Cleantech Group®

Spotlight

Agriculture & Food

Plant-Based Protein: Enhanced Ingredients & Manufacturing

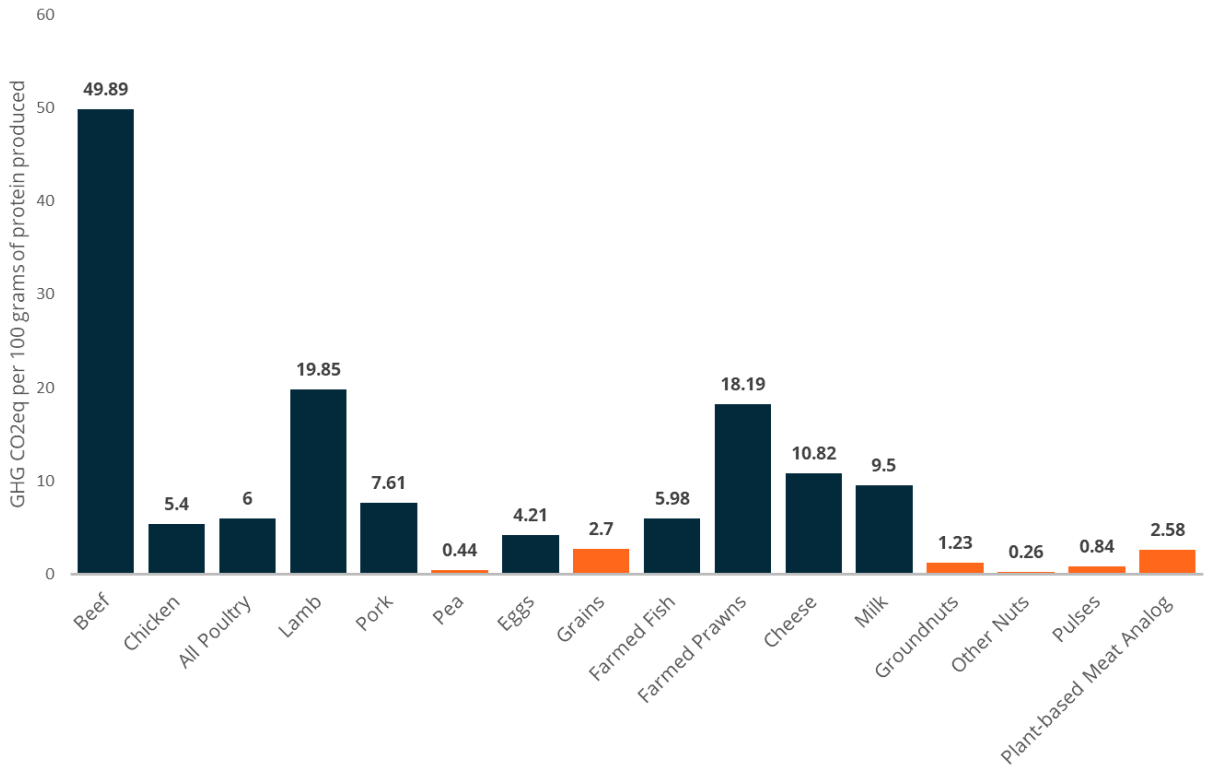
September 2023

Executive Summary: Plant-based Protein Ingredients & Manufacturing

With improvements in manufacturing and raw materials, plant-based protein can ease livestock's environmental burden

- Plant-based protein products represent a sustainable pathway to meet rising protein demand, but market contractions cast doubt on the category's future
- Product life cycle assessments indicate that, at the lower end, plant-based substitutes offer a **93% reduction in land use-related environmental impacts** compared to conventional beef burger patties; as well as an **85% reduction in GHG emissions** (*Beyond Meat, Impossible Foods, Kellogg's*)
- While several innovators have gained global brand recognition and reached multibillion dollar valuations, consumer demand is flatlining
  - Plant-based meat end-pricing may be too high at 43% higher than animal-derived counterparts (*Good Food Institute*)
  - Consumers generally consider taste and texture of plant-based analogs as inferior to animal-derived protein, particularly for beef and seafood substitutes
- Innovations emerging to address these issues include:
  - Selective breeding / genetic engineering of key raw plant ingredients such as soybean (eg, Benson Hill), field pea, chickpea (eg, NuCicer)
  - Hybridization with cell-cultured / precision fermented products (eg, Mission Barns, Nourish Ingredients)
  - Advances in texturization and processing incl. improved extrusion capabilities, fiber spinning, and 3D printing (eg, NovaMeat, Tender)
- Future market growth is reliant on:
  - Some level of acceptance of gene-editing technologies to develop protein-optimized crop varieties, as well as exploration of alternative crops (eg, lupin)
  - Driving down manufacturing costs to maintain price parity with animal products

GHG Emissions (CO2eq) per 100 grams of Protein Produced



Graph depicts global averages of Green House Gas (GHG) emissions per 100 grams of protein across different food products and 141 countries, Source: American Association for Advancement of Science (AAAS)

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Plant-based Protein Ingredients & Manufacturing: Setting the Stage

