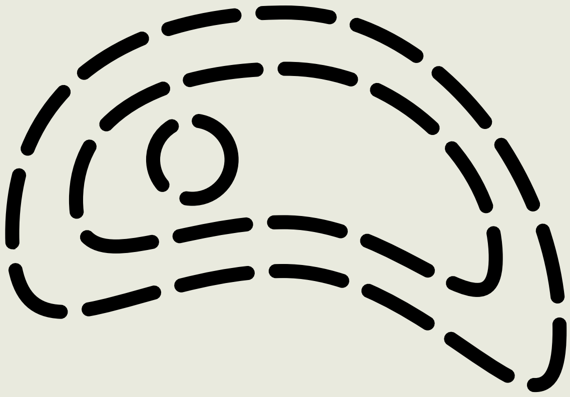
Global Innovation Needs Assessments

Protein diversity

November 1, 2021



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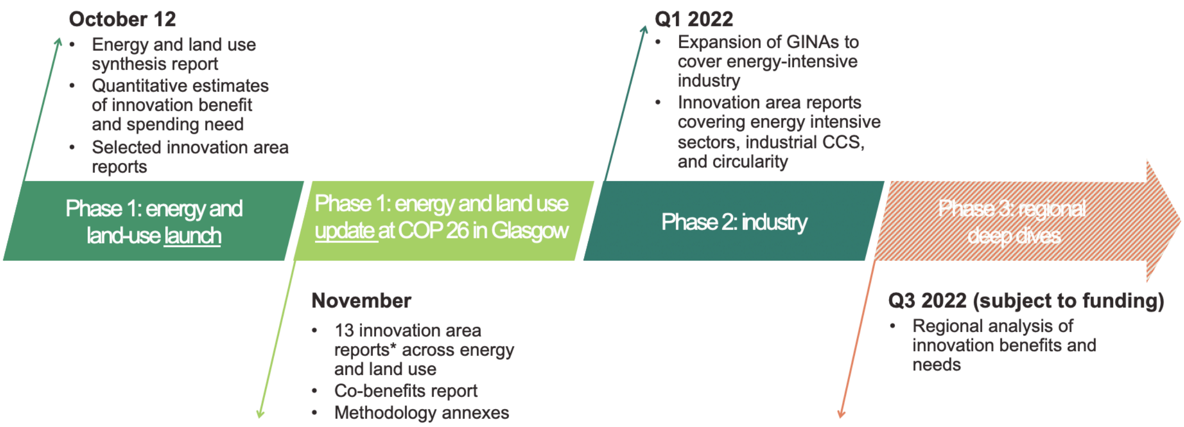
The Global Innovation Needs Assessments

The Global Innovation Needs Assessments (GINAs) is a first-of-its-kind platform for assessing the case for low-carbon innovation. The GINAs take a systemwide perspective, explicitly modeling the impact of innovations across the global economy. Uniquely, the analysis quantifies the economic benefits of low-carbon innovation and identifies the levels of public investment—from research and development to commercialization—needed to unlock these benefits. The analysis is divided into three phases: Phase 1, global energy and land use; Phase 2, global industry; and Phase 3, regional deep dives. This protein diversity report is part of Phase 1's investigation of innovative technologies in the energy and land systems.

The analyses do not assess all relevant technologies, nor do they evaluate all relevant factors for policy judgments. Instead, the work is intended to provide a novel evidence base to better inform policy decisions. The Phase 1 analysis looks across a broad range of climate mitigation technologies in energy and land use, including demand response to protein diversification, to model the economic value of related innovation investment. Later phases expand the research. As with adoption of all technologies, including some controversial ones described in this report, there are risks and potential downsides. Technology investment is ultimately a policy judgment. This analysis provides no policy recommendations for that investment.

Phases of the Global Innovation Needs Assessments



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The findings and views expressed here do not reflect the view of ClimateWorks, the Government of the United Kingdom, or Mission Innovation.

Phase 1 GINA outputs

The suite of reports across innovation areas methodological annexes and a synthesis report for GINAs are available on the GINA website at https://www.climateworks.org/report/ginas/.

The suite of outputs for Phase 1 of the Global Innovation Needs Assessments

1. **Energy and land use synthesis report: slide-based summary for policymakers and executives**
   Synthesis of the findings across the innovations considered in energy and land use
2. **Innovation reports** – in depth quantitative analysis for industry and policy analysts

Energy

- **Wind power** – Offshore and onshore wind turbines
- **Low carbon hydrogen** – Electrolyzers and gas reforming with CCS
- **Solar power** – Utility-scale and distributed PV
- **Low carbon fuels** – 2nd generation biofuels, synthetic fuels (H_2 + CO_2)
- **Nuclear power** – Small modular and large-scale advanced reactors
- **System flexibility** – Battery storage, power-to-X, demand response
- **Buildings** – Heat pumps, building fabric
- **Power CCS** – CCS in power generation (coal, gas and biomass)
- **Zero-carbon road transport** – Battery electric vehicles, fuel cell electric vehicles

Land use & agriculture

- **Protein diversity** – Novel protein-rich food and feed
- **Decarbonizing agrochemical inputs** – Innovative fertilisers and pesticides
- **Yield enhancing technologies** – Digital agriculture and vertical farming
- **Irrigation** – Improved irrigation methods and systems

The selected innovation areas were selected for their potential for further innovation and the potential magnitude of the associated system benefits. Their selection here is because they could play a key role in a net zero pathway but does not imply that an optimal net zero pathway necessarily includes them. Further notes on the rationale behind their selection is provided in the methodology annex on the GINA website

3. **Co-benefits of innovation report** – qualitative analysis of the environmental and other non-economic benefits of net-zero innovation
4. **European case study** – analysis of jobs and growth benefits in Europe specifically
5. **Methodology annex** – description of the modeling approach

Executive Summary

Diversifying global protein production while reducing animal-source foods would make food and agriculture decarbonization far more affordable**.** Five key technologies, or product categories, comprise most of the alternative protein market:

- **Classic plant-based products**: This wide range of protein-rich foods, including legumes, tofu, jackfruit, and tempeh, have distinct sensory profiles from animal-source foods.
- **Plant-based products**: These primarily plant-based products have sensory profiles approximating those of conventional animal-source foods.
- **Precision fermented products**: Produced by micro-organisms, these products are composed of complex organic molecules that can mimic the sensory and nutritional profile of key components of conventional protein-rich foods.
- **Cellular agricultural products**: These lab-grown alternatives, which are identical to conventional animal protein products, have great potential for disruption but are not yet commercially available.
- **Insect-based products**: These replacements made from mealworms or crickets offer relatively high nutrition but a relatively inadequate sensory profile and therefore have greater potential as animal feed than as food for humans.

