Good Food Institute

Plant-based meat: **Anticipating 2030 production requirements**

Prepared by The Good Food Institute

2022

Agenda

1. Introduction, motivation for this analysis, and methodology
2. Facility footprint and investment needs at industrial scale
3. Ingredient needs at industrial scale
4. Conclusion and next steps
5. Q&A

Acknowledgements

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The Good Food Institute

GFI is a 501(c)(3)nonprofit developing the roadmap for a sustainable, secure, and just protein supply. We focus on three key areas of work:

Science and Technology

Advancing foundational, open-access research in alternative proteins and creating a thriving research and training ecosystem around these game-changing fields.

Corporate Engagement

Partnering with companies and investors across the globe to drive investment, accelerate innovation, and scale the supply chain—all faster than market forces alone would allow.

Policy

Advocating for fair policy and public research funding for alternative proteins.

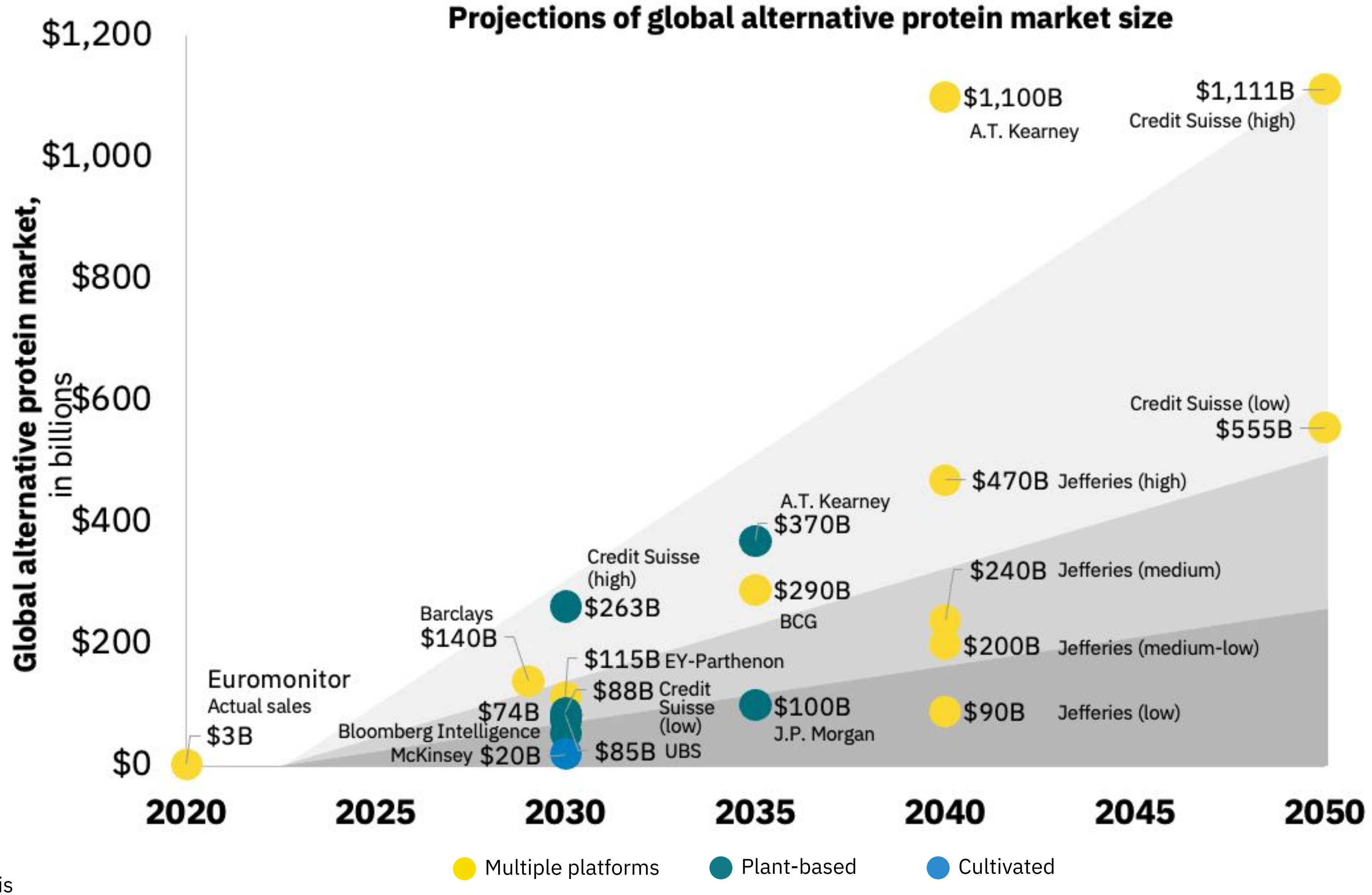
GFI officially earned GuideStar's 2019 and 2020 Platinum Seal of Transparency—obtained by less than 1% of nonprofits—reflecting our commitment to maximum impact, efficiency, and inclusion.

We work as a force multiplier, bringing the expertise of our departments to the rest of the world.

United States
Brazil
India
Europe
Asia Pacific
Israel

100+ staff in 6 regions

Companies estimate the global alternative protein market may be as large as $1T by 2050.



Global alternative protein market size by 2050:

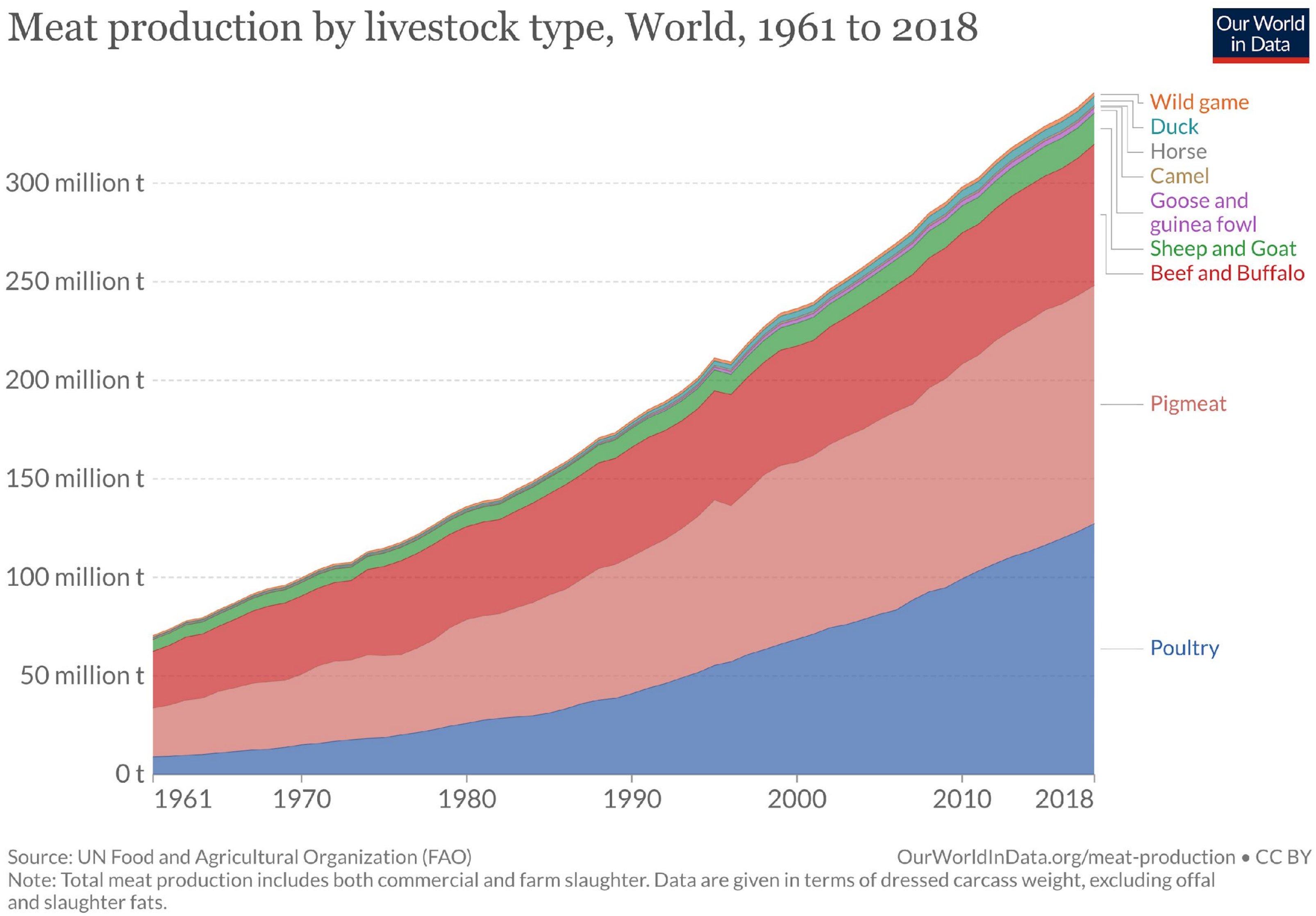
High-yield scenario:
$500+ billion
20%+ CAGR

