **breakthrough in computational design** of enzymes.



For a comprehensive view of the state of the science in fermentation-enabled meat, seafood, eggs, and dairy, check out GFI’s **science of fermentation** page.

**Figure 13: A visual overview of the technology value chain for fermentation**



## Target selection and strain development

Success in target selection and strain development is often defined within a solution space containing three variables, only two of which may be maximized simultaneously:

1. How thoroughly optimized the target and strain are for their intended purpose and production process.
2. How fast the production strain can be developed.
3. The cost of the strain-development process.

Motivations for ingredient and strain identification may be driven by a number of factors, including the following:

- **Market signals** such as price points.
- Relevance to an innovative new **manufacturing technology**.
- **Clean label** status.
- Expedient **regulatory approval**.
- Time to market.

- Degree of **similarity** to previous products.

Additionally, target molecule identification for alternative proteins can be motivated by **measured differences** between animal-based and plant-based analogues, with the goal of improving the biochemical match between the two.

In 2021, automation and computational tools were a striking area of progress in target selection and strain development. Published research reviewed methods and technologies associated with high-throughput strain screening methods:

- **Scale-down of bioreactor conditions** to screen microbial diversity.
- Design of **fermentation characterization** experiments.
- **Microfluidic single-cell bioreactors**.
- Assessment of the scalability of fermentation results from **microbioreactors** to larger scales.
- Rapid strain phenotyping using **untargeted mass spectrometry methods**.
- Methods for **automated biofoundry** design.

**Biofoundries** have emerged as a particularly powerful potential tool for alternative proteins, with promise for the rapid development of target proteins in a design-build-test-learn format. Biofoundries provide integrated molecular biology infrastructure to enable the rapid design, construction, and testing of biological solutions. When used by alternative protein companies, this can dramatically speed up research and development.

- A **collaboration recently announced** between cloud-based biosoftware and machine learning provider TeselaGen and Agile BioFoundry will provide a template for advanced computational design and development of **strains** and functional bioproducts.
- Ginkgo Bioworks announced their **Grow with Ginkgo** program, a streamlined cell-development kit that gives developers access to the company's Foundry and Codebase resources to design and evaluate new strains.
- **Cultivarium** continued to develop computational tools to promote the use of nonmodel microbes for biotech.
- Next-generation analytical capabilities were given a computational boost by new biotech company **SpectraPass**, who developed a rapid, high-throughput microbial strain characterization tool that integrates mass spectrometry, machine learning, and robotic automation.

These achievements build on existing analytical and modeling approaches that **integrate** genome mining, constraint-based modeling, omics methods, machine learning, and **virtual screening** to detect novel functional molecules from fermentations or **predict strain performance**.

Computational methods emerged in 2021 that provide a glimpse into the future of protein engineering through **machine learning**. A step change in target molecule design was achieved when Google DeepMind protein-structure prediction algorithm AlphaFold2 was made freely

accessible to the public. The computational capability to predict protein structure accurately launches **a new era in protein science** that will accelerate the design of novel functional proteins across all biotech industries, including the alternative protein industry. Protein **companies** that optimize their use of these tools will be situated to design high-functionality proteins with superior **sensory characteristics** for use as animal-free food or food ingredients.



“We [Shiru] use computational approaches to predict proteins that deliver optimal food functionality, ingredients we then produce via precision fermentation and characterize analytically leveraging high throughput screening. We use precision fermentation both to screen hundreds of promising ingredients at a small scale and to scale the best ones, delivering them to the industry as part of our rapidly growing ingredients catalog. Our screening and production process enables us to create industry-first ingredients that deliver properties such as emulsification, gelation, solubility, color, and binding that underpin the success of non-animal meat, dairy, or egg alternatives.”

—**Jasmin Hume, founder and CEO, Shiru**

Traditional strain engineering and target selection efforts also made remarkable progress in 2021:

- The U.S. Department of Energy doubled down on its decades-long commitment to synthetic biology funding, awarding **\$35 million in research funds** for re-engineering microbes for the production of useful bioproducts through strain engineering.
- Likewise, breakthrough academic research on industrial workhorse strain *P. pastoris* reported **CRISPR-Cas9 genome editing** tools as well as **methanol-free promoter systems** that exhibit superior bioprocess performance, generating up to ninefold greater productivity while maintaining yields.

Well-established food-tech companies like **NIZO** continued to optimize strain development platforms with a full suite of tools, including extensive culture collections, scaled-down micro-platforms for performance testing, omics analytics resources, and industrial scale-up workflows. Meanwhile, additional breakthroughs in commercial precision fermentation continued to be reported, such as the commercialization of one **egg protein** and proof-of-concept expression of **another**; the unveiling of an **animal-free myoglobin**;

animal-like lipids that can be **tailored** for different types of meat-analogue products; and the production of specific **functional** animal proteins, including animal **muscle** proteins.

## Feedstock optimization and side streams

Feedstocks that support microorganisms' growth are a major cost driver for most fermentation processes. Optimizing feedstocks used in alternative protein production promises both economic and sustainability advantages. Several key areas for innovation within feedstocks are outlined below.

Optimizing or diversifying crops to develop cheaper and more sustainable substrates:

- From a crop improvement perspective, much of the **research** from previous years geared toward making crops more amenable to fermentation for biofuels may be applied directly to feedstock optimization for protein fermentation.
- A **2021 LCA/TEA report** suggested that lignocellulosic plant materials—the leafy or woody vegetative parts of plants, which are usually left over after harvesting crops for edible tissues such as their fruits or seeds—may feasibly serve as inputs for mycoprotein production and proposed methods to decrease costs.
- Conversely, rather than lignocellulosics, alternative protein fermentations may be better suited for minimally processed sugar inputs or **food-grade co-product streams** from food processing. For the former, **bolt-on, upstream technologies** offer a method to generate a minimally purified, industrial sugar stream from grain.
- Additionally, a potential breakthrough in yeast research discovered a growth strategy to **avoid acetate inhibition** of yeast when growing on sugars derived from lignocellulosic plant materials.

