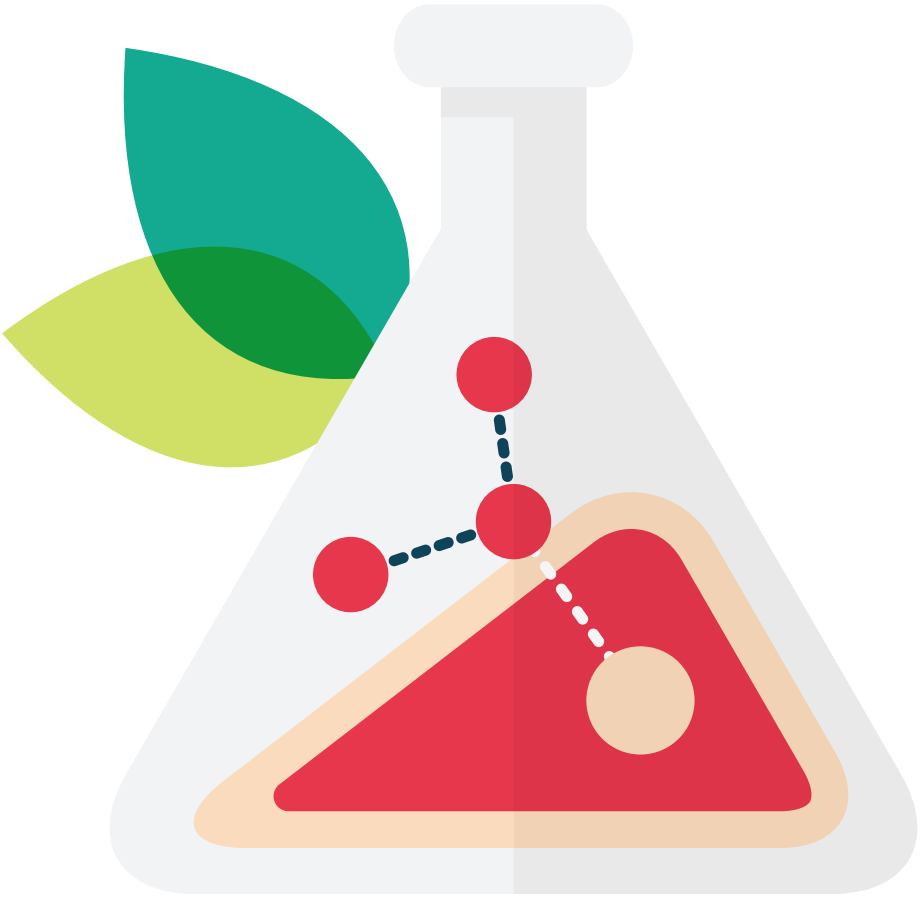
BREAKTHROUGH INSTITUTE

THE CASE FOR PUBLIC INVESTMENT IN ALTERNATIVE PROTEINS



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EXECUTIVE SUMMARY

This report makes a comprehensive case for robust public investment in research and development for alternative proteins. It also provides a framework for how to spend these funds and maximize their benefit for reducing the environmental and health costs of meat consumption.

Currently, the United States consumes more meat per capita than any other country in the world. The American diet's emphasis on meat contributes to greenhouse gas (GHG) emissions, health problems, animal suffering, local pollution, and poor labor conditions.

In the past decade, however, the U.S. has seen a burgeoning alternative meat industry, including cultivated products from companies like Beyond Meat and Impossible Foods, Mosa Meat, Memphis Meats, Blue Nalu, and Eat Just. Despite the industry's growth, these products — still more expensive than conventional meat and lacking diversity — have yet to meaningfully reduce U.S. meat consumption.