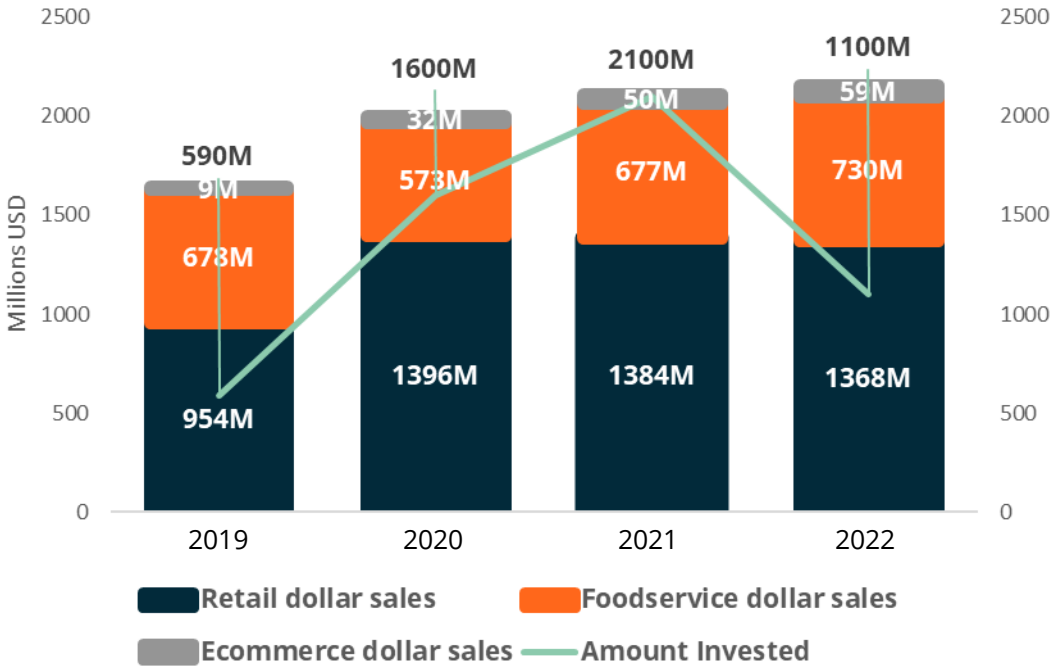
Status quo & global challenges

- **Livestock production accounts for an estimated 11% of GHG emissions** (*UN Food & Agriculture Organization*), with **global meat consumption projected to grow by 14%** between 2021 and 2030 (*OECD*)
- Livestock farming (incl. aquaculture) also contributes to land degradation, water overuse, eutrophication, pollution via chemical / effluent runoff, ecosystem destruction / biodiversity loss, and antibiotic resistance
- **Plant-based** is most mature of the three 'animal-free' alternative protein product categories - which also incl. **cultivated** (cell-cultured) and **fermented** - with lower barriers to entry and more immediate impact potential
- Despite this, VC funding to plant-based is on a downward trend
- Market growth rate for plant-based is slowing (18% growth in 2020 to 2% in 2022) and retail sales declined in consecutive years (*Good Food Institute*)
- Several issues requiring technology and strategy innovation
  - Scaled production has not lowered costs as expected
  - Taste and texture are still generally seen as inferior to animal products
  - Growth in market share is concentrated in foodservice and online retail

Impact

- Plant-based proteins represent an ≈85% reduction in GHG emissions compared to animal-derived proteins, and reduce other negative environmental impacts incl. deforestation and water eutrophication
- Reducing production costs to bring down end prices can expand consumer base so long as taste / texture expectations can be met
- Novel manufacturing technologies offering greater production flexibility seek to reduce costs while improving end consumer choice and experience; could also spur category growth in less mature markets (APAC, LatAm, Africa)

USA Plant-based Meat Sales and Investment per year (millions USD)



Source: Good Food Institute & Cleantech Group

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Plant-based Protein Ingredients & Manufacturing: Quality & Efficiency Improvements