Medium-yield scenario:
$250 billion to $500 billion
~15-20% CAGR

Lower-yield scenario:
Up to $250 billion
<15% CAGR

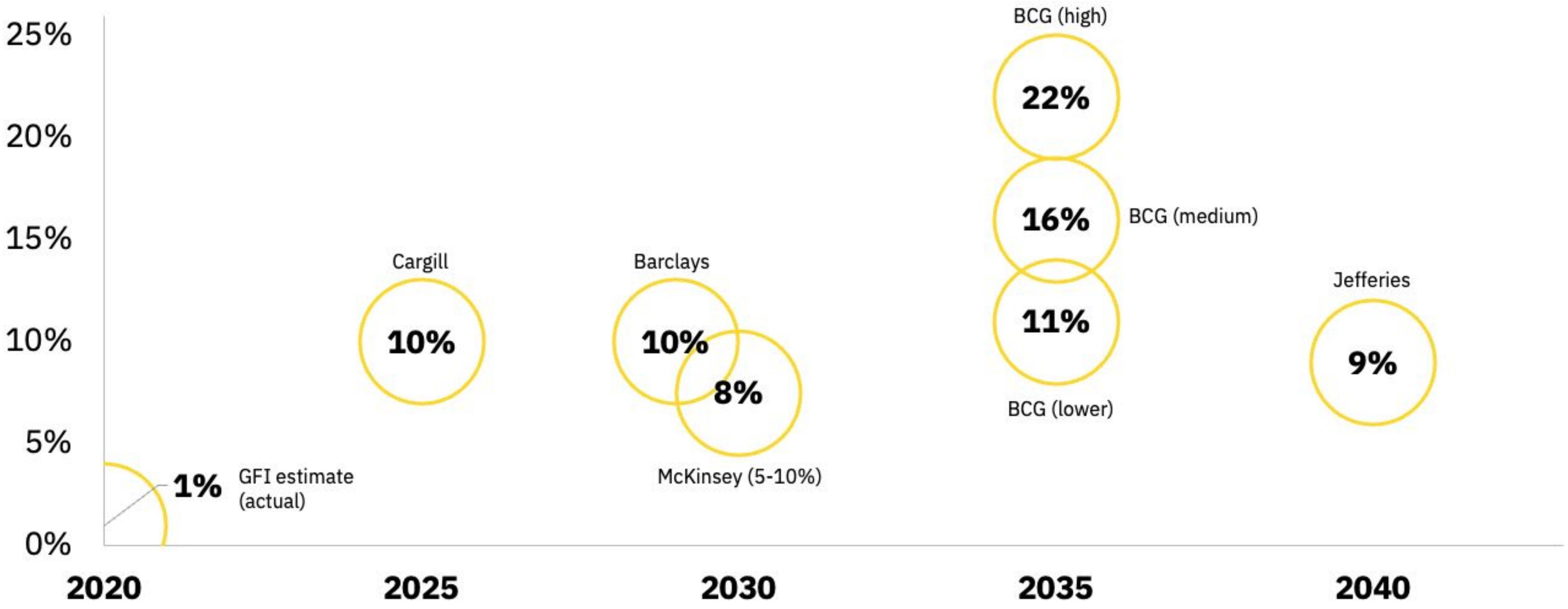
Source: GFI analysis

Significant shifts in protein consumption have happened before



Source: Our World in Data

Estimates for alternative protein's share of the global meat market



Source: GFI analysis

Hypothetical production scenario: 6% market share requiring 25 MMT production

2021

~1%

2030

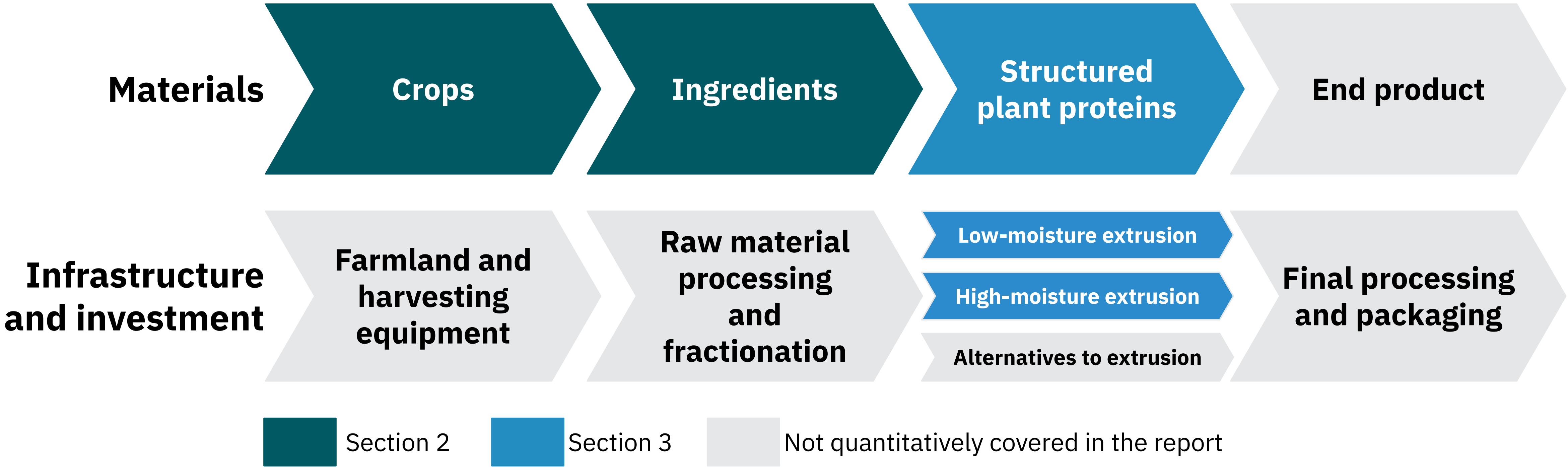
6%

25 MMT

This production model uses a hypothetical production scenario set in **2030**, where plant-based meat has captured **6% of the global meat and seafood market**, necessitating the production of **25 million metric tons (MMT)** of plant-based meat **annually.**

Source: GFI analysis. This analysis is based on a hypothetical scenario that assumes 6% market share for plant-based meat in 2030 with annual production of 25 million metric tons (MMT). This production figure is not GFI's forecast of future demand. The analysis is benchmarked to estimates from third-party market research groups and is intended to provide directionally predictive insights that illustrate the supply chain innovation and investment required to hit commonly-cited production targets.