Alternative Meats Mitigate Externalities Related to Animal Agriculture

With sufficient research and development (R&D) for new and improved products and production, the benefits for the environment, public health, and animal welfare could be enormous. The externalities from animal agriculture, such as GHG emissions and health impacts, cost the American public at least $388 billion per year. Replacing 45% of beef with plant-based alternatives could, for example, reduce U.S. GHG emissions from agriculture by around one sixth. Substantial replacement would also reduce deaths associated with air pollution; overuse of antibiotics by livestock producers; and rates of colorectal cancer, heart disease and other diet-related issues.

To realize these benefits, the U.S. government should make sizable investments in alternative meat R&D.

Public Investment in Alternative Meats Will Drive Economic Growth

With the help of the federal government, the U.S. alternative meat industry can be a driving force for domestic economic growth by becoming an international leader in the fast-growing market for alternative meats. According to Farm Animal Investment Risk and Return (FAIRR), projections of future market share put alternative proteins — including milk and egg alternatives — between 16 and 62 percent of the global protein market by 2050.

A $50 million federal investment would create more than 2,000 jobs and add nearly $1.5 billion to the U.S. economy over 10 years. If the alternative meat market grows ten-fold by 2030, as some posit it can, the industry could create nearly 200,000 jobs in the U.S.

The Federal Government is Uniquely Suited to Fund the Necessary Research

High-risk, pre-competitive, and multidisciplinary R&D is key to the alternative meat sector overcoming its barriers to growth and widespread adoption. Such research often necessitates public support.

For long-term growth, the cell- and plant-based meat industries must answer basic scientific questions about cell biology, genomic sequencing of potential inputs, and techniques to improve production processes.

Due to the multidisciplinary nature of the needed scientific research, alternative meat producers and researchers are hard-pressed to find capable collaborators and partners. This is an issue the U.S. government has a proven track record of solving — a notable success story being the Advanced Manufacturing Institutes created by the Obama administration.

How The Federal Government Should Invest

To ensure that plant-based and cultivated meat can be a real alternative to conventional animal agriculture, we recommend that the federal government:

- Fund and develop collaborative and multidisciplinary public-private partnerships aimed at alternative meat R&D.
- Expand existing R&D funding for alternative meat at agencies such as the Agricultural Research Service, the National Institute of Food and Agriculture, and the National Science Foundation.
- Apply a mission-oriented approach that targets innovations that could lead to price reductions, cell-line identification, and the development of whole-cut meat alternatives.

Altogether, limiting the social, monetary, and ethical costs of animal agriculture and ensuring American competitiveness in the growing global market for alternative meats requires large-scale, organized public investment in plant-based and cultivated meats.

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INTRODUCTION

Currently, the United States consumes more meat, per capita than any other country in the world.[1] The American emphasis on meat is linked with greater GHG emissions, health impacts, disregard for animal welfare, local pollution, and poor labor conditions.

Alternative meats, namely plant-based and cultivated meats, present a rare opportunity for large-scale consumption shifts. Alternative meats are of two types. Plant-based meats, defined for this report as meat alternatives that attempt to mimic meat without utilizing animal products, have already found success across the United States. On the other hand, cultivated meat — alternatives to conventional meat that are composed of actual animal cells grown completely in a cell-culturing facility — is a relatively new and emerging technology.

With animal agriculture responsible for GHG emissions, local pollution, widespread COVID-19 outbreaks at facilities, and the unethical treatment of billions of animals, alternative meats represent a real pathway towards a greener, cleaner, and friendlier food system. Yet, barriers remain for technological growth, product taste and texture, cost parity, and production processes.

Federal investment in alternative meats could help firms overcome these barriers, mitigating the externalities related to animal agriculture while also growing a nascent industry and benefiting the U.S. economy.

Currently, the federal government provides almost no funding for alternative meats R&D.[2] Although the U.S. federal government has provided funding in the past — and recently, the NSF even provided a $3.5 million grant to researchers at UC Davis to study cultivated meat production — alternative meat has been a mainly private venture.[3]

In this report, we make a comprehensive case for robust public investment in R&D for alternative meats. We also provide a framework for how to spend these funds and maximize their benefit for reducing the environmental and health costs of meat consumption.