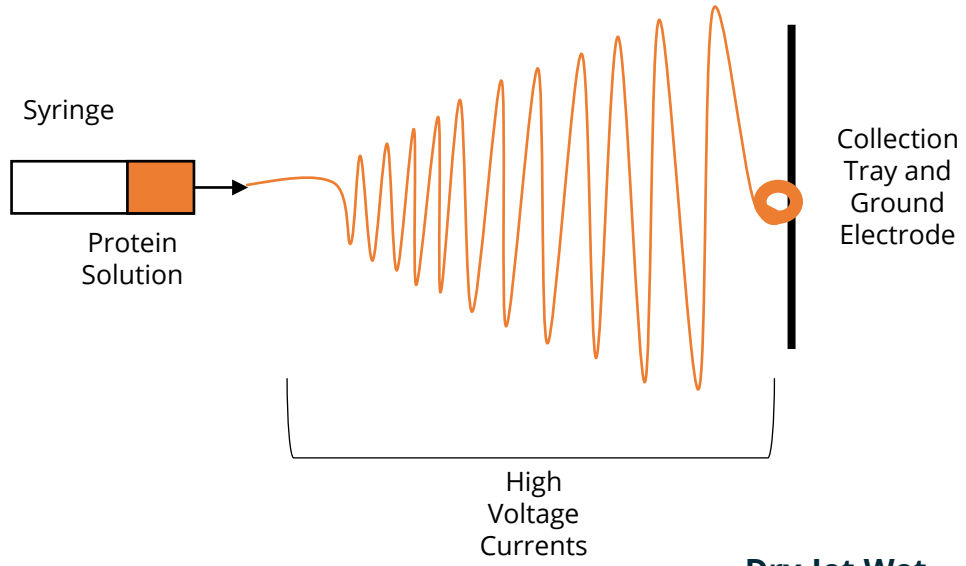
Production processes need optimization

- Ingredient discovery and prototyping for optimal plant-based protein formulations are slow, expensive, and require varying degrees of collaboration with third parties
- Manufacturing has been scaled but still comprises bulk of costs and is inflexible in terms of outputs (especially extrusion, which remains the main texturization method), limiting ability to produce 'whole cuts' as opposed to patties, nuggets, links
- Market penetration for new products is slow and sensitive to consumer preferences around taste, texture, aroma, nutrition, and price

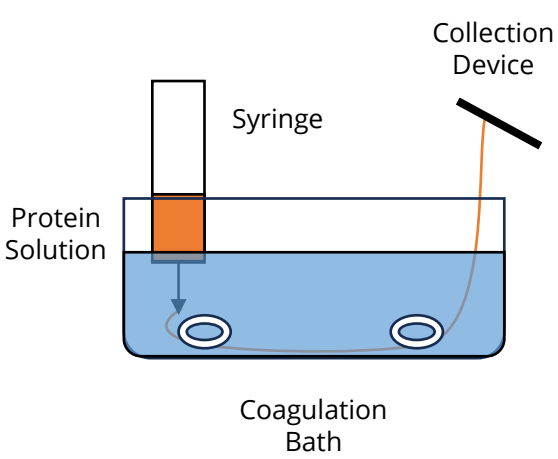
Innovation in ingredients, prototyping, and manufacturing

- Innovation focus areas include:
  - **Engineering/breeding ingredients for optimized protein content or manufacturing qualities** (eg, Benson Hill's Ultra-High Protein soybeans, NotCo's AI discovery platform)
  - **Expediting prototyping** (eg, NovaMeat's 3D printing and Lifeasible's use of shear cell)
  - **Improving manufacturing efficiency/flexibility** (eg, NovaMeat and Project Eaden)
- Artificial intelligence usage in ingredient genomic editing for improved protein yield, gene discovery, resequencing protein structures, as well as manufacturing optimal flavor / texture / smell formulations
- Genetic engineering (oligonucleotide-directed mutagenesis, CRISPR/Cas9) used to increase appearance of desired traits like sweetness in lupine, foaming or extrusion properties in chickpeas
- Modular extrusion units and 3D printers provide small to medium sized start-ups valuable flexibility in prototyping phases, inputs accepted, and products produced
- New spinning technologies (electrostatic, wet, dry-jet wet) offer new products, improved taste and texture, potential for massive cost reductions in manufacturing