Illustrative plant-based meat production supply chain



Source: GFI analysis. This analysis is based on a hypothetical scenario that assumes 6% market share for plant-based meat in 2030 with annual production of 25 million metric tons (MMT). This production figure is not GFI's forecast of future demand. The analysis is benchmarked to estimates from third-party market research groups and is intended to provide directionally predictive insights that illustrate the supply chain innovation and investment required to hit commonly-cited production targets.

Key assumptions and analysis limitations

- Among other variables, our model is sensitive to:
  - Forecasted demand growth rate
  - Current volumetric production estimates
  - The species and end product formats of plant-based meat and seafood produced
  - The usage levels of different ingredients in plant-based meat formulations
  - Projected production of global crops and ingredients
  - Production facility utilization rates
  - The balance of production methods used (e.g., high- vs. low-moisture extrusion)
  - Relative mix of small and large production facilities
- We conservatively assume that there will not be major innovation breakthroughs in crop breeding, protein fractionation, or plant protein structuring technologies such as extrusion or fiber spinning, even though we strongly believe that innovations are likely in these areas with sufficient investment in R&D from the public and private sectors. More detail on report simplifications, assumptions, and potential sources of error can be found in the report in Tables 1 and 6.
- This report should be considered a living document, subject to frequent revision, updates, and more sophisticated modeling as new information becomes available. The results presented here should not be interpreted as an authoritative prediction but rather a working model for providing directional guidance based on future crop, ingredient, infrastructure, and investment demands for the plant-based meat industry.
- Data on key variables like costs, production facility capacity, and process efficiency are often proprietary and hard to obtain. We welcome any countervailing data and/or feedback since it will help us improve the model!

Key findings: Ingredient and facility constraints

There is a looming potential for **global supply squeezes of cornerstone ingredients**, like coconut oil and pea protein, in the coming years.

There are also clear opportunities for the industry to proactively **mitigate these supply strains**.

We conservatively estimate that the industry will need to **operate at least 800 manufacturing facilities** at a **global capital cost of at least $27B** within the decade in order to satiate even modest consumer demand growth for plant-based meat.

This underscores the importance and urgency of **incentivizing bold infrastructure investments** to facilitate this transition.

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Facility footprint and investment needs at industrial scale

Structured plant protein (SPP) manufacturing approaches

- **V1.0 (traditional processes):** Products like seitan are produced in a reasonably simple manner, by kneading a dough of wheat flour, yeast, and water. Traditional meat analogs like seitan have been produced for centuries, but they bear minimal organoleptic resemblance to conventional meat.
- **V2.0 (low-moisture extrudates):** Since the 1960s, low-moisture extrusion has been used to produce textured vegetable protein in the form of strips, crumbles, and flakes. Plant-based meat manufacturers use this shelf-stable, low-moisture extrudate (LME) to produce comminuted products like sausages, burgers, and meatballs. Plant proteins processed using LME are also widely used as extenders in the conventional meat sector.
- **V3.0 (high-moisture extrudates):** The 2000s saw the advent of high-moisture extrudates **(HME)** produced via twin-screw extrusion lines. This approach, which today is not as widely utilized in the plant-based meat industry, more convincingly replicates the taste and texture of conventional meat.
- **V4.0 (next-generation techniques)**: There are now efforts by researchers, manufacturers, and entrepreneurs to expand the reach of plant-based meat production methods to further optimize for texture and taste. Researchers and companies are developing novel alternatives to extrusion including shear cell technology, 3D printing, spinning technology, and other novel manufacturing approaches.

The report's estimations of the industry's SPP manufacturing needs in 2030 assume LME accounts for 80% of the global SPP volume and HME accounts for 20% of the global SPP volume

Four archetypal extrusion lines were modeled for this analysis—two LME lines and two HME lines

- **Line 1: LME (throughput: 1,000 kg/hr).** Ingredient suppliers and plant-based meat manufacturers operate extrusion lines at this capacity today in small- to medium-scale facilities.
- **Line 2: LME (throughput: 2,500 kg/hr).** Extrusion lines of this capacity are often located in large-scale facilities operated by ingredient suppliers who sell their SPP to plant-based meat manufacturers. This scale represents the upper bounds of SPP throughput based on today's manufacturing technologies.
- **Line 3: HME (throughput: 500 kg/hr).** Due to the limitations that cooling dies impose on the HME production process, 500kg/hr has been the maximum throughput achieved at industrial scale until very recently.
- **Line 4: HME (throughput: 1,000 kg/hr).** The current market leading cooling die for HME is capable of 1,000kg/hr. It is highly likely that other industrial equipment manufacturers will soon follow suit.

Source: GFI analysis. This analysis is based on a hypothetical scenario that assumes 6% market share for plant-based meat in 2030 with annual production of 25 million metric tons (MMT). This production figure is not GFI's forecast of future demand. The analysis is benchmarked to estimates from third-party market research groups and is intended to provide directionally predictive insights that illustrate the supply chain innovation and investment required to hit commonly-cited production targets.

Estimated global extrusion line and extrusion facility quantities

Global production volume assumptions	Facility A	Facility B	Facility C	Facility D
Type	Medium LME	Large LME	Medium HME	Large HME
Extrusion lines per facility (#)	1	4	2	10
Annual output per facility (MMT)	0.007	0.07	0.007	0.07
Share of global SPP production (%)	12	68	3	17
Extrusion facilities (#)	**413**	**234**	**104**	**59**

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Estimated capital expenditure per facility for generalized hypothetical SPP extrusion facilities

Facility CapEx components ($M)	Facility A	Facility B	Facility C	Facility D
Type	Med LME	Large LME	Med HME	Large HME
Land acquisition	0.3	1.0	0.3	1.2
Extrusion lines	2.0	16.0	4.9	36.0
Facility development	10.5	43.2	13.1	54.0
Total CapEx ($M)	**12.7**	**60.2**	**18.2**	**91.2**