In Section I, we outline the state of the plant-based and cultivated alternative meat industries and why their continued growth requires further R&D. In the short term, we suggest that targeting fast food and institutional dining markets can drive adoption of meat alternatives by taking advantage of existing and efficient supply chains. But increasing consumption of alternatives — and subsequently reducing demand for animal-based meats — means that the industry must

overcome barriers related to consumer acceptance, product taste and diversity, cost, production capacity, and basic science. All of this requires significant research and development.

In Section II, we explain why the federal government should fund alternative meat R&D. First and foremost, alternative meats provide a unique opportunity to mitigate the environmental, social, and ethical costs of animal agriculture. Public investment could create a domestic alternative meat industry capable of growing the U.S. economy by meeting rising demand from international markets. The federal government is also best suited to fund the needed research. Private investment is unlikely to be as effective because the plant-based and cultivated meat industries are young industries, requiring high-risk research. Further, the research is multidisciplinary and collaborative, which can lead to the kind of "network failures"[4] the federal government has successfully mitigated over several decades of research in technological innovation.

Finally, in Section III, we outline recommendations for federal investment to maximize its impact. We argue the federal government should take three steps. First, invest in research and commercial networks capable of improving the possibilities of collaboration and cooperation between firms and researchers working on alternative meats. Second, appropriately fund agricultural and scientific research agencies — the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), or the National Science Foundation (NSF) — and include language in appropriations bills for these agencies that focuses funding on alternative meat research topics. Lastly, utilize a mission-oriented R&D approach to reduce cost, develop new cell lines, and identify methods for the creation and production of diverse and improved products.

We believe these steps could go a long way toward growing the alternative meat industry, strengthening the U.S. economy, and reducing the environmental, ethical, and health impacts of meat consumption.

SECTION I: THE NEED FOR R&D IN ALTERNATIVE MEAT FOR INDUSTRY GROWTH

In the past decade, increasingly viable alternatives to animal protein products have emerged. Companies like Beyond Meat and Impossible Foods have successfully marketed their plant-based burgers, ground meat products, and plant-based sausages through grocery stores, restaurants, and fast-food chains. Even more recently, firms like Mosa Meat, Memphis Meats, BlueNalu, and Future Meat Technologies have made cultivated meat production a real possibility for the future.

The recent success of these firms is in large part due to private investment from philanthropic organizations, individuals, and venture capitalists who see these alternatives as vehicles to "disrupt" the meat industry. Although this initial disruption has been well received by consumers interested in lowering their meat consumption, alternative meats remain a small percentage of total U.S. protein consumption. Despite launching high-profile and capital-backed products, the alternative meat industry has not yet been able to reach price parity nor produce diverse product lines, and thus provide a meaningful large-scale reduction of U.S. meat consumption. To compete with animal protein, the industry needs further R&D.

STATE OF THE INDUSTRY

Up to now, a few major players have dominated the U.S. plant-based alternative meat industry. Recently, Beyond Meat and Impossible Foods have cracked into consumer and restaurant markets with their novel plant-based burgers, sausages, and ground beef. Based in California with roots in Silicon Valley start-up culture, both Beyond and Impossible exploded onto the scene as their products found places at fast-food chains like Burger King and Dunkin'.

These plant-based meat alternatives have been a great success for fast-food chains. For example, Burger King saw a 5 percent growth in sales in the third quarter of 2019, which they attributed to the introduction and success of the Impossible Whopper. Dunkin's same-store sales rose 2.8 percent in the fourth quarter of 2019 — their highest increase in six years — due mainly to the introduction of Beyond Sausage Sandwich.[5]

The success of these companies has been due to several factors, ranging from federal support to entrepreneurial innovation and growing cultural awareness of meat's environmental and ethical problems.