A shift away from livestock products driven by innovation in the diversified protein sector could yield US$5.5 trillion in climate mitigation benefits by 2050. The development of innovative alternative protein products will decrease emissions of all major greenhouse gases (GHGs). These avoided emissions include methane from enteric fermentation (i.e., fermentation occurring in the digestive systems of animals) and animal waste management and CO_2 emissions from avoided fertilizer use and deforestation. Other benefits, including restored natural habitats, improved biodiversity outcomes, contributions to nutrition through food security, and reduced risk of pandemics and anti-microbial resistance, only strengthen the case for innovation.

Unleashing the potential of the protein transition could deliver major socioeconomic benefits. Rapid deployment of alternative proteins for human consumption is expected to increase gross value added (GVA) by the sector by 10.9% per year, reaching US$1.1trillion in 2050. An additional US$12 billion in GVA is possible if feed additives are adopted. By 2050, the market is expected to support 9.8 million jobs. In terms of social benefits, average crop prices could be more than 12% lower globally by 2050 in a high-innovation scenario, compared with a 1.5˚C future with slower uptake of diversified protein. Price reductions will enhance access to nutritious, protein-rich diets, thereby improving nutritional outcomes. In terms of ecological benefits, alternative proteins will produce the same total calories as traditional proteins but do so using 640 million fewer hectares, thus freeing land for nature and making both biodiversity and deforestation targets easier to meet.

To unlock the full benefits of alternative proteins, global public spending on RD&D and on commercialization needs to increase to at least US$4.4 billion and US$5.7 billion per year, respectively. Additional enabling factors would also speed adoption. Targeted public efforts are required to accelerate diet shifts to alternative proteins, which will result in substantial socioeconomic and environmental benefits. Public support should be focused on creating an environment in which the private sector can invest with greater confidence and at a lower cost. Cost, affordability, regulatory, and consumer acceptance barriers add extra risks to investor decisions, which can prevent the investment landscape from reaching its full potential. Regulatory and consumer acceptance barriers are particularly salient for some protein sources. For proteins that are closer to commercial viability, cost and affordability barriers can prevent full market uptake. Though the public sector needs to ensure that it does not crowd out private investment, it has a role to play in ensuring technologies have sufficient access to finance to scale at the required pace to achieve climate targets.

Public benefits (i.e.,	Annual average 2021–50, undiscounted: US$260 billion Cumulative 2021–50, undiscounted: US$8 trillion Cumulative 2021–50, discounted at 5% per year: US$3 trillion

decarbonization cost savings)	
Business opportunities	2035: US$177 billion GVA, 2.2 million direct jobs 2050: US$218 billion GVA, 2.3 million direct jobs
Co-benefits	Net reduction in land required for agriculture by 640 MHa, opportunities for nature conservation and habitat restoration, reduction in biodiversity loss and depletion of fish stocks, reduced water and air pollution, reduced average food price, improved food security
Public spending required	Commercialization, annual average 2021–30: US$5.7 billion RD&D, annual average 2021–50: US$4.4 billion

1. Adoption of alternative proteins

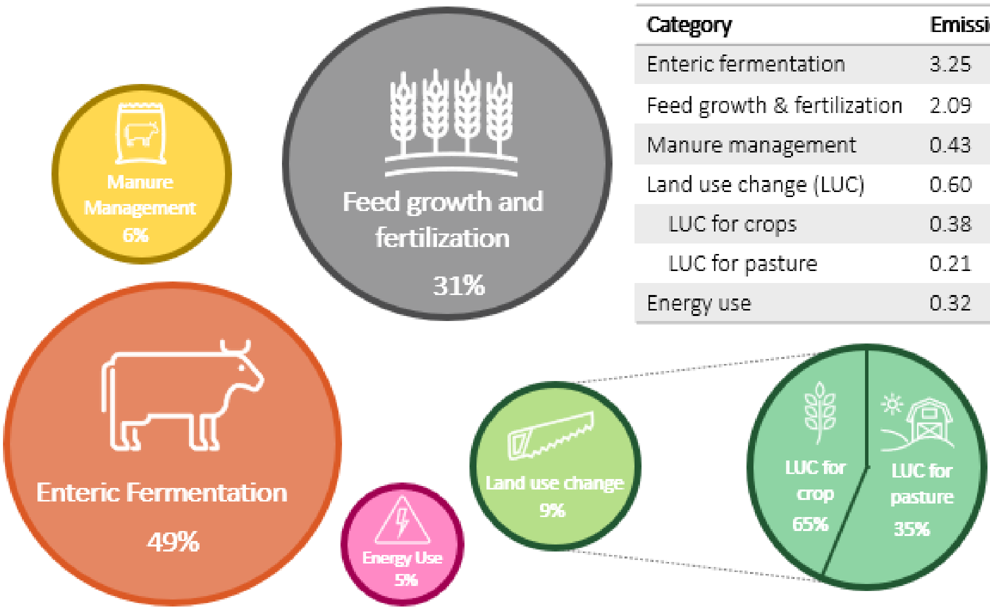
Current role in the food system

The livestock industry has expanded due to explicit subsidies, unpriced negative externalities, a growing population, and rapid economic development in recent decades. Population growth and rising incomes shape food consumption patterns and drive demand for food. Livestock products have played a crucial role in the food system because they are a main source of protein and several micro-nutrients, which are required for balanced nutrition. Because livestock products are often more expensive than other food products, diets shift to livestock products when household incomes increase (SUSFANS 2016). Most of the world's recent population growth has taken place in developing countries, where the need for increasing protein consumption and economic growth is greatest (FAO 2003). As a result, the demand for livestock products has grown significantly. Although expanding access to animal products globally has had some health and social benefits in developing countries, it has also created significant environmental damage (Xu et al. 2021). In particular, the expansion of the livestock industry is a major contributor of global GHG emissions.

The livestock industry is responsible for more than 70% of the land-use sector's emissions.[1] The industry emits more than 8 Gt CO_2-equivalent (CO_2-eq) per year in the form of CO_2, N_2O, and CH_4 (FAO 2017). As shown in Figure 1, activities across the value chain are responsible for emissions, including feed production, conversion of forest to pastureland for grazing and feed production, enteric fermentation (ruminant digestive processes), and manure management.