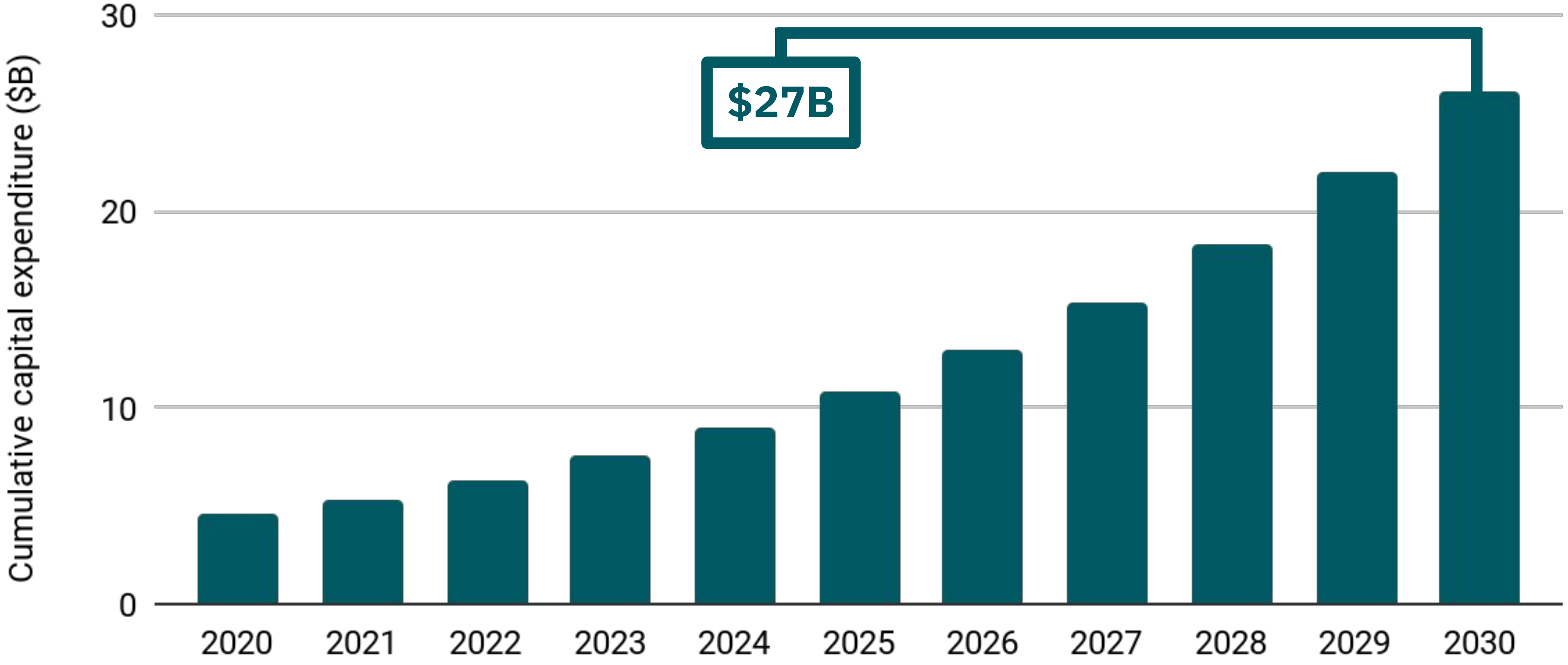
Source: GFI analysis. This analysis is based on a hypothetical scenario that assumes 6% market share for plant-based meat in 2030 with annual production of 25 million metric tons (MMT). This production figure is not GFI's forecast of future demand. The analysis is benchmarked to estimates from third-party market research groups and is intended to provide directionally predictive insights that illustrate the supply chain innovation and investment required to hit commonly-cited production targets.

Generalized hypothetical extrusion facility operating expenditures

Facility operating cost components ($M annually)	Facility A	Facility B	Facility C	Facility D
Type	Medium LME	Large LME	Medium HME	Large HME
Utility: water	<0.1	<0.1	<0.1	<0.1
Utility: electricity	0.3	1.8	0.9	4.4
Raw materials	4.2	21.0	10.2	51.3
Labor	6.1	11.0	6.1	11.0
Miscellaneous	2.2	4.9	2.5	6.6
Total annual operating costs ($M)	**12.8**	**38.7**	**19.7**	**73.4**

Source: GFI analysis. This analysis is based on a hypothetical scenario that assumes 6% market share for plant-based meat in 2030 with annual production of 25 million metric tons (MMT). This production figure is not GFI's forecast of future demand. The analysis is benchmarked to estimates from third-party market research groups and is intended to provide directionally predictive insights that illustrate the supply chain innovation and investment required to hit commonly-cited production targets.

Estimated cumulative global capital expenditure in structured plant protein extrusion facilities by 2030



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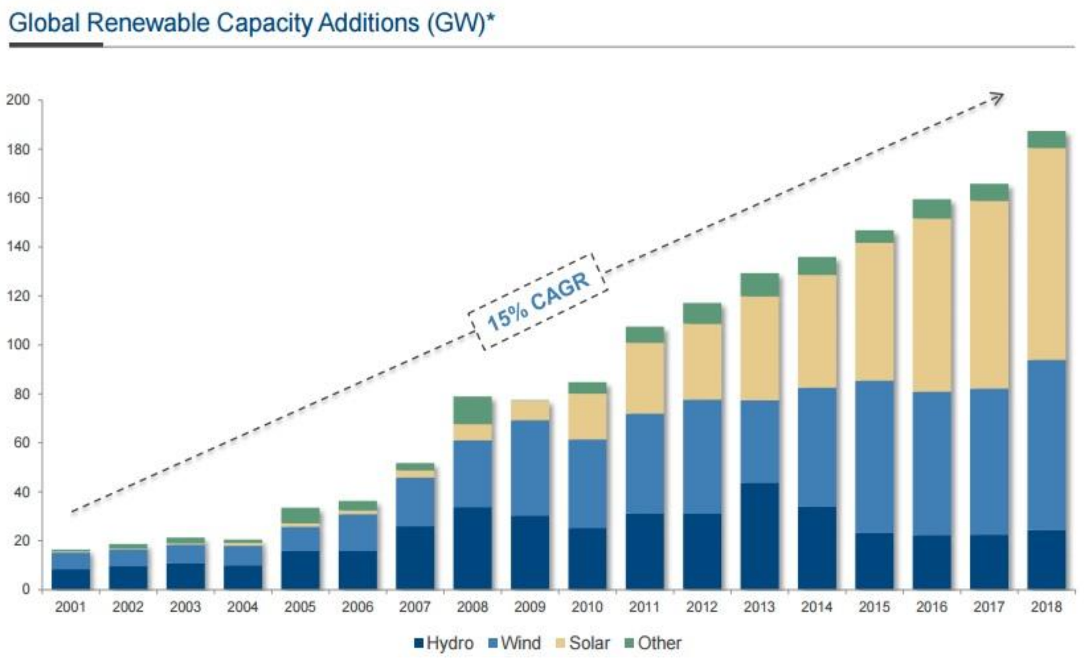
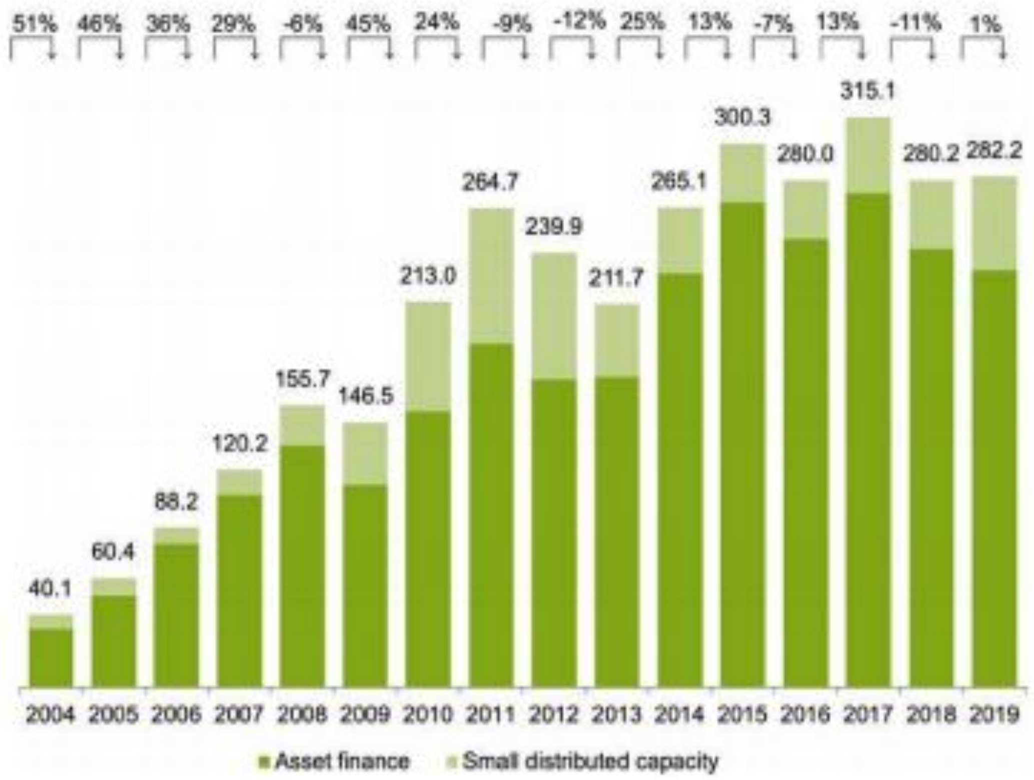
Clean energy investment grew 7x from 2004 to 2019, from $40B to $282B, a 14% CAGR over 20 years despite high CapEx