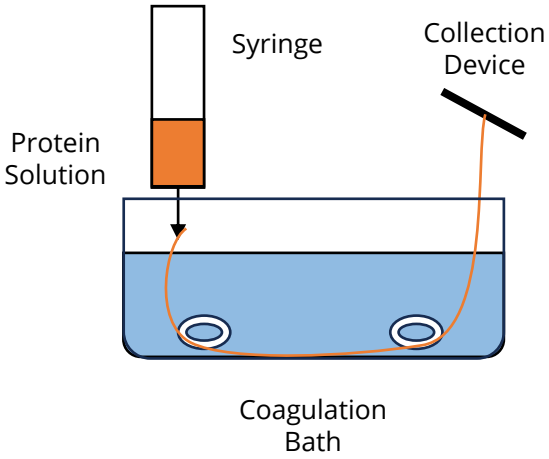
Electrostatic Spinning



Wet Spinning

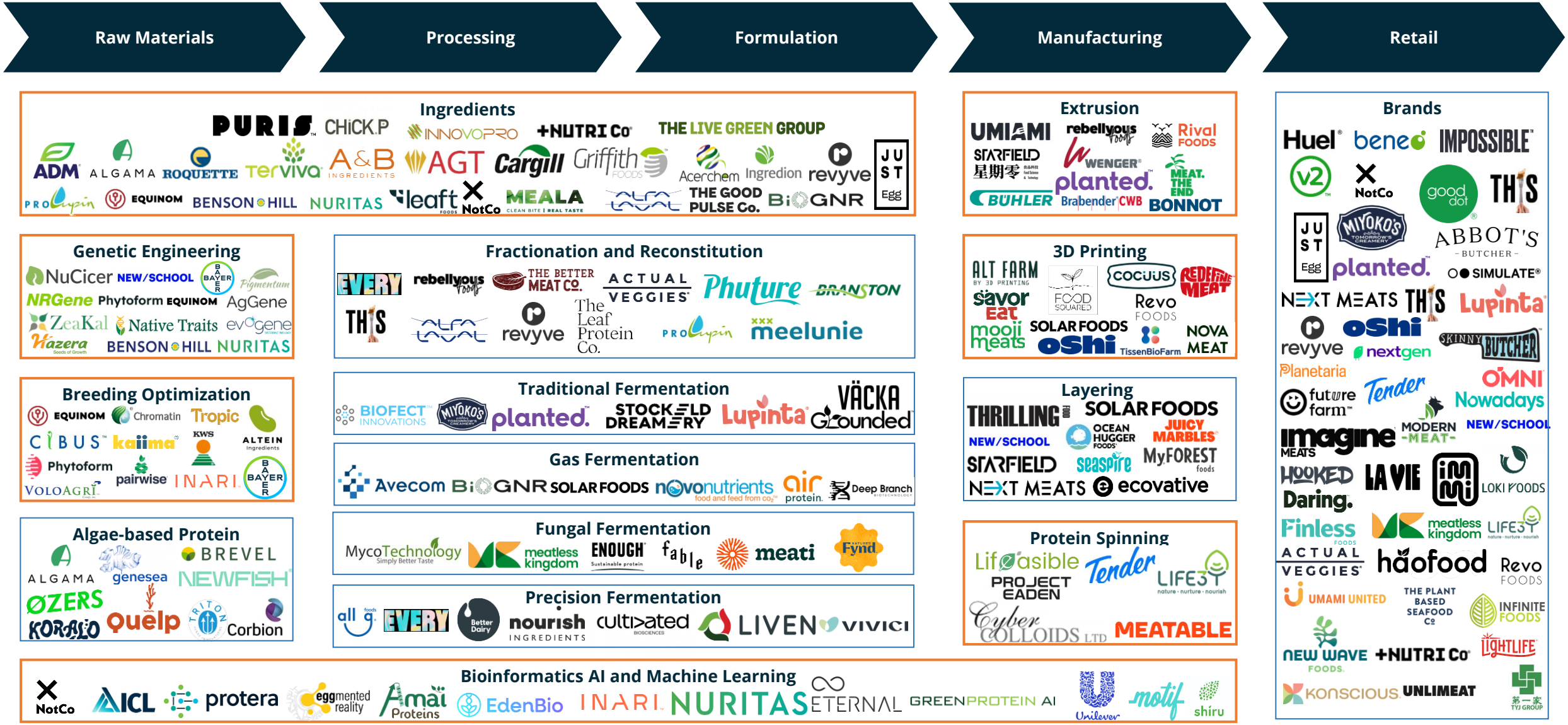


Dry-Jet Wet Spinning



Source: Cleantech Group

Plant-based Protein Ingredients & Manufacturing: Value Chain



Plant-based Protein Ingredients & Manufacturing: The ABCs

	Discussion
Attractiveness	• Global plant protein market is valued at $17B, poised to reach $25B by 2027 (*Good Food Institute*) • Proliferation of gene-editing technology has reduced barriers to entry for start-ups working on ingredients, breaking up dominance of large corporate ingredient companies • University, private, and government research is plentiful, leading to high frequencies of spin-outs and partnerships • Rapid international growth with Europe boasting a 9% growth rate and largest market ($3.3B) while Latin America is the fastest growing market at an annual growth rate of 36% (*Good Food Institute*) • Large number of incubators and accelerators directly targeting plant-based protein industry
Business Models	• Established players choose to sell **directly to consumers** through grocery stores (often large, established companies like Beyond Meat or Impossible Foods) in addition to foodservice; smaller start-ups focus on foodservice **channel partners** or **online sales** • Smaller B2B producers like NovaMeat simultaneously manufacture their own products while offering prototyping and research for larger B2C companies without production flexibility • Gene-editing has multiple business models: production of crops or proteins for sale to manufactures (Pairwise, AgGene, Forte), **gene-editing software as a service**, IP or genetic library licensing, consulting • 3D printing is still finding a market fit: wholesale of printers (SavorEat) to restaurants that act as automated chefs, printing as a service for larger companies, full integration as a retail brand (Redefine), prototyping technologies to speed up production (NovaMeat)
Competitive Trends	• Corporate entities targeting new advancements in ingredient production and moving away from generic label plant-protein sales • US consumer demand for plant-based retail brands contracted in Q2 yet demand for plant-based products in restaurant/fast food locations rose by 7%, especially amongst 18-24 year olds • Emergence of wide input variation including new high protein sources (lupin, chickpea, pea), new extraction processes in sources like green leafy vegetables, and increased protein gene-edited crops like rice, peas, potatoes • Innovations in manufacturing and assembly promise to cut production costs from a prototyping, wholesale, and flexibility standpoint • Trend in US Midwest of transitioning grazing or feedstock lands to plant-based protein crops

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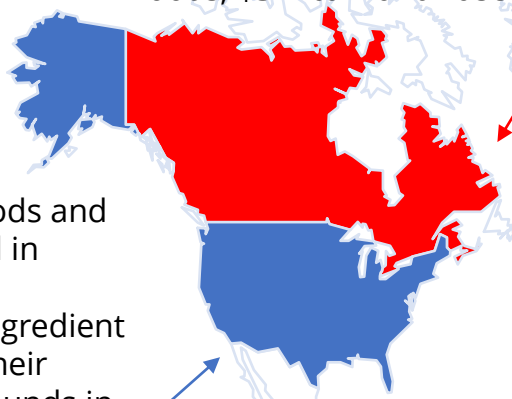
Plant-based Protein Ingredients & Manufacturing: Regional Drivers