The growth of Beyond and Impossible has brought major investors into the field, pushing money to a bevy of startups aiming to get in on the newfound plant-based market.[6] For example, Beyond Meat received a massive $760 million IPO, sparking greater investor and corporate interest in alternative proteins.[7] This success has also spurred existing meat-producing corporations to enter the market, producing similar products in an attempt to maintain their role as protein supplier.[8] According to the Good Food Institute (GFI), the top five meat processing companies have invested in plant-based meats, either through partnerships, financial investment, or the development and launch of their own product lines.[9]

Unlike previous plant-based protein products, such as tofu or seitan, newer plant-based meats utilize novel ingredients and processing methods that can match the nutritional and sensory attributes of conventional meat products. Many of the recent entrants to the plant-based meat category have embraced a diversification away from traditional soy and wheat alternatives and towards pea proteins and other novel ingredients.

Like plant-based meat alternatives, the cultivated meat industry has grown at a staggering pace over the past few years, from nonexistence in 2014 to currently more than 60 startup companies and concerted efforts by major multinational companies in fields such as the life sciences.[10] Yet, the industry is still in its early stages.

Memphis Meat recently raised $161 million for their pilot-scale facility and process development efforts.[11] BlueNalu, a cultivated seafood company, recently announced its own pilot production plant, aiming to develop commercialization capabilities in the next two to three years.[12] Further, Future Meat Technologies in Israel is currently utilizing funding for the creation and development of a production facility. Future Meat aims to produce hybrid plant-based and cultivated meat products by 2021 and have 100 percent cultivated meat products by 2022.[13] Additionally, in September 2020, Mosa Meat, the Dutch cultivated meat company, announced the closing of a $55 million series B funding round.[14]

Although investment in cellular agriculture has come mainly from finance and equity firms looking to take advantage of disruptions in food production, cultivated meat alternatives have garnered investment interest from existing powers in the agriculture economy, including Tyson Foods and Cargill.[15]

Due to the rapid growth and investor interest in cultivated meat alternatives, the United States Department of Agriculture (USDA) and the Food and Drug Administration (FDA) began charting a regulatory path for cultivated meats in 2019, a necessary step towards commercial expansion.[16]

THE POTENTIAL FOR FURTHER GROWTH

Central to the promise of alternative meat is the idea that plant-based and cultivated products can efficiently and effectively replace demand for conventional meat. This is especially important as demand for meat grows. Projections by market research firms are inconsistent but suggest a real potential for alternative meats to make up a large portion of the total meat market. According to Farm Animal Investment Risk and Return (FAIRR), projections for alternative protein — including milk and egg alternatives — growth range from 16 to 62 percent market share by 2050.[17] In either case, alternative meat has other high-level options for reaching consumers and increasing adoption: increasing penetration into fast-food markets and entering into institutional dining facilities.

Fast food has already proven to be a successful and efficient route for delivery of alternative meat replacements to customers across the country. Broad marketing campaigns have introduced consumers to plant-based meat alternatives in products at Burger King, Dunkin', Qdoba Mexican Eats, and Starbucks. These early successes signal the opportunity for increased expansion into fast food and other limited-service restaurants — establishments where you pay ahead of consumption, often designed for take-away.[18]

Fast food and limited-service restaurants prove to be great entry points for alternative meats for a few reasons. First, these restaurants often use low-quality and heavily processed meat that can be replaced by alternatives with little sensory difference in the final product. Second, fast-food chains, in particular, have a long and successful history of new-product integration and well-established supply chains and infrastructure. And finally, fast-food and limited-service restaurants make up a plurality of American meals outside of the home, meaning introduction of alternative meats could lead to high adoption rates.

Institutional dining also represents an effective means of introducing alternative meats to customers. This includes dining services at educational, military, government, health, or business facilities. Like fast food, institutional dining feeds a significant percentage of Americans eating out and provides cheap, often heavily processed meats that can be easily replaced. It also has existing and robust supply chains through companies like Aramark and Compass Group. In fact,

the Humane Society of the U.S. has already partnered with institutional dining companies to provide more meatless options at American government facilities, schools, and universities.[19]

Although these are not the sole strategies for increasing consumption, they represent some of the lowest-hanging fruit for raising awareness of alternative meats and replacing cheap animal-based meat.