New investment in clean energy worldwide



Total values include estimates for undisclosed deals

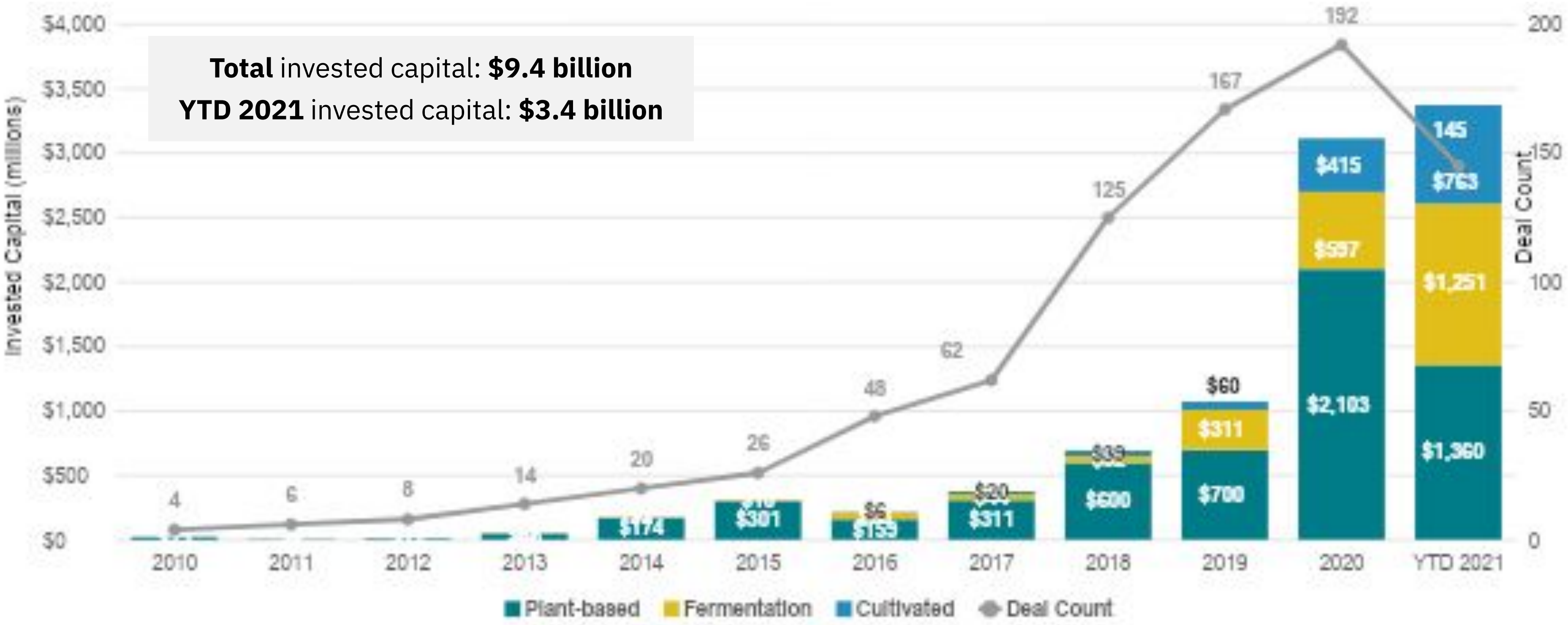
Source: UNEP, Frankfurt School-UNEP Centre, BloombergNEF

Sources: SimplySafeDividends, UNEP

Alternative protein investment (mostly VC equity deals) has grown rapidly – 47.6% CAGR over past 6 years – but this is only a fraction of what is needed for future growth

Annual investment in alternative protein companies
2010 – 3Q 2021

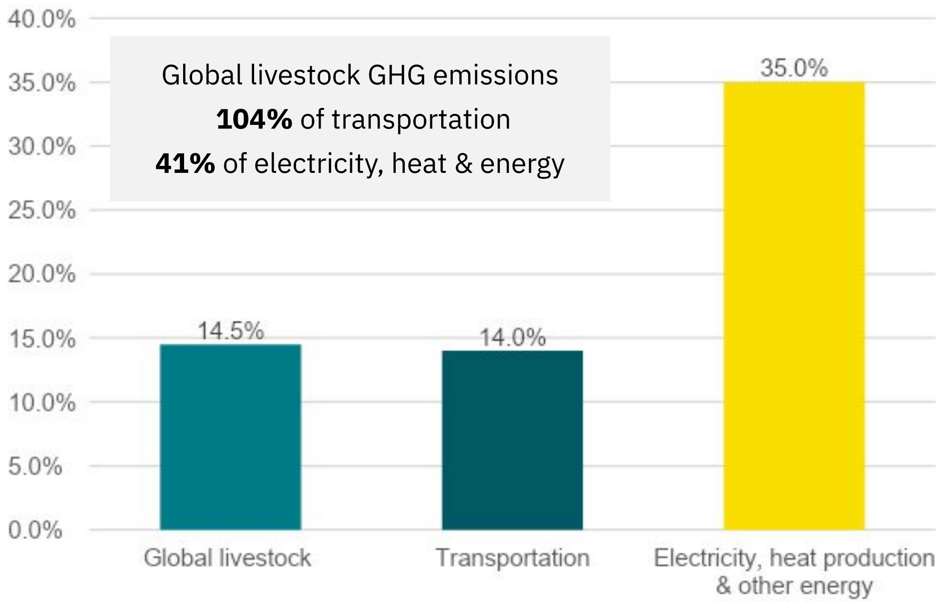
Total invested capital: **$9.4 billion**
YTD 2021 invested capital: **$3.4 billion**



Source: GFI analysis of PitchBook Data, Inc. Invested capital includes 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.
Note: Data has not been reviewed by PitchBook analysts.