Co-production and valorization of feedstock side streams:

- On the co-production front, companies like Afineur, Aqua Cultured Foods, Mycorena, and Hyfé have demonstrated at scale the potential for co-product side streams to serve as inputs for fungal biomass fermentation, while **Liven Proteins** aims to use side streams as inputs to their precision fermentation platform.
- In the case of bacterial fermentation (whether precision fermentation using a strain like *E. coli* or biomass fermentation like that of Superbrewed), the production process itself generates its own valuable **co-products** that may offset production costs.
- Other emerging strategies to feedstock optimization include using computational tools to **design a precise medium** formulation or using a preliminary fermentation by one organism to **transform** starting material into a form that can be used as an input for the main fermentation.

Co-locating fermentation production facilities alongside critical inputs:

- A key factor to consider when using side streams is that the fermentation facility must be located near the source of the side stream, such as a food-processing plant. Companies that already operate food- or feed-processing facilities will have considerable advantage and influence regarding the location, design, and use of side-stream fermentations, as well as the quality and cost of inputs.
- New types of biorefinery models will be required to integrate alternative protein fermentation modules into overall process designs.

Diversifying feedstocks:

- Gas fermentation companies generating protein from carbon in air continued to garner awards and attention in 2021: Solar Foods won the CSA/NASA **Deep Space Food Challenge**, while Air Protein was a semifinalist for a \$15 million **Feed the Next Billion Award** from XPRIZE.
- Perhaps the most unexpected feedstock proposed for fermentative protein production in 2021 was **plastic waste**. The winners of the 2021 **Future Insight Prize** demonstrated conversion of plastic to edible protein by microbial consortia after an initial pyrolysis step.



“Air Protein’s process is similar to fermentation, which is the way we make wine, yogurt, cheese, and other foods and beverages today. We also use cultures, similar to probiotic cultures that are used to make yogurt. The difference is that instead of using milk as a feedstock as in the case of yogurt, we use elements of the air. If you think about whey, which is produced when making yogurt, when whey is dried, it creates a protein-rich flour. We similarly create a protein-rich flour. The difference is that our process is carbon negative and the inputs don’t require any arable land, which make our process an ESG game changer.”

—Lisa Dyson, founder and CEO, Air Protein

## Addressing infrastructure needs

Perhaps the greatest hurdle that alternative protein fermentation efforts (and the alternative protein industry as a whole) will face over the next decade is the looming shortage of available fermentation **manufacturing capacity**. An analysis by Warner Advisors LLC states:

- 61 million liters of fermentation volumetric capacity associated with contract manufacturing organizations (CMOs) is available globally.
  - 49 million liters (80 percent) is already under contract.
  - Only two million of the remaining 12 million liters has suitable downstream processing capabilities for food applications.
- Approximately 95 percent of contract fermentation capacity was not originally designed for food applications, and much of the existing capacity was built decades ago or lacks updated automation controls.

Forecasts of alternative protein demand suggest that by 2030, meeting the demand for alternative protein from fermentation would require **three orders of magnitude** more fermentation capacity than is currently available.

The severity of the deficiency in fermentation capacity suggests that, even with the digitization of process design and outsourcing of process development to high-throughput service providers, additional manufacturing fermentation capacity will be required:

- In the United States, **bioethanol fermentation capacity** may become available as demand for liquid transportation fuels decreases with increasing vehicle electrification.
- Repurposing brownfield bioethanol plants for food usage, however, is a **costly process** (more than 50 percent of the cost of building new facilities) and imposes limitations that may render the repurposed facility less well suited for protein fermentation than a new facility that was built for purpose.
- Moreover, locating and purchasing an existing fermentation facility at large scale is increasingly unlikely, especially in North America.
- **CMOs** around the world have **emerged** to meet the need for contract **research** and manufacturing in fermentation.

Increasingly, some design and construction firms are starting to address the need to **increase** manufacturing **capacity** for **alternative proteins**, including **fermentation**:



- While capacity is needed at pilot (<10,000 L), intermediate (10,000–100,000 L), and commercial (100,000–500,000 L) scales, perhaps the most urgent need is at the **intermediate scale**.
- Results from intermediate-scale runs provide critical data needed to inform decisions around moving to commercial scale. Because of venture investor preference for “capital light” projects, **government support** is necessary to adequately address the scale of expected demand in the short term.
- One factor that may be important during the design and construction of new fermentation capacity is that while proximity to sugar or side-stream inputs is important, fermentation offers the possibility to make any protein of interest in **any location**.
- **High-risk** or nonagricultural regions of the world will be able to generate high-quality protein for their communities, as long as appropriate inputs can be obtained.

In addition to physical assets, fermentation infrastructure also includes **human resources**:

- There is a need for **operators, scientists, and engineers** experienced in fermentation manufacturing and scale-up of fermentation processes from bench to commercial scales.
- While many universities offer programs in fermentation technology, most are focused on **traditional fermentation** (fermented foods and beverages).
- In order to recruit and train the fermentation workforce who will be in high demand to power the protein transition over the next decades, **university** and **workforce training programs** focused on biomass and precision fermentation processes will need to be developed.