Canada

- **January 2023:** $111M grant to Protein Industries Canada, undisclosed grant to Modern Meat for plant-based seafood
- **November 2022:** Sustainable Development Technology Canada provides $5M grant to New School Foods
- **November 2020:** Canada invests $100M in Merit Functional Foods, $3M to Plant-Based Foods of Canada



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United States

- **June 2023:** Impossible Foods and Motif FoodWorks engaged in multimillion dollar patent infringement lawsuit on ingredient discovery platforms and their resulting products (compounds in question are heme, sugars, and sulfur compounds)

Denmark

- **October 2021:** Announces $100M in public investment toward innovation in plant-based protein
- **October 2021**: Announces $85M in bonuses to farmers who grow crops intended for plant-based protein

Australia

- **July 2023**: Nourish Ingredients receives $3.9M, partners with Australian National University, The University of Queensland, Macquarie University, Flinders University, Queensland University of Technology, and The University of Western Australia to research animal fat mimicking
- **January 2023:** GrainCorp, CSIRO, and v2Foods enter into $4.4M research project on non-imported plant-based protein
- **March 2022:** Modern Manufacturing Initiative invests $113M in plant-protein processing facilities

United Kingdom

- **August 2023:** Biotechnical & Biological Sciences Research Council (BBSRC) and Innovate UK invest $19M to create sustainable protein research hub

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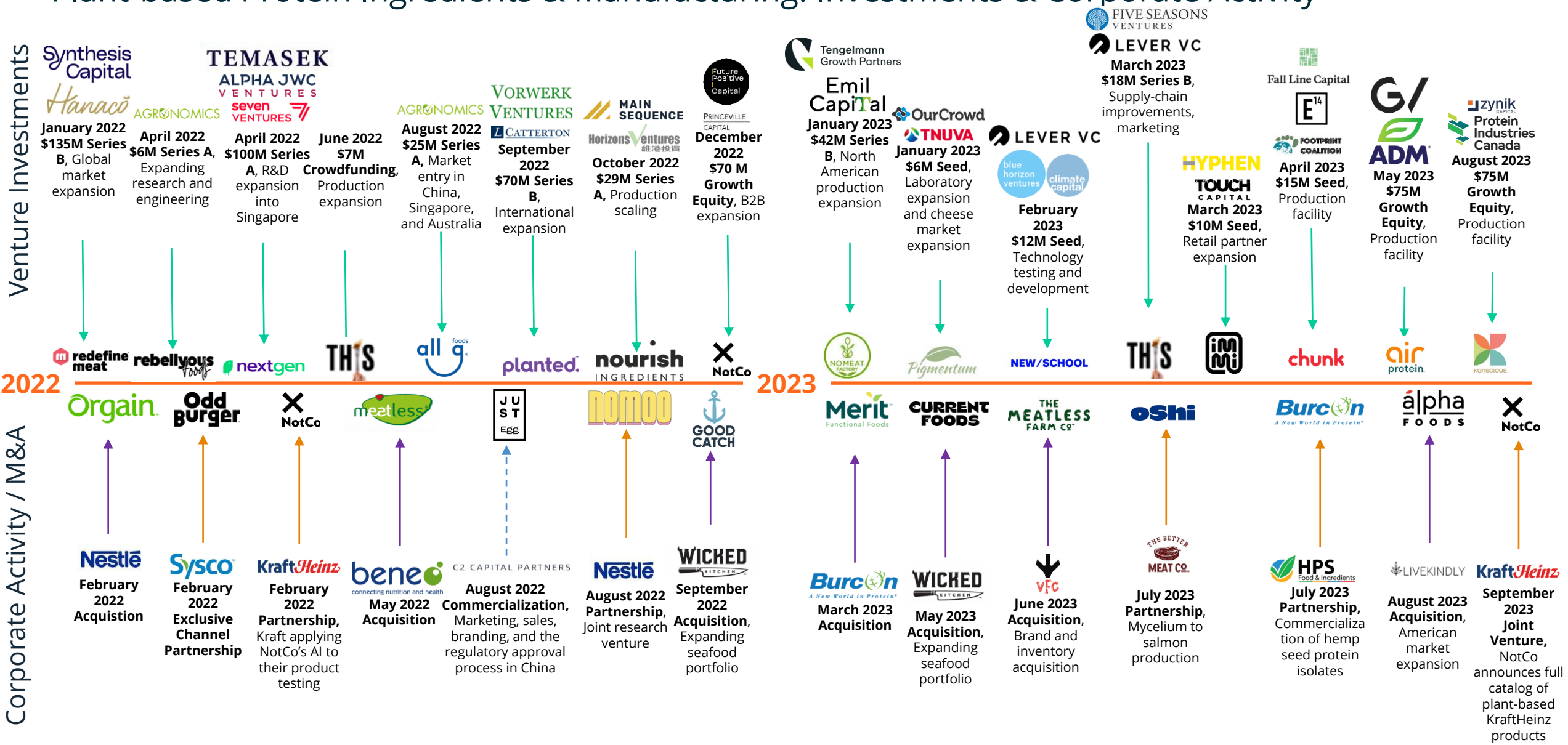
Plant-based Protein Ingredients & Manufacturing: Investments & Corporate Activity