[1] In 2010, according to the Intergovernmental Panel on Climate Change (IPCC), in 2010 Agriculture, Forestry and Other Land Use (AFOLU) emissions were 10–12 Gt CO_2-eq per year. In that same year, the Food and Agriculture Global Livestock Environmental Assessment Model (FAO 2017) estimated that the livestock industry was responsible for 8.1 Gt CO_2-eq per year. The reported 70% is obtained as a ratio of the two estimates (the actual value is 73.6%).

Figure 1. Total emissions from the livestock industry amount to more than 8 Gt CO_2.eq.



Category	Emissions (Gt CO_2 eq)
Enteric fermentation	3.25
Feed growth & fertilization	2.09
Manure management	0.43
Land use change (LUC)	0.60
LUC for crops	0.38
LUC for pasture	0.21
Energy use	0.32

Note: Values are calculated using global emissions in 2017 reported by FAO (2017).
Source: Vivid Economics.

Innovations in alternative proteins offer the potential to reduce meat consumption, limiting the adverse impacts of the food system. A transition to alternative proteins could support global efforts to reduce GHG emissions, stop deforestation, and help alleviate malnutrition. A wide range of products exists in the alternative animal protein market, which can be divided into the five broad categories summarized in Table 1.[2]

[2] Blue foods—farmed and wild-caught fish and seafood and their plant-based, precision fermented alternatives—are also part of the potential to diversify protein. However, they were not a part of this analysis. Novel blue foods have very low emissions profiles and can help to alleviate pressure on marine and terrestrial ecosystems. Conventional blue foods typically have much lower emissions than their terrestrial counterparts, but their harvest has been associated with massive pressure on marine ecosystems and biodiversity. Farmed fish also impact ecosystems because they can be hotspots for diseases, can contribute to marine pollution, and can threaten wild gene pools.

Table 1. Five categories of products exist in the alternative protein market

Category of alternative proteins	Feedstock/ substitute	Description
Classic plant-based	Tofu, seitan, mushrooms, or jackfruit	A wide range of products, including legumes, tofu, jackfruit, and tempeh, have been on the market for some time as alternative proteins.
Precision-fermented	Feedstocks vary, but glucose is common, especially for fermentation yeast	Precision fermentation uses microbes to produce organic molecules to be used as ingredients to improve the taste, structure, or nutrient content of alternative meats and dairy.
Plant-based	Plant protein concentrates extracted from plants such as peas and algae	Production of plant-based products involves protein manipulation through fermentation or the use of genetically modified organisms.[a]
Insect-based	Insects such as mealworms or crickets	Products are made from high-protein insects.
Cellular agriculture	Feedstocks vary, but glucose is common	These meats, commonly known as cell-based, slaughter-free, lab-grown, cultivated, or clean, are produced with a variety of mechanisms to culture and grow animal cells.

[a] *Whole biomass fermentation is included in this category because germane product and technological characteristics are similar.*
Source: Vivid Economics.

Although the market for plant-based meat substitutes accounts for only 1% of the global protein market, sales grew by 38% between 2018 and 2020. An increased awareness of the health and environmental benefits of alternative proteins has driven fast market growth (CORDIS 2020). In the last two years, the plant-based market grew by 49% in Europe and 43% in the United States, leading to a global market that stands at some US$60 billion (The Good Food Institute 2020).[3] Alternative milk is the most popular product among consumers, with a household penetration rate that ranges from 30% to 50% in key markets (ING Think 2021). However, plant-based meat is the fastest-growing category. In the United States, for instance, the plant-based meat market has grown 72% in the last two years. Approximately 18% of US households have purchased plant-based meat. Of these, 63% repeat purchases (CORDIS 2020).

Future role and deployment potential

By 2050, the demand for livestock products is expected to grow significantly due to an increasing population with higher incomes. The main drivers for food demand are population and

[3] This estimate of the market value of classic plant-based and novel plant-based meat products includes meat and dairy replacements.

economic growth. Under a central pathway of socioeconomic development,[2] food demand is expected to grow between 62% and 98% between 2005 and 2050; during that period, livestock products are expected to increase between 61% and 242% (Valin et.al 2014). The relative greater growth of livestock products is because diets tend to shift to livestock products as incomes rise. Although livestock products can contribute to improved health outcomes in developing countries, the expansion of the livestock industry is not consistent with decarbonization pathways, and there is some evidence that the protein requirements of developed countries' populations are already dramatically exceeded.

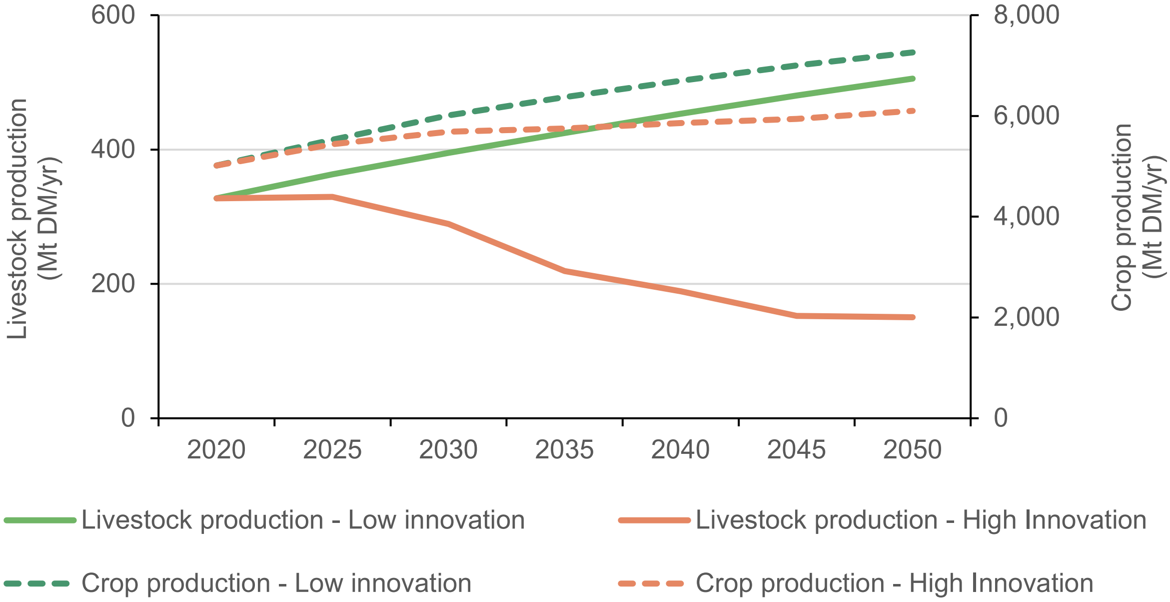
Sustainable agricultural systems are essential for meeting future food demand, and alternative proteins will play a major role in these systems. Under a high innovation scenario, the alternative proteins market is expected to continue to grow rapidly by 2050, when novel plant-based, precision-fermented, and cellular agriculture could account for more than half of the total protein market (Figure 3).[3] Modeling by Vivid Economics suggests that sales of these alternative proteins could increase to US$1.1 trillion by 2040, with traditional meat products declining to less than half of the total market.