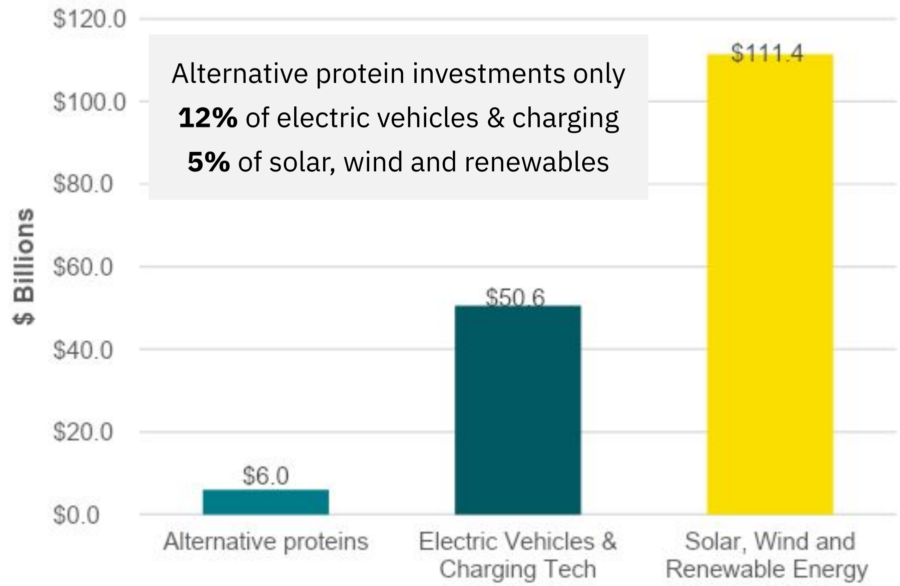
Under-investment in alternative proteins as a climate technology solution

Percent of global GHG emissions[1]



Invested capital[2]

Through December 31, 2020



[1] U.S. Environmental Protection Agency (EPA), Food and Agriculture Organization of the United Nations FAO).

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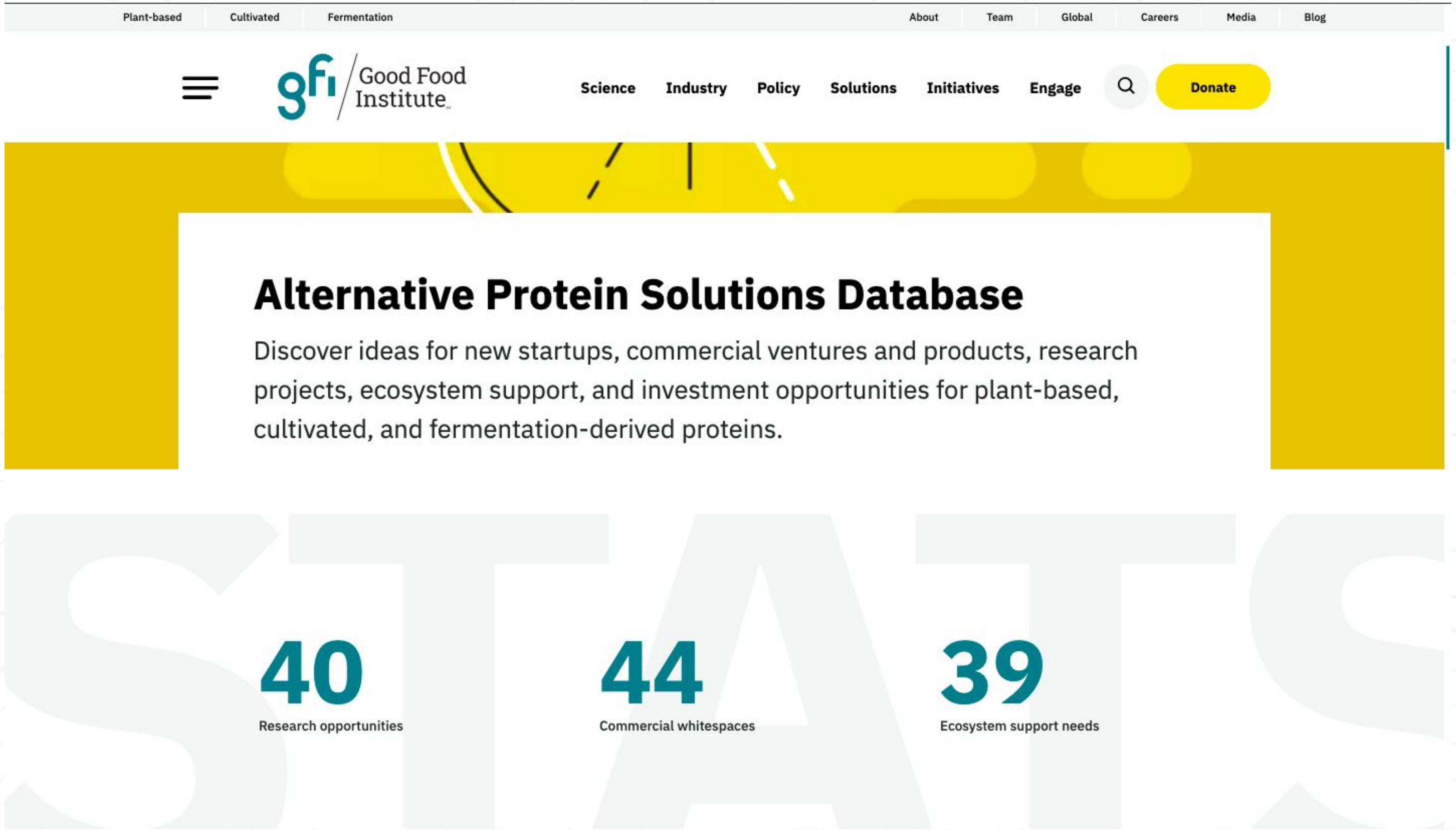
We need to establish alternative proteins as a bankable and investable green asset class every bit as impactful, profitable, and sizeable as renewable energy

Solutions to overcome scaling barriers

- **Expanding capacity at existing facilities**. Today, there are thousands of facilities that process various packaged foods using extrusion and related technologies. It is reasonable to expect that plant-based meat manufacturers can purchase and upfit existing facilities instead of constructing entirely new factories.
- **Production equipment innovation**. Investment in production equipment research and development would not only support likely improvements in product quality but could also ease capacity constraints if resulting innovations allowed for higher throughput and better utilization of existing and new production facilities without significantly increasing costs.
- **Partnerships and other commercial strategies**. Partnerships between ingredient companies and equipment manufacturers, such as a recent collaboration between Givaudan and Buhler on a manufacturing innovation center, can significantly accelerate R&D and commercialization timelines of novel manufacturing approaches.
- **Near-term investments in capacity expansion**. Production capacity for plant-based meat does not appear overnight. On the contrary, it often takes many years to conceive, finance, and construct an SPP processing facility. Financiers and ingredient processors seeking to expand their footprint in the rapidly growing plant-based meat industry should begin planning and investing now to meet the industry's ambitious production targets for this decade and beyond.
- **Private capital:** This need for greater capacity and infrastructure, including to manufacture plant-based meat end products, will require substantial capital from financiers like banks, PE funds, and institutional investors, not just early-stage VCs.
- **Public investment:** When blended with private sector funding, public funding can incentivize bold supply chain innovations and capacity-building, enabling the alternative protein sector to grow as fast as consumer demand does