## Advances in bioprocess design

Historically, the food and pharmaceutical industries have utilized bioprocess design improvements to increase the scale, lower the cost, and improve the quality of industrial fermentation processes. But these improvements have focused narrowly on optimizing select culture conditions and fermentation platforms to attain a desired end product, such as bioethanol, beer, or precision-fermented pharmaceuticals. New paradigms in bioprocess design are necessary for new strains being used by fermentation-derived alternative protein products to achieve the taste and texture needed to function as true analogues of animal products.

Although further advancements are needed to improve the scale, cost, and taste of fermentation-derived alternative proteins, significant improvements were seen in 2021. Multiple companies associated with process scalability signaled their interest in bringing fermentation-derived alternative proteins to the scale needed for global industrial production:

- Industrial engineering firm **CRB** released their report *Horizons: Alternative Proteins*, which identifies commercial manufacturing as a critical next step for the majority of alternative protein companies.
- **ZX Ventures**, the innovation arm of AB InBev, one of the largest owners of fermentation capacity worldwide, is helping The EVERY Company **scale the production of their animal-free egg substitutes** and bring the startup **BioBrew's** precision fermentation platform to industrial scale.
- Culture Biosciences **raised an \$80 million Series B for cloud-based bioreactors** that will help precision fermentation companies scale up their processes to the manufacturing level.

Additionally, multiple companies have developed platforms for fermentation as an upstream or downstream processing unit operation:

- New York-based **Afineur** is developing mixed-culture microbiomes to process plant-based proteins into alternative protein end products.
- Chicago startup **Hyfé Foods** uses a fungal platform to convert food-safe wastewater streams into low-carbohydrate, high-protein biomass.
- In the Netherlands, the public-private partnership **Bio-Purification of Plant Proteins** aims to develop entirely new fermentation processes to eliminate off-flavors in plant-based ingredients.
- Fungal bioconversion also appeared at CES 2021, where attendees could sample **Goodside Foods' plant-based meatless crumbles that were bioconverted with MycoTechnology's** shiitake mycelia fermentation platform.

One area of immediate opportunity in bioprocess design is the development of **continuous processes** for precision fermentation:

- *P. pastoris* is an industrial workhorse microbial host for expression of recombinant proteins. While commercial fermentations with this strain currently operate in fed-batch mode, running in continuous mode has the potential to increase **protein productivity manyfold** owing to the lack of batch cycles.
- Such an improvement in productivity would present a clear process advantage in a commercial environment of severely constrained industrial volumetric capacity and high product demand.
- Recent reports of the development of **CRISPR-Cas9 genome editing** tools and **methanol-free promoter systems** for this strain, along with strategies to reduce process variability using **machine learning** and **metabolic flux** modeling, suggest that continuous operation may be feasible in the near future.
- Given that *P. pastoris* is already commonly used in the alternative protein industry to produce commercialized products such as **soy leghemoglobin** and **egg protein**, efforts

should be made to adapt process analytical technology and quality-by-design methodologies to continuous production of alternative proteins with this strain.

Another major emerging theme in bioprocess design in 2021 was a move to virtual platforms such as “**digital twin**” models:

- These platforms digitize bioprocesses in order to **model them precisely and optimize** them before real-world implementation, decreasing process-development time dramatically.
- A **hybrid modeling** approach integrates both **metabolic information from the organism and bioprocess information** from fermentation to identify conditions that will achieve desired manufacturing targets.

Improved modeling approaches often originate from broader fermentation innovations. But this kind of data-driven, **Industry 4.0** approach will dramatically accelerate speed to market in the emerging alternative protein industry, eventually **becoming the norm**, especially for smaller companies lacking access to fermentation manufacturing capacity. Contract manufacturing and design **firms** with well-developed fermentation **digitization** capabilities will become in-demand partners of choice, especially as companies using **nonstandard bioprocesses** continue to scale up.

Finally, innovative bioprocess design for fungal biomass fermentation was demonstrated by multiple companies in 2021 as they scaled their products:

- Glasgow’s **ENOUGH**, previously 3FBIO, announced plans to build a first-of-its-kind **fungal biomass protein factory to produce 10,000 metric tons per year**.
- **The Better Meat Co.** opened the doors of their new fermentation plant in West Sacramento, California, to scale up production of their fungal biomass ingredient (see Figure 6).
- **Aqua Cultured Foods** debuted their raw whole-muscle cut, sushi-quality seafood using biomass fungal fermentation.
- In a market-signaling move, enzyme producer Novozymes launched a **call for innovation** for using mycelia to accelerate the use of fungi in alternative protein production.

Innovations in the past year across culture conditions, production platforms, and facility designs have shown progress on multiple fronts for fermented alternative proteins. Still, significant opportunities for innovation remain in the realm of bioprocess design.



To learn about other critical white spaces in bioprocess design, check out GFI’s **solutions database**. This frequently updated ideas database includes solutions to key white-space challenges facing bioprocess design for alternative proteins.