Adoption of alternative proteins will be characterized by a mix of products. The timeline for the uptake of each product will depend on several characteristics, including consumer preferences and ability to overcome market barriers (explained in the following section). With robust innovation support, including appropriate emissions pricing and public sector investment, the alternative protein market will account for a majority of the global protein market by 2050, implying the following:

- Classic plant-based products will sustain market share.
- The market share of plant-based proteins will grow steadily in the short term, accounting for some 15% of the protein market by 2030. Between 2030 and 2050, it will continue to grow, but at a slower rate as the segment matures and as other alternatives achieve price parity with conventional meats.
- The expansion of novel plant-based products will result in substitution of a third of cow milk proteins by precision-fermented proteins by 2030.
- Cellular agriculture products will be commercially available in the next few years and will be competitive with traditional livestock on a price basis by the early 2030s.

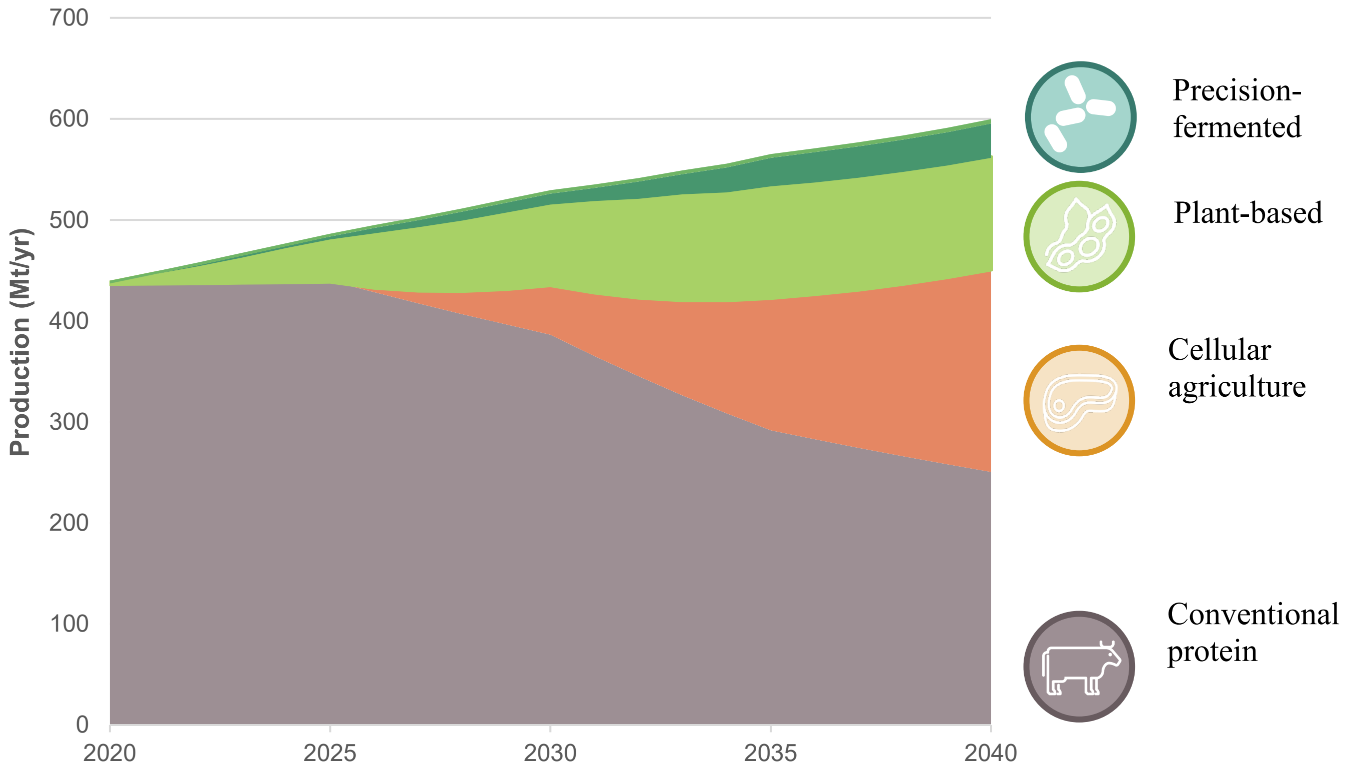
[2] The “Middle of the Road” Shared Socioeconomic Pathway (SSP2) accounts for a 42% increase in population and a growth of more than double in average incomes.
[3] Research estimates a compound annual growth rate of between 7% and 15%.

Figure 2. Effects of alternative proteins innovation on livestock and crop production.



Source: Vivid Economics.

Figure 3. Decline of animal source foods (including dairy) in the high-innovation scenario in alternative proteins.



Novel plant-based products reach cost parity with traditional meat.	Cell-based cultured meat reaches cost parity with traditional meat. By 2030, the uptake of plant-based products could save over 800 Mt CO_2 eq/year in emissions through enteric fermentation.	Marginal cost of cultured meat production approaching cost of sugar, energy, and water.	The market for meat substitutes is larger than the traditional meat market following a rapid increase in the uptake of cultured meat. By 2050, the alternative proteins transition could save more than 5Gt CO_2 eq/year.

Source: Vivid Economics, supported by projections developed by Tubb and Seba (2019).

2. Innovation opportunities

Costs and deployment barriers

Growth of classic plant-based products is hindered by their taste and texture as well as by cultural preferences. Classic plant-based products represent an important source of protein and micro-nutrients, but the fact that their taste profile is dissimilar to meat products limits their capacity to substitute for meat. The market for classic plant-based products is relatively mature, with growth expected to continue at roughly its historical pace.