Find additional white space ideas and solution ideas at gfi.org/solutions



Ingredient needs at industrial scale

Key ingredients present in the top 75 plant-based meat products

Share of products in each category that contain the respective ingredient for the eight most common ingredients, *2020*

Key ingredient	Burgers, meatballs, and grounds	Sausage links and patties	Nuggets, tenders, and cutlets
Soy protein concentrate	48%	36%	40%
Soy protein isolate	40%	48%	64%
Wheat gluten	48%	72%	76%
Pea protein*	32%	32%	20%
Coconut oil	40%	28%	-
Canola oil	76%	44%	19%
Sunflower oil	40%	36%	40%
Cocoa butter	12%	-	-

Without market transformation, the plant-based meat industry will continue to rely heavily on a select group of **well-established, commoditized ingredients**. Supply chains for **novel plant proteins** and **lipids** are currently **underdeveloped**, and difficult and costly to build.

*Includes both pea protein concentrate and isolate as this differentiation is not made in many ingredient lists. The Top 75 products includes the products with the highest U.S. sales in 2020. Source: The Good Food Institute research.

Archetypal plant-based meat formulations used in this analysis

Wheat/Soy-based (62% or 16 MMT)	**Pea-based** (16% or 4 MMT)
Water, **soy protein concentrate**, **wheat gluten**. Less than 2% of salt, methylcellulose, corn oil, onion powder, garlic powder, caramel color, yeast extract, malt extract, natural flavor, spices.	Water, **pea protein**, expeller-pressed **canola oil**, refined **coconut oil**, rice protein, natural flavors, **cocoa butter**, mung bean protein, methylcellulose, potato starch, apple extract, pomegranate extract, salt, potassium chloride, vinegar, lemon juice concentrate, sunflower lecithin, beet juice extract.
Soy-based (14% or 3 MMT)	**Chickpea/Pea-based** (8% or 2 MMT)
Water, **soy protein concentrate**, **coconut oil**, **sunflower oil**, natural flavors. Less than 2% of potato protein, methylcellulose, yeast extract, cultured dextrose, food starch modified, soy leghemoglobin, salt, mixed tocopherols, **soy protein isolate**, vitamins, and minerals.	Water, textured pulse protein (chickpea flour and **pea protein**), **sunflower oil**, chickpea flour, **coconut oil**, porcini mushrooms, sea salt, vegan Worcestershire sauce, black pepper, garlic powder.

Source: The Good Food Institute research

Data and methods: FAO commodity projections and industry ingredient production data

Data inputs

25 MMT demand

+

PBM formulations

+

Ingredient production data

+

FAO data

2030 projections

Projected ingredient demand

Share of projected global ingredient production

Share of projected global raw commodity production

Source: GFI analysis

Different ingredients may require different types of production scale-up

If | **Share of projected global ingredient production** | **is high percentage** → **Expanding intermediate processing will be sufficient** (e.g., protein isolate or concentrate production)

Source: The Good Food Institute research, **FAO Food and agriculture projections to 2050**.

Different ingredients may require different types of production scale-up

If	**Share of projected global ingredient production**	**is high percentage** →	**Expanding intermediate processing will be sufficient** (e.g., protein isolate or concentrate production)
If	**Particular cultivars**	**are required** →	Some **additional cultivation of the cultivar** may be required.

Source: The Good Food Institute research, **FAO Food and agriculture projections to 2050**.

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If **Share of projected global ingredient production** is high percentage → **Expanding intermediate processing will be sufficient** (e.g., protein isolate or concentrate production)

If **Particular cultivars** are required → Some **additional cultivation of the cultivar** may be required.

If **Share of projected global raw commodity production** is relatively high → **Increases in raw material production** AND **increases in intermediate processing capacity** may be required.

If **Higher yields can be obtained via ag intensification and ingredient process optimization** (e.g., breeding, improved ag practices, better protein extraction techniques) → **No new acreage** necessarily needs to be committed to cultivation.

Source*:* The Good Food Institute research, **FAO Food and agriculture projections to 2050**.

Plant-based meat may dominate the global demand for certain ingredients by 2030

Volumetric demand of plant-based meat ingredients and the relative burden on global production capacity for ingredients and corresponding raw commodities, *2030*

Ingredient	Projected Demand (MMT)	Share of Projected Global Ingredient Production	Share of Projected Global Raw Commodity Production
Soy protein concentrate	2.43	3x	Soy: 2%
Soy protein isolate	0.01	1%	
Wheat gluten	1.48	98%	Wheat: 2%
Pea protein	0.74	10x	Pea: 34%
Coconut oil	0.61	16%	Coconut: 19%
Canola oil	0.31	1%	Canola/Rapeseed: <1%
Sunflower oil	0.24	1%	Sunflower Seed: 1%
Cocoa butter	0.04	2%	Cocoa Beans: 2%

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Source: The Good Food Institute research, **FAO Food and agriculture projections to 2050**.

Exploring opportunities in emerging protein sources

Protein	Protein Concentration	PDCAAS	Allergen Risk	Commercial Stage	Flavor	Functionality	Cost (/kg protein)	Global Crop Volume (MMT)
Soy	Excellent	Excellent	Poor	Excellent	Low	Excellent	Good	Excellent
Pea	Good	Good	OK	Good	OK	Good	Good	OK
Wheat	OK	OK	Poor	Excellent	OK	Excellent	Excellent	Excellent
Canola	Good	Excellent	Poor	OK	OK	Good		Good
Chickpea	Good	OK	OK	Good	OK	Good	Low	Good
Fava Bean	Good	OK	Low	OK	OK	OK	Low	OK
Lentil	Good	OK	OK	OK	OK		Low	Good
Lupin	Excellent	OK	Poor	OK	Low	OK		OK
Mung Bean	Good	OK	OK	Good	Good	Good	Low	OK
Navy Bean	Good	Good	OK	Poor	Good	OK		Low
Peanut	Good	OK	Poor	OK	Good	Good		Good
Sunflower	Good	Good	Excellent	OK	OK	Good	Low	Good
Almond	Good	Low	Low	OK	Good	OK	Low	OK
Corn	OK	Low	Excellent	OK	Good	Low	Low	Excellent
Oat	OK	Good	Good	OK	Good	Low		OK
Potato	Low	Excellent	Excellent	Good	OK	Good	Low	Excellent
Quinoa	OK	Good	Good	Poor	OK	Good	Low	Low
Rice	Low	OK	Excellent	Good	Good	OK	OK	Excellent
Sorghum	Low	Low	Excellent	Poor	Good	Poor		Good

Legend

- Excellent
- Good
- OK
- Low
- Poor

Note: For some proteins, certain metrics are not available

Source: The Good Food Institute research, Plant Protein Primer

Sidestream utilization can improve the economic viability of existing ingredients