## Algae: plant-based or fermentation?

“Algae” is an informal term used for an extraordinarily diverse group of aquatic photosynthetic organisms that transcend phylogenetic categorization. Within alternative proteins, both macroalgae and microalgae show promise:

- **Macroalgae** comprise seaweed and kelp species, some of which are true aquatic plants, while others, such as giant kelp, are technically not plants because they lack the vasculature and tissue differentiation of true plants. However, for the purposes of pragmatic distinction for exploring uses in alternative protein applications, we classify macroalgae in the **plant-based** pillar. The growth, harvesting, and processing of macroalgae—aspects that are highly relevant to cost and infrastructure—are more similar to those of terrestrial crops than to the cultivation, harvesting, and processing of microbial cells.
- **Microalgae**, in contrast, are aquatic photosynthetic organisms that live as single cells or small clusters of cells, which either float freely in suspension or adhere to surfaces in a similar fashion to fungi or bacteria. Microalgae include photosynthetic bacteria (called cyanobacteria or, colloquially, blue-green bacteria) as well as multiple phyla of eukaryotic cells with diverse properties. Many microalgae have tough walls, including the silica-based coatings of diatoms, which can make protein extraction challenging but which can also endow certain species with hardiness.
- Microalgae can be advantageous for large-scale cultivation in the same types of fermentation infrastructure used for cultivating nonphotosynthetic microbes, such as bacteria and fungi. Thus, we classify microalgae in the **fermentation** pillar according to their potential use in alternative protein applications. In fact, with a few notable exceptions, such as spirulina and chlorella used as supplements and colorants, most of the commercially relevant algae strains presently used in food and industrial biotech are grown heterotrophically, which means they are fed sugars—just like a classical fermentation process—rather than photosynthesizing light into usable energy.
- While growing microalgae without light may seem counterintuitive, it makes the process much more **efficient** and **cost-effective** because algae can be grown at much higher densities and with less expensive, well-established infrastructure and equipment. If grown photosynthetically, they must be grown either at very low densities outdoors (high densities become self-limiting because the cells begin blocking light from penetrating to the whole culture, so growth slows) or in expensive, hard-to-clean

photobioreactors with elaborate tubing to increase the surface area contacted by light.

Regardless of energy source, algae's appeal is often rooted in the vast **biological diversity** they represent. Algae produce an enormous range of unique molecules, including pigments like the red astaxanthin that gives shrimp and salmon their red color as well as desirable long-chain omega-3 fatty acids like EPA and DHA. In fact, algae are the **direct source of the vast majority of the omega-3s present in seafood**. These fats are consumed and accumulated by fish, not produced by fish.

While algae have been grown commercially for some of these high-value products for decades, we are now witnessing an **explosion of interest** in tapping into the **largely unexplored potential** of the thousands of uncommercialized species and strains, in addition to screening and adapting well-known strains for new purposes.



For more information on this topic, see [GFI India's technological review of algae-based proteins](#).

## Finding new solutions for fermentation-derived fats

In 2021, GFI's research grant program launched a **request for proposals** focused on plant-based and fermentation-derived fat solutions to address the growing need for novel fat sources, production methods, and functionalities across all alternative protein platforms.

- We received 16 proposals from nine countries for fermentation-related research projects, three of which were selected for funding.
- Findings from this work will be made publicly available in 2022 or early 2023, and brief summaries of two projects already underway are below.

GFI also maintains a **database of third-party research funding opportunities** that are relevant to alternative proteins, and GFI plays an active role in helping researchers secure research funding from external sources, such as government or philanthropic grants.

## Production of animal fat substitutes by oleaginous yeasts

**Research highlight:** Dr. Kyria Boundy-Mills, a researcher in food science and technology at University of California, Davis, has served as the curator of the university's Phaff Yeast Culture Collection for more than 20 years. She is leading a project to **screen the culture collection's oleaginous yeast strains for fat yield and composition, among other food-relevant properties**, to find those closest to animal fats in specific types of meat, including beef and pork. Her team will then optimize the fat content and profile by adjusting the culture conditions of the top-performing strains, in addition to characterizing other nutritional characteristics of the whole cell biomass. This project includes collaborators from the UC Davis Cultivated Meat Consortium who are well versed in the needs of the alternative protein sector.

## Utilization of microalgal fermentation to produce structured plant-based fat for meat analogues

**Research highlight:** Dr. Salma Mohamad Yusop, a researcher in the Department of Food Sciences at Universiti Kebangsaan Malaysia, is leading a project to leverage **omega-3-rich oils from a species of microalgae in combination with structured plant-derived fats and proteins**. The goal of the project is to develop ingredients that mimic the properties of fatty animal tissues. Using a variety of methods to incorporate the algal oils into a network of plant fat crystals and crosslinked proteins, the team will test the functional properties of the resulting mixtures against animal fats as well as commonly used plant-based saturated fats, such as palm oil. The research team also plans to model costs for industrial-scale versions of this process.



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.

## Highlight

### Plant molecular farming: Plants as a scalable expression platform

In 2021, plant molecular farming gained increased attention as an innovative production process. Molecular farming itself is not a new technology. It has long been used in developing pharmaceutical therapeutic end products (e.g., insulin, antibodies, antigens, enzymes), but recent advances demonstrate its promise for alternative protein production. The process is similar to precision microbial fermentation but uses plants instead of bacteria or fungi as cell factories to produce ingredients like animal proteins. It is potentially cheaper and more scalable than precision fermentation because it does not require the capital-intensive equipment associated with fermentation. However, plant molecular farming can pose some unique regulatory hurdles, depending on whether the plants are intended to be grown outdoors rather than contained in greenhouses. There may also be processing and purification challenges associated with extracting proteins from plant cells with strong cell walls, depending on which tissues the ingredients are expressed in.



### Commercial landscape

Currently, 13 known companies are advancing plant molecular farming for the alternative protein sector. Here are a few examples of product approaches:

- **Nobell Foods** (formerly Alpine Roads) has developed soybeans that produce casein proteins.
- **Moolec Science** uses soybean, pea, and safflower crops to produce bovine- and porcine-based proteins.
- **ORF Genetics** creates growth factors for cultivated meat media using barley as the expression host.

Additional companies applying molecular farming to develop alternative protein ingredients and cultivated meat media include **Mozza, Miruku, Greenovation Protein, Tiamat Sciences, Core Biogenesis, BioBetter, Bright Biotech, Veloz Bio**, Fantastic Farms, and **InVitria**.