Commercialization of insect-based products is affected by the products' taste and by cultural preferences. The scalable potential of insect-based products is hindered by consumer acceptance, especially in Western countries. Although insect-based food is high in protein, it has significant consumer acceptance barriers. Consumers cite safety, taste, and emotional factors, such as disgust and neophobia, as sources of concern (Wendin and Nyberg 2021).

Uptake of plant-based meats is affected by developing supply chains and subsidized incumbents, which can increase production costs. On average, plant-based meats remain more expensive than animal-based alternatives. Plant-based burgers from Beyond Meat, for example, are currently about triple the cost of beef burgers (VOX 2020). Similarly, plant-based milk is about 2.5 times more expensive than cow milk (Settembre 2019). Price is commonly mentioned as the main deterrent to buying plant-based food. That price reflects high investment needs and an undeveloped supply chain, which limits the amount, type, and quality of inputs. It is expected to become increasingly competitive with the price of conventional alternatives as plant-based products begin to benefit from economies of scale and the learning associated with commercial deployment. Adoption and deployment of plant-based products is, therefore, expected to increase as supply chains become increasingly robust and prices fall.

Cellular agriculture products are not yet commercially available due to high investment and production costs. One of the major challenges of commercializing cellular agriculture is efficiently scaling up cell manufacturing. There are billions of cells in a bite of a cultured-meat burger, meaning the industry will have to create far more new cells than for cellular agriculture than for any other application of tissue engineering and precision fermentation currently known (Bellani et al. 2020). At current levels of cell-culture productivity, the industry would need anywhere from 220 million liters to 440 million liters of fermentation capacity. By comparison, the pharma industry, which uses similar cell manufacturing techniques, has an estimated cell-culture capacity of between 10 million liters and 20 million liters. The capital that will be required for the cellular agriculture sector to scale will be substantial, especially given that the available cell-manufacturing technology is not yet designed for cellular agriculture.

Key innovations

Development of innovative food-processing technologies could lead to significant cost reductions for plant-based, precision-fermented, and cellular agriculture products. To date, innovation in biotechnology has significantly reduced production costs, and it is expected to continue to do so in line with advances in bioprocessing and ingredient optimization. Efficient grain-processing and the screening of new protein sources could further reduce the production costs of plant-based products. Developments in biomass fermentation at scale could make commercialization of cellular agriculture viable.

Once plant-based and cellular agriculture products become price-competitive with traditional livestock products, investment in commercialization will continue to reduce production costs. Commercialization of plant-based and cellular agriculture could lead to further cost reductions due to learning-by-doing technological improvements. In recent years, prices of plant-based food have significantly decreased thanks to greater demand that supports larger and increasingly robust distribution channels and production facilities, unlocking economies of scale.

Enhancing the sensory profiles of alternative proteins to mimic livestock products is currently among the top research priorities. Between 2018 and 2020, sales of plant-based burgers increased more than 500%. This increase was not due to a surge in vegan and vegetarian consumers, but rather to the growing number of meat-eating consumers considering plant-based products as a substitute for conventional meat. Scientists are, therefore, working to make the sensory profies of cellular agriculture as similar as possible to those of traditional meat. Researchers from Tufts University (*Science News* 2019), for example, have been exploring the addition of the iron-carrying protein myoglobin to improve the growth, texture, and color of bovine muscle grown from cells. If a reasonable similarity is achieved, a big market awaits.

Innovation in fermentation and food processing could increase the nutritional value of alternative proteins, potentially making them healthier than traditional livestock products. The nutritional composition of plant-based and cellular agriculture products can be controlled by adjusting the ingredients and components used in production. Screening of new protein sources could lead to higher protein values in plant-based products. Similarly, extraction of fat composites used in the growth medium for cellular agriculture production could help make the products healthier (Chriki and Hocquette 2020). Improving the nutritional value of alternative proteins could make the products more compelling to consumers, especially in developing countries, where nutrient deficiencies may be common.

Table 2. Barriers to and innovations in alternative proteins

Type of meat replacement	Development stage	Scalable potential	Price parity with animal-source foods	Sensory profile
Classic plant-based	Already produced at scale	Limited by consumer tastes and preferences	Already cheaper	Unlike animal-source foods
Precision-fermented	Early stage of commercialization	High once becomes price-competitive with other proteins	Expected by 2025	Identical to animal-source foods
Plant-based	Early stage of commercialization; sold in restaurants and grocery stores	High, increasingly popular among consumers	Expected by 2025	Very close to animal-source foods
Insect-based	Early stage of commercialization; sold in some countries	Potential limited to livestock feed due to persistent consumer preferences	-	Unlike animal-source foods
Cellular agriculture	Prototype stage	High once becomes price-competitive with other proteins; not yet produced at scale	Expected by early 2030s	Identical to animal-source foods

Source: Vivid Economics.

3. Benefits of innovation

Climate benefits

Achieving net-zero targets will require significant reductions in emissions from both the energy and the agricultural sectors, with any remaining hard-to-abate emissions offset by carbon removals in the short and medium terms. Carbon sequestration in forests and peatlands and other nature-based solutions is not sufficient to offset current emissions from the agricultural sector. Moreover, the land sector is being called on to offer negative emissions to offset persistent emissions from the energy sector. Simply put, technical innovation in the agricultural sector is critical to achieving climate targets.

By reducing emissions from agriculture and enhancing carbon sequestration of the land use sector, innovative agricultural technologies can reduce the overall cost of mitigation. Innovative agricultural technologies can both reduce emissions in the land use sector and make land-based offset strategies less expensive, reducing the need for ambition in the energy system to stay within the emissions budget associated with a given climate target. This climate benefit, or net reduction in costs across the energy and land systems resulting from aggressive RD&D and commercialization of agricultural innovations, is what this work attempts to estimate. (Other benefits of agricultural innovations, such as positive impacts on health and biodiversity, are analyzed in a separate report.)