To be sure, firms must gain a foothold in retail markets and sit-down restaurants to ensure long-term growth of alternative meats. At the same time, alternative meat firms can continue a strategy aimed at fast-food chains, schools, hospitals, and other institutional dining facilities to replace cheap ground beef and introduce consumers to alternatives for fried fish, chicken breast, meatballs, chicken nuggets, and other staples of fast-food and institutional dining operations.

THE BARRIERS TO GROWTH AND THE NEED FOR R&D

To achieve the growth outlined above, alternative proteins must be able to overcome general scientific barriers, as well as barriers related to consumer acceptance, product quality, cost and price, and production capacity.

Overcoming these barriers — with the possible exception of consumer acceptance issues — will require significant investment in research and development.

Consumer Acceptance

Both cultivated and plant-based meat alternatives have been called "Frankenfoods," suggesting they are unhealthy because they are unnatural.[20,21] Plant-based alternatives have repeatedly faced criticism from activists who are opposed to genetically modified organisms (GMOs). Push back has also come from the meat industry and "foodies" who point to bioengineering and the number of ingredients in products. [22,23]

Despite these claims, consumer receptivity for and acceptance of plant-based and cultivated meat products are promising, especially as messaging and product marketing progresses.[24] At the same time, receptivity and acceptance of alternative meats depends, in part, on consumer awareness. In a survey completed in 2019, around 57 percent of U.S. respondents were not at all familiar with cultivated meats and another 32 percent were only "slightly or moderately" aware of cell-based products.[25] In comparison, the same survey found that only around 36 percent of

U.S. respondents were not at all familiar with plant-based alternatives.[26] For the alternative industry to grow, producers, advocates, and others must educate consumers on the varied products available and their benefit for consumers, animals, and the environment.

Product Quality

The taste and texture of alternative protein products are of fundamental importance to industry growth.[27]

For plant-based producers, improving taste and texture could ensure increasing acceptance from meat eaters who hope to reduce their meat consumption. This can be done in a variety of ways, such as seeking out novel ingredients that can better replicate meat flavor and consistency, and by improving manufacturing methods to impart more realistic fibrous textures.

For cultivated meat firms, the challenges are varied and correspond more to how consumers perceive highly processed foods and the desired role of technology in food production. Still, as cultivated meat products come closer to market, their ability to successfully mimic the taste, texture, and feeling of meat from livestock production will be a major factor in early adoption.

Although both plant-based and cultivated meat producers have begun developing and, in some cases, marketing whole-cut alternatives — products that resemble cuts like steak, chicken breast, or salmon filets — companies have their work cut out for them. Improving existing products remains important, but many firms will need to develop and improve new, whole-cut product lines. Plant-based producers may not be able to realistically mimic some kinds of meat products, such as large cuts of meat meant for slow roasting or smoking. For cultivated meat producers, this is more of a barrier than a limitation. Still, although early attempts to expand product types have been successful — Memphis Meats, for example, has produced chicken breasts in their production lab — new products and further improvement will be needed.[28]

While plant-based alternatives that mimic ground meat can expand into fast-food, institutional, and retail markets, whole-cut alternatives can help further drive growth of the industry, adoption, and the replacement of animal-based meats. According to industry groups, ground beef makes up about 45 percent of total beef consumption.[29] Replacing any existing portion or even just the *growth* of demand for ground beef will be a success. But, if alternative producers can crack the taste, texture, and visual code for whole cuts, the potential for disruption will only increase.

Cost

For both plant-based and cultivated meat, costs and price reduction remain top priorities.