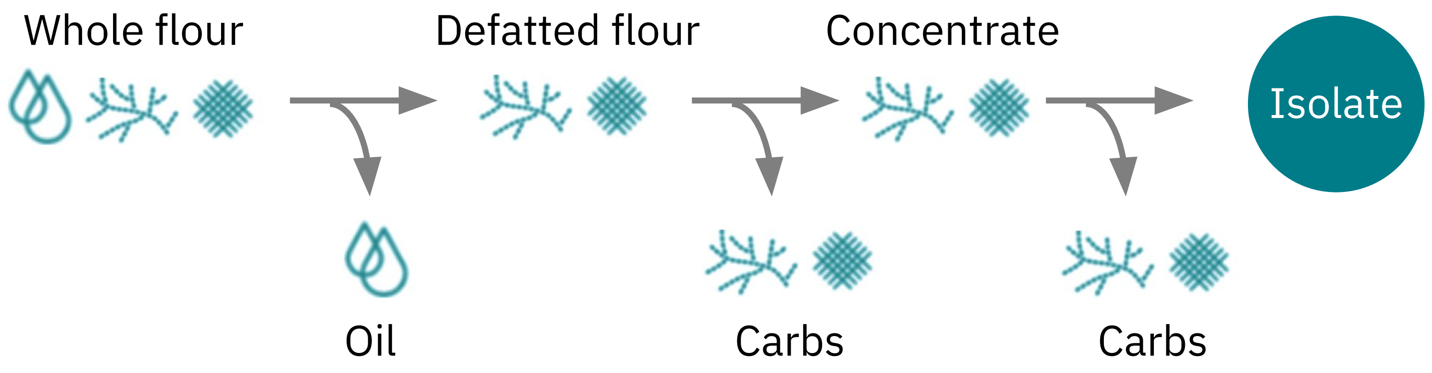
SIDESTREAM BIOMASS

High molecular-weight proteins	• High utility for **plant-based meat**, egg, and dairy products
Amino acids, small peptides, hydrolysates	• High utility for **cultivated meat** production; may need to supplement with fermented amino acids
Simple sugars, fiber, and starches	• High utility for **microbial fermentation** (production of enzymes, ingredients, protein, etc.)

Forging partnerships among ingredient suppliers and manufacturers

Commercial proteins are complex mixtures—properties depend on source and process.

Proteins are often **extracted** or **enriched** to improve their properties.



Processing can also influence protein functionality via **denaturation**, **hydrolysis**, **modification**, and **cross-linking**.

Investing in new technologies for fat production and incorporation in plant-based meat

MYCORENA

Mycorena unveiled a new fungi fat ingredient that releases flavor in a similar way to animal-based fats, during the cooking process and the eating experience. Their new fat could replace coconut or other vegetable based oils currently used in alternative meat products.

yali bio

Yali Bio, which recently came out of stealth mode, is creating fats tailored to the needs of the end product formulation of meat, eggs, or dairy.

nourish INGREDIENTS

Nourish Ingredients raised $11M 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.

cultivated BIOSCIENCES

Cultivated Biosciences announced they are 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.

Melt& Marble

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

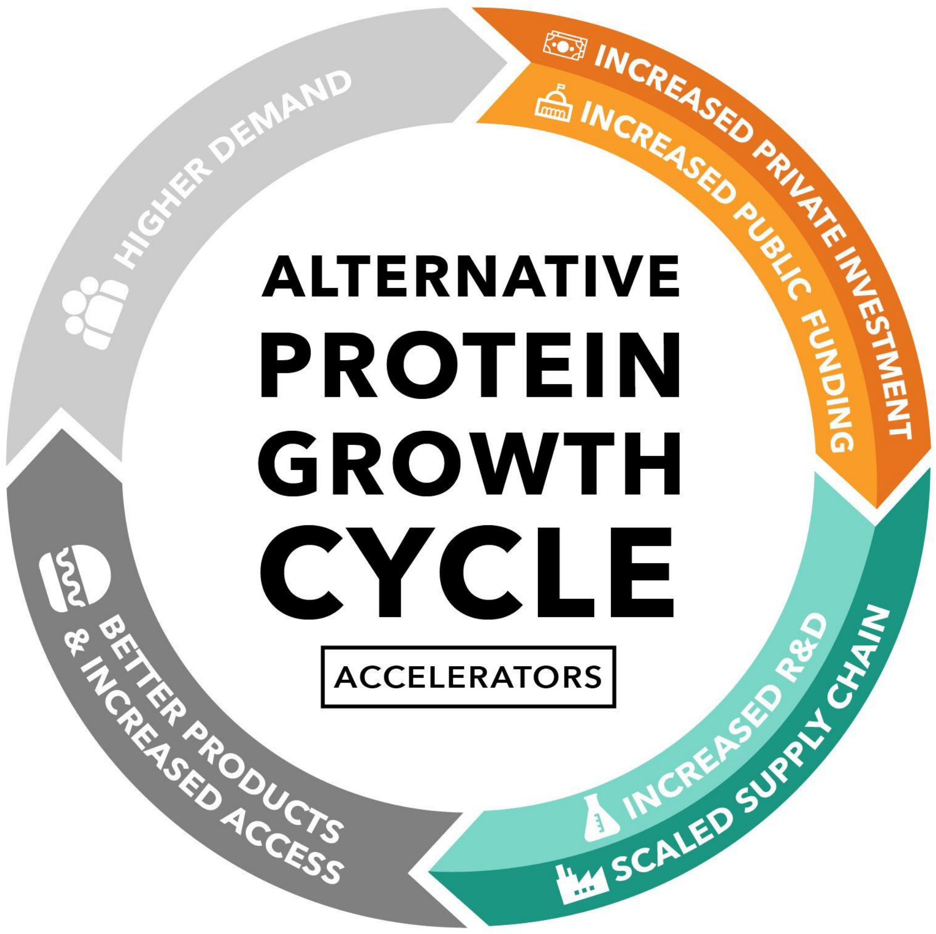
Where do we go from here?

- **We welcome feedback and data!** This analysis serves as the first iteration of a model that will increase in complexity and accuracy as additional data are added. Next steps include:
  - Additional plant-based meat manufacturing strategies to increase the model's robustness and real-world applicability.
  - Adding fermentation and cultivated meat production into the model.

- Soaring demand for plant-based meat will continue to place substantial supply constraints on the industry. Ingredient and end-product production capacity will likely be the rate-limiting links of the plant-based meat supply chain in the coming decade. Here's what we hope to see:
  - **Innovation:** Without rapid advances in greater processing capacity and new ingredient solutions, there will be substantial bottlenecks for key ingredients, including plant protein concentrates and non-animal sources of saturated fats.
  - **Private capital:** This need for greater capacity and infrastructure, including to manufacture plant-based meat end products, will require substantial capital from financiers like banks, PE funds, and institutional investors, not just early-stage VCs.
  - **Public investment:** When blended with private sector funding, public funding can incentivize bold supply chain innovations and capacity-building, enabling the alternative protein sector to grow as fast as consumer demand does.

Increased investment is a key driver of the alternative protein industry

- To speed up the flywheel, we need to optimize:
  - **Public, private, and philanthropic investment**
  - **Research and technological commercialization**
  - **Startup, manufacturer, and supplier scaling**
- All with a focus on **lower prices and improving end-product quality and lowering prices**



Q&A

Download this report at:

gfi.org/resource/anticipating-plant-based-meat-production-requirements-2030/

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Contact the corresponding author at **ryand@gfi.org** with any questions!