In the context of this report, the climate benefit is calculated as the difference in the total system costs of a high-innovation scenario and those of a low-innovation scenario, whereby

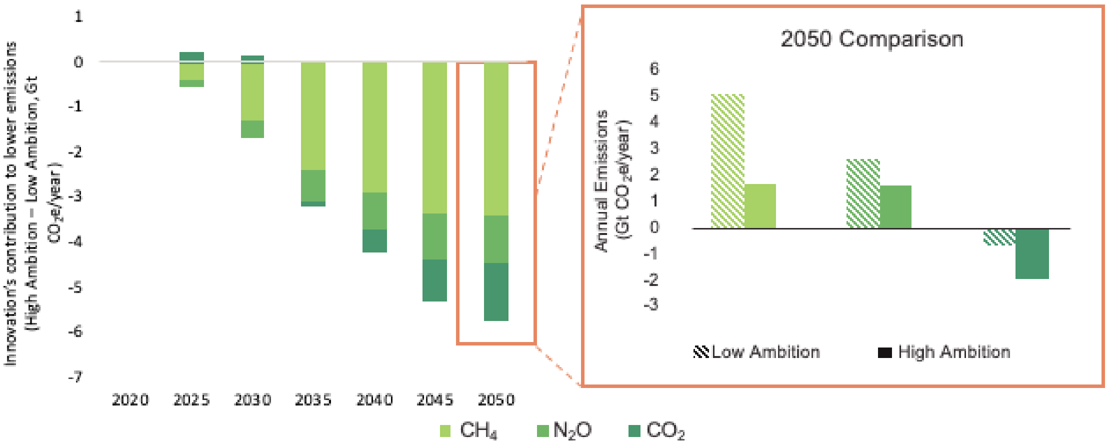
- **System costs** are all capital, operating, and fuel costs within the global energy system
- **Low-innovation scenario** represents market-driven progress in the absence of public sector support
- **High-innovation scenario** represents progress driven in part by government support of RD&D and deployment (i.e., commercialization) that accelerates cost reductions.

Uptake of animal-source food substitutes could yield US$5.5 trillion in climate mitigation benefits by 2050. Development of innovative alternative protein products will decrease emissions across the board:

- **Methane emissions** from enteric fermentation and animal waste management will more than halve between 2020 and 2050. This reduction in emissions is linked to the reduction in demand for traditional livestock products, particularly ruminant meat.
- **Nitrous oxide emissions** from fertilizer use stabilize as the decline in feed demand is compensated by an increase in demand for food crops.
- **Carbon emissions** from land use change decline rapidly and remain close to zero after 2035. The reduction in demand for livestock products results in a decrease in the amount of land dedicated to agricultural production (both cropland for feed production and pastureland for livestock production). This land can be allocated to restoration projects and to managed regrowth of natural vegetation, increasing levels of carbon sequestration.

The shift away from conventional livestock products is associated with a substantial reduction in methane emissions. Methane is an 84 times more powerful driver of climate change than carbon dioxide over a 20-year period, and it has been responsible for 40% of warming since the industrial revolution (Tubb and Seba 2019; CCA Coalition 2021). Agriculture currently contributes 42% of total anthropogenic methane emissions, and mitigation of livestock emissions, particularly from enteric fermentation, is key to meeting global climate targets. High carbon prices (central scenario) alone will not substantially reduce methane emissions unless they are coupled with a shift in demand (high-ambition scenario). Innovation could facilitate this shift by providing substitutes for livestock products, particularly emission-intensive ones like ruminant meat.

Figure 4. Additional greenhouse gas mitigation from innovations to diversify protein.[4]



Source: Vivid Economics.

Human health and nature benefits

A switch to alternative proteins results in additional benefits for biodiversity and human health. Vivid Economics estimates that average crop prices are 10% lower globally by 2050 in a high-ambition scenario, compared with a 1.5°C future with slower uptake of diversified proteins. Lower prices mean protein-rich diets are affordable for more consumers, reducing malnutrition. Moreover, diversified proteins can produce the same total calories as traditional proteins but do so using 640 million fewer hectares, making both biodiversity and deforestation targets easier to meet. Under the high-innovation scenario, soybean production, which is heavily used for feed production and is often linked to deforestation of the Amazon rainforest, would halve by 2050, reducing both deforestation risk and pastureland, thereby allowing for the restoration of natural ecosystems, including biodiverse and carbon-dense forest area.

These benefits are explored in more detail in a separate report, the *Co-benefits of Agricultural Innovation*.

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[4]Estimates represent the additional emissions reductions from innovation in a world that has committed to limiting global climate change. Because the low ambition scenario already achieves a 1.5ºC temperature target, the quantitative estimates presented in this brief are conservative, and likely understate the contribution that these technologies can make toward mitigating climate change. For example, because conventional meat production is a major driver of deforestation, there could be substantial avoided deforestation benefits associated with diversified proteins if the innovation were taken today without other climate policies in place. In this modelling, these benefits are instead attributed to the policies, such as carbon pricing, that are taken up in the central scenario, understating the potential scale of impact. This is done to avoid the double counting issues that would arise when comparing multiple innovations in the GINA portfolio without the central scenario.

Private benefits of innovation: Business opportunities

Expansion of alternative proteins will disrupt not only just the livestock industry but also the entire value chain associated with meat production. Expansion of alternative proteins will significantly reduce livestock numbers, in turn reducing feed-production demand as well as meat processing, packaging, and distribution. This expansion will require new processing systems for protein extraction and manipulation. Biotechnologies, including genetic engineering, metabolic engineering, and synthetic biology, will make the meat industry capital-intensive.

Innovation disruption in the meat value chain

Feed alternatives
Production of a large fraction of conventional animal feed is based on crops, which are cultivated with the support of agrochemicals and equipment and processed through milling and pelleting. The use of novel protein products as a protein source for livestock will reduce the demand for feed grains, freeing cropland for other purposes and reducing the use of agrochemicals.

Plant-based products
The emergence of novel plant-based products, specifically plant-based proteins, will disrupt the meat production value chain, starting with feed crop cultivation. Rather than growing feed crops intended for livestock consumption, farmers will grow crops that are in demand for protein extraction. Certain high-protein plants, like soy and peas, are already being cultivated; others are yet to be developed through plant genomics. Biotechnologies will be key for developing new protein sources as well as for improving protein extraction from existing crops. Finally, meat processing will rely not on slaughtering and rendering but on the manufacturing of plant-based proteins.

Precision-fermented and cellular agriculture
These technologies will yield an entirely new value chain that involves animal cell extraction, cell proliferation, and tissue maturation. Live animals will continue to be raised, not for mass slaughtering but as cell banks for the meat cultivation process. However, given that each animal is left unharmed by cell extraction, a much smaller livestock population will be necessary to successfully support cultivated meat laboratories. Such a population reduction would likely have ripple effects throughout the value chain, reducing the demand for animal feed and thus for crop cultivation. Biotechnologies will be again at the core of food processing because meat products will be made from cell proliferation in bioreactors.