Historically, the meat industry has benefited from government support through direct subsidies, indirect regulatory leniency, and subsidies for animal-feed crops.[30,31] This support has allowed meat producers to reduce the cost of production, achieve economies of scale, and reduce the price of meat for the consumer. To compete with meat, plant-based alternatives must be close to or lower in price than meat.[32]

Plant-based meat has already taken great strides toward reaching price parity with meat. In November 2020, however, the average price of ground beef sat at just over $4 per pound in U.S. city retail markets.[33,34] But the price of Impossible Food's burger is roughly $13 per pound retail. Although slightly cheaper than Impossible in terms of retail costs, Beyond Burgers are just under $11 per pound when purchased in smaller quantities, or just over $6 per pound when purchased in larger quantities.[35,36,37]

Due to their relatively nascent state of development, cultivated meat products have a much longer trajectory to reach cost and price parity. Like plant-based products, cultivated products have become far cheaper to produce, just in the last few years of R&D and prototyping, but prices remain too high for broad consumption.[38]

This is in part because cultivated meat production has yet to move from laboratory to factory. Small-scale production facilities should be able to begin taking advantage of economies of scale, but they require further technological development.

Production Capacity

To scale up production, improve taste and texture, and compete with animal-based meat, alternative proteins face significant technical hurdles. For both plant-based and cultivated alternatives, existing technologies limit production capabilities and product quality.

For plant-based producers, technical hurdles in production processes and ingredient optimization are most notable. Manufacturing equipment remains underdeveloped and capital intensive, and contract manufacturing capacity is hard to come by, thus putting the onus on new companies to construct their own production facilities. For well-funded firms like Impossible, Beyond, MorningStar Farms, or BOCA, these barriers are lower than for new entrants into the market.

Outside of infrastructure barriers, plant-based firms also face constraints related to the availability of ingredients with suitable functionality at sufficient scale. Plant-based companies' success derives in part from the quality and kind of ingredients they can use. Firms will need to develop high-throughput characterization methods and data-driven approaches to screen for ideal ingredient candidates, while at the same time finding producers capable of providing the necessary quantity of said ingredients.

Cultivated meat producers face similar challenges related to manufacturing and infrastructure as well as key process inputs. But these are made more daunting by the industry's earlier stage of development. Like the plant-based industry, the cultivated meat industry is limited by the availability of optimized production equipment. It needs new technologies related to bioreactors, scaffolding materials, and inputs for inclusion in the cell culture media to make cultivated meat suitable for mass production.

Scientific Barriers

The product of relatively novel technological breakthroughs, alternative proteins face barriers related to basic scientific questions.

Cultivated meat firms face challenges related to cell biology. For example, research into cellular metabolism and signaling could elucidate the relationships between genetic variations, culture conditions, and cell growth, leading to improved efficiency of cultivated meat production.[39] Although extensive scientific literature, genetic data, and research tools are available for some species, there is a paucity of prior research for many food-relevant species, including the majority of seafood species. Thus, open-access, publicly funded resources to address these key knowledge gaps could profoundly accelerate the field.

Plant-based meat firms face similar scientific barriers regarding plant genetics and genomics. As stated above, to improve taste, texture, and nutritional content as well as efficiency of production, the plant-based industry needs to find novel ingredients. One way to do so would be to seek out plants with genetic traits and functions that make them suitable for plant-based meat production.[40] Unfortunately, only a small handful of possible ingredient-plants have been genetically mapped. Like the cell-line database for cultivated meat companies, an open-access genomic and functional database for ingredient-plants would allow the plant-based meat industry to overcome this barrier.

SECTION II: WHY THE FEDERAL GOVERNMENT SHOULD FUND ALTERNATIVE MEAT R&D

There are three principal reasons for the U.S. federal government to invest in alternative proteins. First and foremost, it could mitigate the broad and expansive externalities associated with animal agriculture. Second, it could help create a domestic alternative protein industry capable of growing the U.S. economy by meeting rising demand from international markets. Third, the needed research is risky and multidisciplinary, which means that the private sector would be unlikely to fund it and unlikely to succeed in efficiently coordinating it.