**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 in this state of the industry report as a separate call-out because of its similarity to precision microbial fermentation in terms of the range of potential products it can provide.



## The promise of plant molecular farming

Leveraging plants as recombinant protein hosts offers a number of advantages relative to microbial precision fermentation, including the following:

1. Molecular farming could potentially create proteins at a **much larger scale** because of the possibility of **open field production**, at least for certain classes of ingredients. There is also significant existing infrastructure established for crop production, harvest, and initial processing steps, reducing the need for additional infrastructure investments.
2. Plant molecular farming can produce **animal ingredients in crops that already have uses in alternative protein end products** to further increase functionality and taste. For example, it may be possible to produce baking flour with integrated egg and dairy functional proteins with **minimal need for downstream processing or purification**. Another example could be creating pea protein with functional bovine proteins already incorporated for better end-product formulation, reducing plant-based meat manufacturers' costs associated with sourcing purified versions of these proteins as ingredients. This has the added benefit of promoting zero-waste economies through **whole crop valorization**.
3. Plant molecular farming has the flexibility to create a **range of proteins with use cases across the cultivated and plant-based sectors**. A variety of crops can be used, enabling plant molecular farming to occur in a range of conditions and places. Currently, soybeans, pea, barley, rice, safflower, and duckweed crops have demonstrated promise.



**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.*



“We have barely scratched the surface of what we can do with plants; we’ve been breeding and designing plants to optimize for things like yield per acre and now we have the opportunity to use these tools to actually produce plants that are optimized for the production of better plant-based dairy, meat, and eggs.”

—Magi Richani, founder, Nobell Foods



## 2021 funding highlights

A total of \$132 million has been invested in plant molecular farming companies to date. Of this, \$106 million was invested in 2021. Notably, Nobell Foods **raised a \$75 million Series B in July 2021**. Nobell mixes casein protein made through plant molecular farming with plant ingredients to create plant-derived cheese that has the stretchiness, melting properties, and taste of animal-derived cheese. Andreessen Horowitz led the round, which represented the famed venture capital firm's first announced investment in alternative proteins. Other notable investors in Nobell's Series B included Breakthrough Energy Ventures and Robert Downey Jr.'s FootPrint Coalition Ventures.

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## Section 5

# Government and regulation



## Section 5: Government and regulation

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### Regulatory updates

The food industry has long used microbial fermentation as a processing method and to create ingredients derived from microbial cultures—for example, precision fermentation creates the rennet used in most animal-based cheese products. Given this history, most governments have well-established regulatory systems to ensure the safety of innovations in this platform. But each regulatory agency and framework presents its own nuances and idiosyncrasies.

Multiple companies have already obtained “no questions” letters from FDA for purified fermentation-derived ingredients, meaning FDA does not object to the companies’ view that their ingredients are “**generally recognized as safe**” (GRAS).

- 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.

In December 2020, Impossible Foods received **approval** for their heme from the regulatory agency Food Standards Australia New Zealand. The approval became final in February 2021, opening up another large market.

In the European Union, companies must get premarket authorization for many new fermentation-derived ingredients—when produced without genetic modification—according to the European Union’s **novel food regulation**. The procedure includes a risk assessment conducted by the European Food Safety Authority (EFSA). 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 2021, **Nature’s Fynd** and **Solar Foods** submitted their novel food applications to the European Union. Since 2020, EFSA has been assessing the safety of other fermentation-derived ingredients as novel foods, including **MycoTechnology’s fermented pea and rice protein** and **The Protein Brewery’s Fermotein**. Additionally, **the European Union has been assessing Impossible Foods’ soy leghemoglobin both as a genetically modified food and as a food additive**.

With its exit from the European Union at the end of January 2021, the United Kingdom is no longer participating in the European Union’s common regulatory approval process. A fermentation company wanting to sell their products in the United Kingdom needs to apply for authorization to the UK Food Standards Agency (FSA). So far, the United Kingdom has adopted the most relevant aspects of EU food safety law into UK law, meaning there has been no significant change to the content of the risk-assessment procedure. The FSA provides general **guidance** on how to submit a novel food application.

## **Singapore Food Agency updates guidance for assessing fermentation-derived foods**

In December 2021, the Singapore Food Agency (SFA) updated a **guidance document** on safety assessments for novel foods. 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. According to SFA, the framework set forth in prior versions of the guidance document steered SFA’s approval of **Impossible’s soy leghemoglobin** in 2020 and **Triton Algae’s *Chlamydomonas reinhardtii* algae** in November 2019.

## **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 did reject 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.

The alternative protein fermentation sector—companies producing animal-free dairy, eggs, and other novel proteins—have not yet aligned on standard terminology for products or ingredients derived from precision fermentation, although there is an acknowledged need for nomenclature studies. Several leading companies in the precision fermentation sector are

working together to identify appropriate nomenclature, with some consensus appearing to emerge around the modifier “animal-free.” Currently, several distinct terms are in use.

For ingredients (primarily B2B communications):

- The ingredients disclosure on labels for **N!ck’s ice cream**, **Modern Kitchen** cream cheese, and **Bold Cultr** cream cheese, all of which are 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. Smitten’s packaging also includes a dairy allergy warning.
- **Perfect Day** uses the term “**microflora**” for microbial hosts and “flora-based” or “flora-derived protein” for animal-free dairy proteins in marketing materials but not on product labels. Unlike probiotic products that also use the term “flora,” Perfect Day’s products do not contain live cultures.
- **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**, which 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:

- **Quorn** coined the term “**mycoprotein**” to describe their fungal-derived protein ingredient, but another term may work equally well or better for this type of biomass. Note that as a **settlement term of a class action suit, the company has since modified their packaging in the United States**. The allergen warning now reads: “Mycoprotein is a mold (member of the fungi family). There have been rare cases of allergic reactions to products that contain mycoprotein” (even though fungal food allergies are much less common than soy allergies).
- Other biomass companies develop 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.