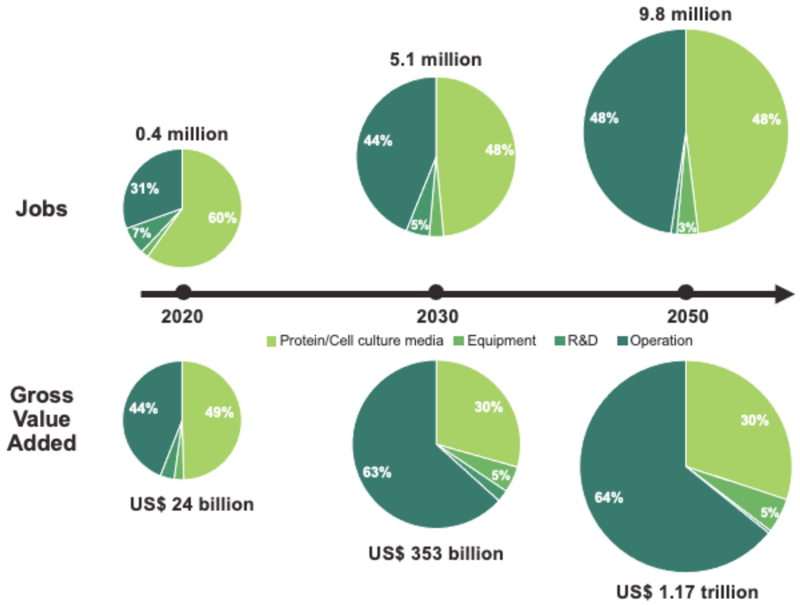
The transition to alternative protein products could deliver more than US$740 billion in GVA by 2040 and up to US$1.1 trillion by 2050. The GVA from alternative protein products currently stands at US$29 billion, with plant-based milk being the main contributor. With rapid deployment of plant-based products, cellular agriculture, and alternative dairy, GVA is expected to grow by 10.9% per year, reaching US$1,100 billion in 2050. Of this increase, plant-based options account for 24%; cellular agriculture, 56%, and plant-based dairy, 20%. In terms of the sectors involved in the value chain, one-third could be associated with the provision of key materials (plant-based protein/protein cells) and two-thirds with the operation and maintenance of processing equipment and fermentation labs.[5] An additional US$12 billion in GVA could be delivered if feed additives are promoted.

By 2040, the alternative protein market could support 8 million jobs, some of them requiring highly skilled workers with specific technical expertise. The impact of alternative proteins on employment is quite uncertain because production processes are still in development. Conventional farming employment will continue to be demanded to supply the key ingredients, as will manufacturing

[5] The analysis is limited to the impact that these technologies have on protein extraction and processing.

jobs to produce food-lab equipment such as bioreactors. Similarly, engineering and science roles will be required to manipulate ingredients and produce final products. Using the average sector labor productivity (GVA/job) of the subsectors involved in the value chain, and assuming improvements in labor productivity, it is estimated that the alternative protein market could create more than 8 million jobs globally by 2040, and up to 9.5 million by 2050.

Figure 5. Economic benefits of diversified proteins.



Source: Vivid Economics.

4. The case for supporting innovation

Government support for RD&D and commercialization of meat replacements is not sufficient to limit global warming to 1.5ºC, but it is critical and could unlock the substantial benefits of innovation. When complemented by suitable enabling and integrating policies, public support for innovation can meaningfully help meet the challenge of climate change.

Investment need and public support

PUBLIC SPENDING ON INNOVATION

Private investment in RD&D and deployment has increased significantly in recent years, but further support will be needed to accelerate the transition to sustainable food systems. In 2020, total investment in alternative solutions reached US$3.1 billion, nearly three times that in 2019 (The Good Food Institute 2021a). Plant-based products attracted roughly 60% of total investment; cellular agriculture received US$360 million, six times the investment in 2019. Although investment has increased significantly, current levels are below those justified by the scale of economic, social, and environmental benefits. Greater investment will more rapidly lower production costs of alternative proteins, supporting their commercialization.

To unlock the full benefits of alternative proteins, global public spending on RD&D and commercialization needs to increase to US$4.4 billion and US$5.7 billion per year, respectively. By way of comparison, public spending on RD&D and commercialization amounted to only US$55 million and US$30 million, respectively, in 2020 (The Good Food Institute 2021a). Because private organizations do not account for the positive externalities of alternative proteins (including emission and pollution reductions, improved biodiversity outcomes, and knowledge spillovers), spending in RD&D and commercialization is expected to be below the optimal level. The public sector has a key role in filling this gap. Although some governments have already deployed funding schemes to help deliver the protein transition (The Good Food Institute 2021b; Protein Industries Canada 2021), public support needs to be expanded globally.[6]

OTHER FORMS OF GOVERNMENT SUPPORT

Further public support is needed in the form of enabling policies and R&D funding. To ensure the preferences of a wide pool of consumers are met, investment should be distributed across all technologies. Facilitating funding is particularly relevant for technologies that are not yet close enough to commercialization for private sector investment. Moreover, it is fundamental to enabling a policy environment that ensures the suitability of the global ecosystem for agriculture. This policy environment may encompass support for intellectual property rights, raising awareness of the new technologies' benefits, or facilitating the creation of legal standards that are appropriate for the new technologies. Policy setting in adjacent sectors like education, science, and technology should be coordinated with agriculture innovation priorities.

Policy actions are required to create an environment in which the private sector can invest with greater confidence and at a lower cost. The aforementioned barriers add risk, preventing the investment landscape from reaching its full potential. The policy agenda should prioritize regulatory and consumer acceptance barriers to certain alternative protein sources because these barriers prevent market creation. Once these barriers are overcome, cost and affordability barriers should be addressed to ensure that supply is competitive enough to attract as much demand as possible.

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[6] The United Kingdom, through the program Transforming Food Production, has a £90 million budget for creating resilient, efficient, and sustainable food production systems. Similarly, Canada has committed to investing some £88 million over five years to leverage industry match-funding through collaborative projects.