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Plant-based Protein Ingredients & Manufacturing: Innovator Examples

NuCicer

Positioning: Breeder of chickpeas utilizing machine learning and genome-guided breeding platform for higher protein content and other traits

Market insight

- High demand in meat analog market for egg-substitute, extrusion properties, and taste that chickpeas can fill
- Chickpeas are naturally resistant to various areas of climate change - simple genomic editing also improving resistance to heat, drought, acidic soils, and disease

Company insight

- Offered chickpeas excel in gelling and emulsification properties, improved extrusion, and 50-100% increases in protein content
- Financial goal is to reduce cost of chickpea ingredients across plant-based industry by 50%
- Company has a genomic library that is 40x more diverse than commercial market

Milestones:

- Investment and industry/channel partnership support from Bayer
- Longstanding research partnership with UC Davis, established connection with University of Minnesota's Plant Protein Innovation Center

Capital: $7M

Contact: Kathryn Cook, CEO

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NotCo

Positioning: End-to-end producer of plant-based meats utilizing patented AI algorithm and platform for ingredient, texture, and flavor discovery

Market insight

- Plant-based products are usually delivered to chefs to taste but are infrequently developed, refined, and represented in data metrics by those same chefs
- Plant-based analogs need to penetrate all marketplaces, channel partnerships across restaurants, fast food, ingredients, and manufacturers are key

Company insight

- Algorithm and platform connects chefs to new plant-based formulations and provides them NotCo's 300,000 ingredient dataset to create formulations
- AI technology provides ingredient suggestions based on molecular similarity, reducing blind prototyping
- Diverse revenue streams allows company to create world class research infrastructure

Milestones:

- Dozens of proprietary algorithms: smell, industrial ingredient matching, taste profile, texture analysis
- Growing number of institutional channel partnerships including Burger King, Dunkin', Shake Shack, and Starbucks as well as a joint venture with Kraft Heinz

Capital: $462M

Contact: Pablo Zamora, Founder

FORTE

Positioning: Molecular farmers specializing in spray treatments to produce rapid protein expression in leafy plant tissue

Market insight

- View precision fermentation as too expensive for most commercial applications
- Identified lengthy development timelines of GMOs and transgenic organisms as significant barrier to entry
- High cost, scarce proteins will take decades to develop through genetic manipulation at a commercial rate

Company insight

- Spray to cultivation turnaround is less than four days, facilitating rapid production
- Protein yields are higher than transgenic and GMO lines
- Spray vector can be applied to any crop and current proteins include lactoferrin, casein, collagen, and myosin
- Quick turnarounds are optimal for high value proteins that are difficult to source

Milestones:

- Participated in IndieBio Accelerator and Cleantech Open, also have an established relationship with Cornell Center of Excellence for Food and Agriculture
- Finalizing a Series A round in the Fall, focusing on rapid commercial penetration and continued R&D
- Finalizing growing partnerships (greenhouses, farms)

Capital: $525,000

Contact: Kathleen Hefferon, CSO

Plant-based Protein Ingredients & Manufacturing: Innovator Examples

PROJECT EADEN

Positioning: Whole-cut plant-based protein producer utilizing protein spinning technologies from the fashion and textile industries

Market insight

- Both wet and dry spinning are extremely valuable technologies, especially in improving textures
- Spinning has applications in most plant-based production streams and will be integrated by most producers eventually
- Spinning remains an expensive technology with more research needed to determine optimal inputs

Company insight

- Possible to replicate challenging meat textures by mimicking fat while combining wet and dry spinning
- Company's spinning technology is especially effective at creating plant-based beef analogs but requires both dry and wet spinning
- Able to license their patented technology to producers looking to improve their textures in plant-based or cultivated meat

Milestones:

- Numerous secured patents to protect spinning technology
- Planning a commercial release in early 2024
- Several university lab partnerships in the Berlin area

Capital: $12M

Contact: Pierre Khazzaka, Food Scientist

AgGene

Positioning: Plant genetics research company specializing in enhancing protein content and desirable traits for downstream production

Market insight

- Raw ingredient sales and seed modification have low capital costs and allows for flexibility to adapt to market
- Plant-based protein market will always have a need for crops with higher protein content or specific traits
- AgGene fills a research gap in the market where large producers need to reduce costs with tailored crops

Company insight

- Rice and chickpea variants in regulatory testing until 2025, continued research on pea and tissue proteins
- Company works as both a farming company and gene editing service to maximize revenue streams
- Creating a separate retail brand for approved crops and eventually snack goods
- Want to avoid meat replacement market and focus on supplying ingredients to existing producers

Milestones:

- Company securing retail partners by the end of 2023
- Multiple successful IP filings across several crops
- Partnership with University of Calgary staff to develop, research, and test new crop variants
- Several grants and contracts with Canadian government