## Government support

Fermentation is a paradigm-changing innovation. It can unlock new high-value uses for low-value agro-industrial byproducts, affordably nourish the world's growing population, and help ensure protein sovereignty and security. Thus, it is not surprising that some governments have taken action to support companies in this space.

Governments and public entities around the world are starting to fund fermentation work, including in the United States, the European Union, the United Kingdom, Israel, Singapore, and Australia. 2021 brought several new public investments:

- Singapore-based **Sophie's Bionutrients**, a fermentation technology company that creates high-protein foods from microalgae, received a grant from the University of California as part of the school's UC Startup Innovation Challenge.
- Perfect Day and A\*STAR **partnered to launch the A\*Star-Perfect Day Joint Lab**, which will facilitate collaboration between Perfect Day and two A\*STAR research institutes—the Singapore Institute of Food and Biotechnology Innovation and the Institute of Molecular and Cell Biology—to bring new products to Singapore.
- The Minnesota Department of Employment and Economic Development **provided a Minnesota Innovation Grant** to Fybraworks Foods, a company developing animal proteins through precision fermentation.
- As part of its Venture Further startup competition, the **University of Manchester in the United Kingdom awarded a grant to Bright Biotech**, which develops recombinant proteins in plants for a number of applications, including food.
- Israeli company Imagindairy, which uses precision fermentation to create milk proteins, **received funding from the Israel Innovation Authority**.
- Australian alternative protein company All G Foods, which develops both plant-based and fermentation-derived products, **received A\$5 million (US\$3.7 million) from the Clean Energy Finance Corporation**, an Australian government-owned green bank.
- Finland-based Solar Foods **received** a €10 million (\$11.9 million) capital loan from the state-owned Finnish Climate Fund to build a demonstration factory in Finland.
- The Swedish government funding agency Vinnova announced several grants (totaling over €1 million) to fund R&D in fermentation-powered alternative proteins, including R&D involving traditional fermentation of **seaweed, fava bean, and legume and cereal proteins**, as well as biomass fermentation of **yeast**.
- The UK government announced investing in **a studentship** to develop novel strains for the mycoprotein fungus utilized by Marlow Foods and £748,571 for **a project** led by the National Institute of Agricultural Botany to better understand hyphal branching to improve Marlow Foods' existing strains.

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## Section 6

# Conclusion and forecast



## Section 6: Conclusion and forecast

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Fermentation firmly established itself as an indispensable third pillar of alternative proteins in 2021. Fermentation is one of the oldest technologies, yet it is being reimagined for use in the alternative protein sector at a rapid rate of innovation. Because of its vast potential in technical and product development innovation, fermentation is well positioned to exceed the sensory, nutritional, environmental, social, market, and functional paradigms of status quo proteins in today's food system. Alongside plant-based proteins and cultivated meat, fermentation can help us sustainably feed a global population of nearly **10 billion** people by 2050.

This past year, fermentation proved that it offers competitive prices and unparalleled functionality and scalability. It is poised to revolutionize the entire alternative protein industry, with spillover applications in plant-based products and cultivated meat. Fermentation can enable a new generation of proteins, fats, and other functional ingredients to create a range of alternative meat, seafood, eggs, dairy products, and more. Investors agreed, and a record amount of funding poured into the fermentation space, leading the way for even greater advances in 2022.

The alternative protein industry has just scratched the surface of the potential for fermentation-based approaches, and both consumers and existing players in the sector are eager for the innovative products and solutions that fermentation can provide.

As we look ahead, we anticipate several trends to emerge in this sector.



**Fermentation will gain broader recognition for environmental and other benefits.**

Fermentation-enabled products have significant benefits from environmental, nutritional, taste, and economic perspectives. Taste and price remain core drivers of consumer purchasing decisions, and fermentation technology stands to address barriers in these areas.

Sustainability is also an important motivator for plant-based food consumption, particularly among younger consumers. We are seeing fermentation companies elevate their impressive environmental stats as a way of differentiating themselves. **Perfect Day** and **Nature's Fynd** both conducted life-cycle assessments and found that their proteins had significantly smaller environmental footprints compared with animal meat or dairy. Other companies, like Mycorena, released their own **environmental impact estimates**.

Further improving the environmental profile of fermentation, many companies are successfully valorizing other industries' side streams by using them to make their products, leading to cost savings and a better environmental footprint. **MOA Foodtech**, for example, is a biomass fermentation startup that creates high-value proteins from agri-food byproducts. A Canadian startup, Liven, is using leftover pulse starches to create gelatin through precision fermentation. Larger players are getting involved, with **Anheuser-Busch InBev and EverGrain partnering** to



use leftover barley from the beer-making process to create alternative protein products. In 2022, we expect a broader range of investors, companies, and consumers to seek out fermentation-derived products for their environmentally friendly billing and other benefits.