Governments have a wide set of policy options for addressing market barriers:

- **Behavioral barriers:** Governments can enhance consumer acceptance of alternative products by providing information about their health and environmental benefits. Research shows that Gen Z and Millennials, who currently represent more than 60% of the global population, are concerned about climate change and animal welfare and thus are more likely than older generations to shift their diet to include alternative proteins (Britain Thinks 2019).
- **Regulatory barriers:** The regulatory environment is crucial to protein alternatives like insect-based products, whose commercialization is currently contingent on country-specific laws. Public support should focus on deploying jurisdictional mechanisms to facilitate the safe manufacturing and distribution of these products.
- **Economic barriers:** Investment in R&D and commercialization has the potential to significantly reduce production costs, but it can take time. Governments can accelerate price parity of alternative proteins and traditional livestock products by
    - Lowering alternative-protein product prices using public economic instruments such as subsidies, as is the case for traditional meat and dairy products (Ho 2021; Greenpeace 2019).
    - Setting stringent climate change policies and regulations. In 2021, 64 carbon-pricing initiatives, which increase the production cost of emission-intensive products, were implemented around the world (Carbon Pricing Dashboard). However, none of them currently cover livestock products.[7] If included, the costs of livestock products to consumers would move closer to the costs of alternative protein products, making the latter more competitive.

[7] Beginning in 2025, New Zealand is expecting to price emissions from agriculture at the farm level.

Table 3. Magnitude of barriers to food consumption for the four types of novel, protein-rich products

Protein source	Economic barriers	Behavioral barriers	Regulatory barriers
Precision-fermented	Medium	Low	Low
Plant-based meat	Medium	Low	Low
Insect-based	Medium	High	High
Cellular agriculture	High	Medium	Low

Source: Vivid Economics.

References

Bellani, C. F. et al. 2020. "Scale-up technologies for the manufacture of adherent cells." *Frontiers in Nutrition 7*: 575146. https://doi.org/10.3389/fnut.2020.575146.

Britain Thinks. 2019. *Future consumer: Food and Generation Z*. https://www.food.gov.uk/sites/default/files/media/document/fsa191102bt-gen-z_rea_full-report_081019-final.pdf

Carbon Pricing Dashboard. The World Bank. https://carbonpricingdashboard.worldbank.org/.

CCA Coalition. 2021. Methane. https://www.ccacoalition.org/en/slcps/methane.

Chriki, Sghaier, and Jean-François Hocquette. 2020. "The myth of cultured meat: A review." *Frontiers in Nutrition* 7 (February 7). https://doi.org/10.3389/fnut.2020.00007.

CORDIS. 2020. "Europe's plant-based food industry shows record-level growth." https://cordis.europa.eu/article/id/429495-europe-s-plant-based-food-industry-shows-record-level-growth.

FAO (Food and Agriculture Organization of the United Nations). 2017. Global Livestock Environmental Assessment Model (GLEAM). www.fao.org/gleam/en/.

———. 2003. *World agriculture: Towards 2015/2030*. www.fao.org/3/y4252e/y4252e00.htm#TopOfPage.

The Good Food Institute. 2020. US retail market data for the plant-based industry. https://gfi.org/marketresearch/.

———. 2021a. "Record $3.1 billion invested in alt proteins in 2020, 3x the capital invested in 2019." https://gfi.org/press/record-3-1-billion-invested-in-alt-proteins-in-2020-3x-the-capital-invested-in-2019/.

———. 2021b. "Scientists awarded US$5 million to boost research into alternative meats—a powerful and scalable climate solution." https://gfi.org/press/scientists-awarded-5-million-to-boost-alt-protein-research/

Greenpeace. 2019. *Feeding the problem: The dangerous intensification of animal farming in Europe*. www.greenpeace.org/eu-unit/issues/nature-food/1803/feeding-problem-dangerous-intensification-animal-farming/.

Ho, Sally. 2021. "US animal agriculture subsidies soared in 2020 despite climate and health damage." *Green Queen*, April 19. www.greenqueen.com.hk/us-animal-agriculture-subsidies-soared-in-2020-despite-climate-health-damage/.

ING Think. 2021. "Plant-based milk IPO puts dairy alternatives in the spotlight." https://think.ing.com/articles/plant-based-milk-on-its-way-to-going-public

Protein Industries Canada. 2021. Unleashing the potential of Canadian crops. www.proteinindustriescanada.ca/.

Settembre, Jeanette. 2019. "Plant-based milk may be double the price but people are drinking it up." *New York Post*, July 18. https://nypost.com/2019/07/18/plant-based-milk-may-be-the-double-the-price-but-people-are-drinking-it-up/.

SUSFANS. 2016. *The drivers of livestock production in the EU*. https://susfans.eu/system/files/public_files/Publications/Reports/SUSFANS%20D4.1_V1.pdf?_ga=1.220584016.995999759.1483713582.

Tubb, Catherine, and Tony Seba. 2019. *Rethinking food and agriculture, 2020–2030: The second domestication of plants and animals, the disruption of the cow, and the collapse of industrial livestock farming.* RethinkX. https://static1.squarespace.com/static/585c3439be65942f022bbf9b/t/5d7fe0e83d119516bfc0017e/1568661791363/RethinkX+Food+and+Agriculture+Report.pdf.

Tufts University. 2019. “Scientists enhance color and texture of cultured meat: Cultured meat could reduce resources required in meat production, with a smaller environmental footprint relative to animal farming.” *ScienceDaily*, October 22. www.sciencedaily.com/releases/2019/10/191022174414.htm.

UKRI (UK Research and Innovation). 2021. *Transforming Food Production Challenge*: *Alternative Proteins Roadmap Workshop*. Summary report, March 23. https://www.ukri.org/wp-content/uploads/2021/08/UKRI-060821-AlternativeProteinsRoadmapSummaryReport.pdf.

Valin et al. 2014. “The future of food demand: Understanding differences in global economic models.” *Agricultural Economics* 45:1. https://doi.org/10.1111/agec.12089.

VOX. 2020. “The next challenge for plant-based meat: Winning the price war against animal meat.” www.vox.com/future-perfect/21366607/beyond-impossible-plant-based-meat-factory-farming.

Wendin, Karin M.E., and Maria E. Nyberg 2021. “Factors influencing consumer perception and acceptability of insect-based foods.” *Current Opinion in Food Science* 40 (August):67–71. https://doi.org/10.1016/j.cofs.2021.01.007.

Xu et al. 2021. “Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods.” *Nature Food* 2: 724–732. https://www.nature.com/articles/s43016-021-00358-x.