Capital: $1M

Contact: Logan Skori, CEO

NOVA MEAT

Positioning: Wholesale meat mimicry producer utilizing proprietary 3D printing and modular microextrusion technologies

Market insight

- Incumbent producers have achieved high volume production but are inefficient on cost per unit
- High product prices throughout industry due to difficulties in prototyping and inflexibility issues with ingredient inputs/outputs
- Jumping straight to consumer products is risky and requires a best-in-market product upon launch, not a wide variety of products

Company insight

- 3D printers provide rapid and varied prototyping process
- Microextruders are modular, allowing for small scale but rapid production with wide variation of inputs/outputs
- Company has several products they sell to restaurants and take orders from larger producers, currently deciding on future retail approach

Milestones:

- Completing retail product trials over next two years
- Achieved 10x cost reduction compared to traditional extrusion processes
- Providing feedback to ingredient producers/editors to create shared ecosystem and improve revenue

Capital: $7M

Contact: Giuseppe Scionti, CEO

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Plant-based Protein Ingredients & Manufacturing: Incumbent Examples

	Positioning	Engaging Innovation
dsm-firmenich	• Chemicals and materials company with biosciences R&D department conducting nutrition and ingredient research for plant-based protein • Balancing internal R&D focused on developing novel proteins with aggressive acquisitions/partnership strategy	• Partnered Avril Group to launch Olatein, a modified canola variant with enhanced protein and functional features targeting the plant-based market • November 2021: Acquired major pea protein producer Vestkorn Milling for $74M • Invested in Deep Branch (gas-fermented protein ingredient); Meala FoodTech (functional proteins for plant-based products); Paleo (precision-fermented heme for plant-based meat substitutes)
BAYER	• Leading chemicals production company specializing in pharmaceuticals and crop science (plant breeding, gene editing) with over 500 unique seed products • Utilize both CRISPR-Cas9 gene editing tools and plant breeding algorithms to isolate genes with specific economic values (increased yields, weather/disease resistance, or taste) • Looking to reduce average pathway of 13 years, $130M for genetically edited seeds to reach market	• Investment arm Leaps by Bayer has several portfolio companies focused on crop genetics and optimization including NuCicer, Amfora, and Pairwise • Launched Bayer Science Collaboration Explorer (BSCE), public agriculture collaboration tool for universities, public research institutions and individuals to work with Bayer • Launched $100M Marana, Arizona greenhouse that houses Bayer's GM test site and experimentation labs
ADM	• Archer Daniels Midland (ADM) is an ingredients and nutrition company specializing in enhanced crops, foods, and specialty chemicals across the world • Expanded ingredient sources over the last five years with aggressive scaling of pea proteins and reinvestment in soy • Does not operate farms but is integrated across plant-based value chain including seed research/distribution, processing, and retail	• April 2022: Invested $350M to develop Illinois Protein Innovation Center and a similar research facility in Singapore • May 2021: Committed $300M to new North Dakota soy protein isolate refining and extrusion facility, plus large-scale soy processing facility in Brazil • Part-owner of Serbian soy processor Sojaprotein • Invested in Air Protein (gas-fermented protein ingredient) via ADM Ventures • Crop genetics research with Benson Hill • Formed PlantPlus Foods JV with Marfrig to develop and distribute plant-based protein products in the Americas

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On the Radar – New Spin-outs & Pre-commercial Innovation

Ecosystem	Source		Innovation
University Research and Spin-outs	University of Massachusetts Amherst	• UMass Amherst's College of Natural Sciences food science department is the oldest American food science research department • Led by Hang Xiao and David Julian McClements	• Awarded grants from USDA's National Institute of Food and Agriculture to explore plant-based fermentation, processing, and chemistry with a focus on genetic engineering • Acting as a research advisor for Big Idea Ventures' Generation Food Rural Partners and solubility, stability, color formulation partners for Motif Foodworks' ingredient formulation platform
	Plant Protein Innovation Center	• PPIC is a research center at the University of Minnesota organizing collaboration between breeding, genetics, processing, formulation, and marketing researchers/companies in the plant-based protein space	• Members include 56 corporates (Microsoft, General Mills, Cargill), start-ups (NotCo, NuCicer, Motif), universities, and research groups • Corporates are connected to start-ups offering new breeding/genetic engineering technologies, start-ups receive laboratory findings/support
	VTT LUT University SOLAR FOODS	• VTT is a Finnish research institution commercializing innovation in food, materials, and software • Lappeenranta-Lahti University of Technology is a Finnish university specializing in climate tech research and commercialization	• Solar Foods is a spinout from a joint VTT and LUT study aiming to create protein utilizing air fermentation and electric separation • The company has since completed its first factory, broken ground on a second, and released their first series of commercial products • Additional research into alternative proteins including rapeseed, sunflower applications, AI ingredient discovery, and cell-cultivated eggs and meat
	NUS National University of Singapore LIFE3T nature · nurture · nourish	• The National University of Singapore is a research institution with several clusters specializing in sustainability, engineering, and business in Asian and global markets • Life3: plant-based protein company utilizing electrostatic spinning for products	• The partnership between NUS and Life3 focused on translating mass production abilities NUS had been researching with Life3's advances in meaty textures from spun proteins • Further research from Professor Seeram and Dr Subramanian Sundarrajan focused on improving nutritional profiles of spun proteins and refining energy requirements within the process