### **Computational approaches will accelerate innovation.**

For millennia, advances in fermentation technology were largely made via trial and error. Modern technology has sped up the development process for fermentation, and the advent of new computational approaches will continue to accelerate innovation in everything from strain development and target selection to bioprocess design. Advances in broader fermentation technology—which has applications in the pharmaceutical and other industries—have tremendous benefit for alternative protein companies and their ability to bring better products to market. For example, Google’s DeepMind protein-structure prediction algorithm and digital-twin bioprocessing models are broader innovations with applications in alternative proteins. Ginkgo Bioworks’ **Grow with Ginkgo** program and **Shiru’s data science approach** are also making automation and computational tools more widely available to the industry. Alternative protein companies that begin using these tools and virtual platforms will be able to both design proteins with superior sensory characteristics and model and optimize bioprocesses digitally in order to bring better products to market quickly.



### **Hybrid products will become increasingly common.**

Hybrid products and partnerships will become even more common in 2022. We saw the first wave of this in 2021, and as emerging B2B players continue to commercialize their products, this will become an even larger trend. **Motif FoodWork’s HEMAMI™** will pave the way for an increasing number of plant-based products to incorporate animal-free myoglobin and other animal-free proteins. We will also see more partnerships between fermentation and cultivated meat companies, such as the **partnership** between Nourish, a fermentation-enabled fat company, and Vow, a cultivated meat company. Hybrid products that combine animal meat with fermentation-derived or other alternative protein ingredients are also likely to hit the market. The Better Meat Co., for example, sells its Rhiza mycoprotein to **replace a portion of animal meat** in blended products and just entered into an **exclusive partnership with Hormel** to commercialize new products. Companies operating at the intersection of the three alternative protein categories will enable a new wave of paradigm-shifting meat, egg, and dairy products and ingredients that meet consumer expectations for taste, price, functionality, versatility, and variety.



### **A greater variety of sources will be explored for use in alternative proteins.**

Fermentation is an ancient technology in the early stages of development for alternative protein application. Companies like YEAP and Sophie’s Bionutrients are tapping into various sources of fermentable protein, such as spent brewer’s yeast and various microalgae, to create

a wide variety of ingredients and end products. In the future, we expect to see a greater diversity of microbes explored for alternative proteins.



### **Fats, oils, and specialty dairy products made via precision fermentation will hit the market.**

Fats are a critical component of the sensory experience of animal products. But it can be challenging to biomimic the functionality of animal fats with molecules from plants. Precision fermentation is well suited to producing fats that are identical to those found in animals, and an increasing number of companies are focusing on this key ingredient. We expect that additional companies will emerge to seize this white-space opportunity and that a range of animal-free fats will become commercially available as ingredients for the industry.

Specialty dairy products made via precision fermentation will also hit the market in a big way. In 2021, Perfect Day's animal-free whey protein emerged in ice cream, cream cheese, and even cake mix. In 2022 we anticipate even more product launches, with consumer readiness and willingness to try these animal-free dairy products on the rise. **Formo, a German-based microbial fermentation startup producing dairy proteins, co-published a study with the University of Bath around consumer acceptance of animal-free dairy products** and found strong consumer enthusiasm across the countries they studied. Formo also collaborated with Mercy For Animals and Fordham University on **another study examining consumer attitudes and nomenclature for dairy products produced via precision fermentation.**

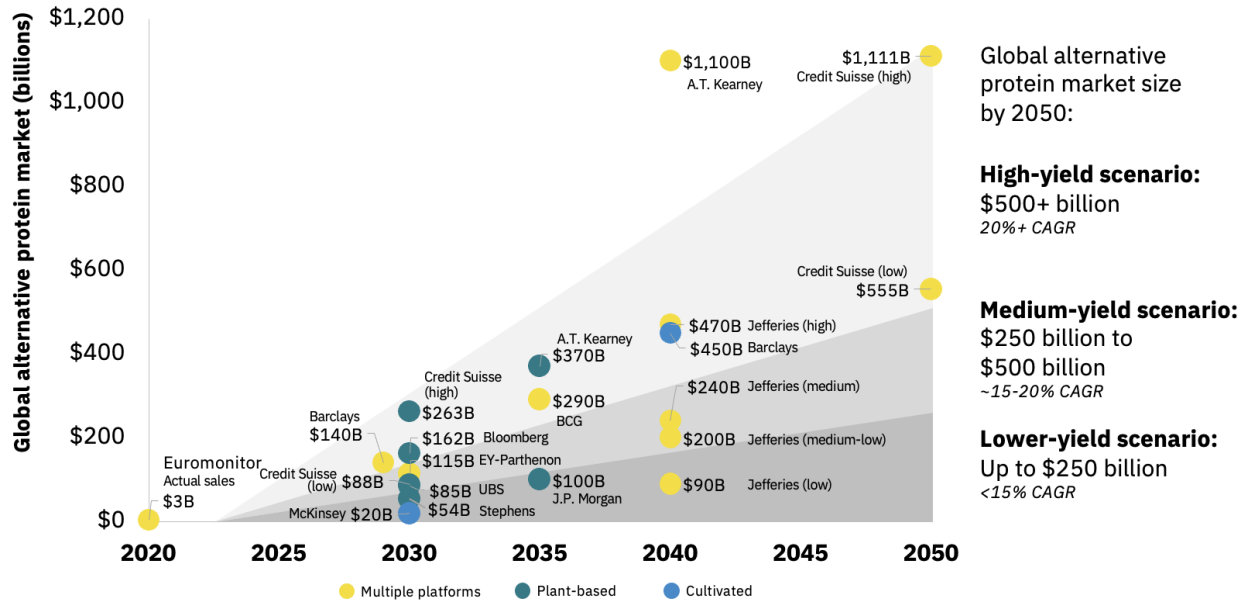


### **Products will be brought to market with increasing frequency.**

Investment flooding the fermentation sector in 2021 will be put to work bringing products to market and building production capacity. Infrastructure constraints are a bottleneck for the industry, and considerable investment is needed to scale and truly realize the potential of fermentation companies. Many new facilities came online in 2021, and we expect even more to be announced in 2022. Human capital is another critical area in developing the capacity to expand. **Protein Industries Canada announced** their investment to provide skills development and training for fermentation that will help build the sector. This combination of production capacity, human capital, and demonstrated early consumer traction will enable the industry to drive down prices while improving the end products' quality to drive further adoption.

## A look forward for alternative proteins

Figure 14: Projections of market size



Source: GFI synthesis of multiple reports.

We expect the alternative protein industry to grow meaningfully over the coming decades. And this view is supported by numerous research organizations, investment firms, and consultants that have published forecasts of the industry’s growth, many of which are mapped in the chart above.

Forecasts range from lower-growth scenarios of up to \$250 billion in annual sales to high-growth scenarios of \$500+ billion in annual sales of alternative proteins by 2050. A couple of key factors could account for the wide range of these estimates:

- The inherent uncertainty of making predictions early in an industry’s life cycle.
- The path-dependency of industry growth based on a range of drivers across the areas of scientific and technological innovation, commercial and consumer trends, and regulatory and government action.

Factors that would drive sales growth include the following:

- **Supportive government and regulatory action.** Governments have incredible power to help the industry grow exponentially by investing in open-access R&D, supporting the private sector, and creating a clear regulatory path to market for cultivated meat.
- **Investment and innovation** that allow scaled production of a wider variety of products that are both organoleptically equivalent to conventional animal products and competitively priced.

- **Product development** to produce key formats like whole muscle cuts and hybrid products that combine cultivated, fermentation-derived, and plant-based ingredients to enhance sensory and functional attributes.
- **Scientific advancement** in areas of cell culture media, scaffolding, cell lines, and bioreactors and bioprocessing technologies.
- **Scaled production capacity** that achieves greater economies of scale and a resilient supply of alternative proteins.
- **Greater consumer adoption** that builds on existing momentum to shift to alternative proteins, driven by a variety of motivators, such as public health risks, animal welfare, and environmental impacts like climate change.

Other factors would nudge alternative proteins onto a slower growth path:

- A lack of public and private investment in innovation and production.
- Persistent technical challenges.
- Climate change risks stymieing ingredient availability or commercial viability.
- A lack of clear regulation impeding innovation.
- Government censorship of labels or other roadblocks to the technological or consumer progress of alternative proteins.

While the industry’s precise growth path will remain uncertain for some time, industry stakeholders—startups and established food companies, consumers, investors, and global governments—are already charting that path and pointing it in the direction of a more sustainable and secure food future.

## Expert predictions

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



One of the big challenges we are looking to address is how to feed an exponentially growing population. It is expected that by 2050 we will need to increase protein production by over 50%. Fermentation we believe will make up a significant portion of the protein we consume in the future... We see the fermentation industry moving towards more complex fermentations because they offer the versatility that is needed to address complex issues at scale. I also think you will see in the near future that more of our food will come from fermenters than farms.

—**Alex Hahn, CEO, MycoTechnology**



Sustainability is first and foremost about circularity. Upcycling food industry side streams into the food system is a key to achieve this goal. The fermentation-based industry will continue to build solid foundations in the coming year and will grow in the B2B sector over the course of the next 5 years, with a focus on specialty, functional ingredients.

—**Jonathan Goshen, CEO and co-founder, YEAP Proteins**



We're convinced that, to achieve our goal of a zero-carbon economy, we need to invest at least as much attention and resources into making our food system radically more sustainable as we are investing into clean energy. Precision fermentation methods are less resource-intensive in comparison to traditional methods of extracting animal proteins from animals. Additionally, consumers are expressing an ever-growing demand for sustainable, environmentally-friendly food options. On this account we see an extensive increase of precision fermentation companies developing innovative solutions for food production. We'll observe a bigger variety of compounds being produced through fermentation with an ever increasing range of application and decreasing price points.

—**Raffael Wohlgensinger, CEO and co-founder, Formo**



In the coming years, I believe we will see food innovation unlocked by the tools we can leverage from adjacent industries, including synthetic biology, automation, and computational capabilities. Fermentation-produced ingredients and food will become mainstream, with more and more food manufacturers sourcing ingredients from the startups producing them initially and soon investing in their own capabilities to produce foods this way as well. Leveraging fermentation to produce food ingredients of many types will become increasingly commonplace in the near future, especially as issues with supply chains, unpredictable effects of climate change on our agricultural systems, and antibiotic resistance in crops and animals increasingly threaten our current ways of producing food.

—**Jasmin Hume, founder and CEO, Shiru**



In 2022, I hope we start to see the creation of lipids through fermentation—that’s really exciting to me. Right now at Helaina, we’re focused on using precision fermentation for proteins, but that’s just the beginning of what fermentation can do for the future of food. Between proteins and lipids, there is massive potential for fermentation to relieve a strain on the environment and to positively impact the overall wellbeing of animals. In 2022, we’ll see more firsts—more innovation showcasing breakthroughs no one has achieved before in food.

—**Laura Katz, founder and CEO, Helaina**



Fermentation provides a viable and sustainable method of production. However, it’s not without its challenges, one of which being capacity—quite simply there isn’t enough. However, there are a number of ways as an industry that we can look at growing fermentation capacity—from individual producers building their own plants, and partnerships between strategic entities and big multinationals with the capacity to build at scale. As well as collaboration between producers, where we pool our resources and tackle this problem together.

—**James Petrie, founder, Nourish Ingredients**

# Acknowledgments

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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](http://www.gfi.org).



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