Plant-based Protein Ingredients & Manufacturing: Milestones

Market Milestones

- Plant-based protein must move beyond the label of premium product through production cost reductions to achieve price parity and consumer demand
- Key consumer profile is 18-24 year olds eating plant-based through food services, continued success with this channel will expand market share while production prices decrease
- Genetic editing and/or modification to boost protein content of produce destined for plant-based protein products (eg, soybean, field peas, chickpea, lentils) and to select specific traits for manufacturing (sweetness, foaming, absence of offnotes)
- Increased utilization and production of non-mainstream protein crops with previously overlooked value or manufacturing qualities (lupins, ancient grains)
- Incumbents are most interested in ingredient markets and slowly integrating into full production of plant-based products through partnerships and acquisitions (Bayer, Cosun, Puris, DSM, ADM, Cargill) and are working closely with accelerators and incubators

Innovator Milestones

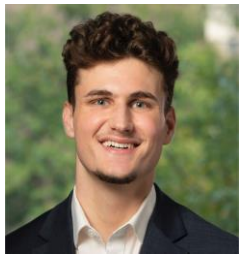
- For extrusion to remain viable, innovators must improve efficiencies and lower costs
- New applications of 3D printing and wet/electrostatic spinning will diversify producers and bring needed market variety
- Increased use of ingredients from adjacent cultivated and fermented protein sectors to improve taste and texture properties (eg, cell-cultured animal fats)
- Machine learning and creation of genetic libraries will be instrumental in constructing future plant-based protein products
- As gene editing grows in acceptance, acquisitions/partnerships take two forms:
  - Leaders in plant-based protein (ADM, Kerry Group, Cargill, DuPont, Glanbia) will target companies with extensive and/or unique genetic libraries to improve their production capabilities, or block competition
  - Small to mid-sized start-ups collaborate for rapid research development and resource sharing

Regulatory/Policy Milestones

- Continued government support in the form of subsidies (EU), research grants (US), and university research centers (Singapore) to aid start-ups and scaled producers
- Greater restrictions on plant-based labels, advertising in Europe with a focus on milk and meat analogs
- Increased specificity of legislation and gradual acceptance of GMO products for human consumption in raw form or in meat analogs
  - EU: Greater specificity on definitions of GMOs and their eventual introduction in Europe should come in early 2024
  - US: Environmental Protection Agency to take on a greater role in analyzing GMOs and their compositions
- Impossible Foods v. Motif FoodWorks will not fundamentally alter the direction of the industry, but could encourage companies to pursue more IP protection
- Expect greater financial support on research from Japan, especially as plant-based seafood market continues developing
- Some attempts in Latin America to introduce joint development plans for plant-based protein production and GMO use, led by Brazil

Agriculture & Food Sector Research

Cleantech Group tracks the start-ups, scale-ups, investors, and multinationals from across the region and the world shaping the future of the climatetech industry



Recently Published Research

- **Spotlight:** Cathodes Manufacturing (Q2 2023)
- **Spotlight**: eJet (Q2 2023)
- **Spotlight:** Flood Resilient Infrastructure (Q1 2023)

Upcoming Topics

- **Spotlight**: Cultivated Meat: Growth Media (Q3 2023)

Upcoming Events

- **Cleantech Forum Europe** – Easy access to startups, scale-ups, investors & multinationals from across the region – Tallinn, Estonia – November 14-16, 2023
- **Cleantech Forum North America** - San Diego, U.S. - January 22-24, 2024

Analyst – Parker J. Bovee

- Focused on emerging innovation & trends across cleantech sectors, including water, advanced materials, & corporate sustainability.
- Prior to joining Cleantech Group, Parker developed wildfire prevention technologies with VegaMX and researched socioeconomic implications of gambling legalization at the RXN Group.
- Parker earned a Bachelor's degree in History and Public Policy from the University of California, Berkeley where he specialized in the history of American environmental entrepreneurship.

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Recent Published Research

- **Spotlight**: Crop Robotics (Q3 2023)
- **Spotlight**: Carbon-Fixing Soil Inputs (Q2 2023)
- **Spotlight**: Soil Carbon Measurement, Reporting & Verification (Q2 2023)
- **Sector Insight**: Carbon Farming (Q1 2023)
- **Analyst Perspective**: Agri-FoodTech Can Have Critical Impact. Here's How (Q4 2022)

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- **Cleantech Forum Europe** - Tallinn, Estonia - November 14-16, 2023
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Lead Analyst – Jack Ellis

- Senior Associate leading Agriculture & Food research at Cleantech Group, based in Singapore.
- Jack's professional background is in journalism, marketing, and venture capital. Prior to joining Cleantech Group, he was Research Lead at agrifoodtech investor AgFunder, and Deputy Editor of industry news site *AFN*.
- Jack earned a bachelor's degree in Philosophy from the University of Sheffield.
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