ALTERNATIVE MEATS CAN MITIGATE EXTERNALITIES RELATED TO ANIMAL AGRICULTURE

Americans are among the most carnivorous people on the planet. Per capita, the United States consumes more meat and meat-based products than any other country (See figures 1 and 2). This is due to a number of sociohistorical, economic, political, and cultural factors.

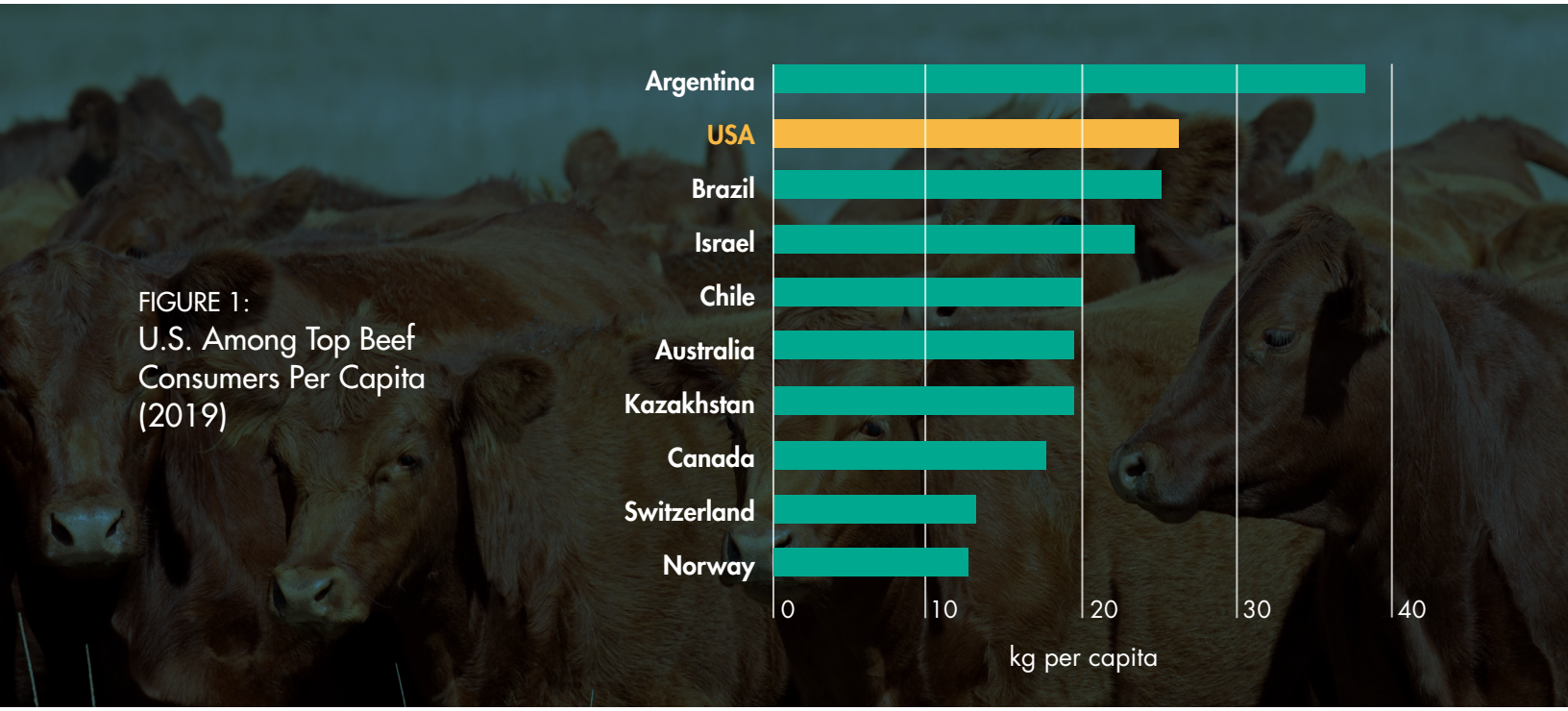


FIGURE 1:
U.S. Among Top Beef Consumers Per Capita (2019)

Source: OECD-FAO

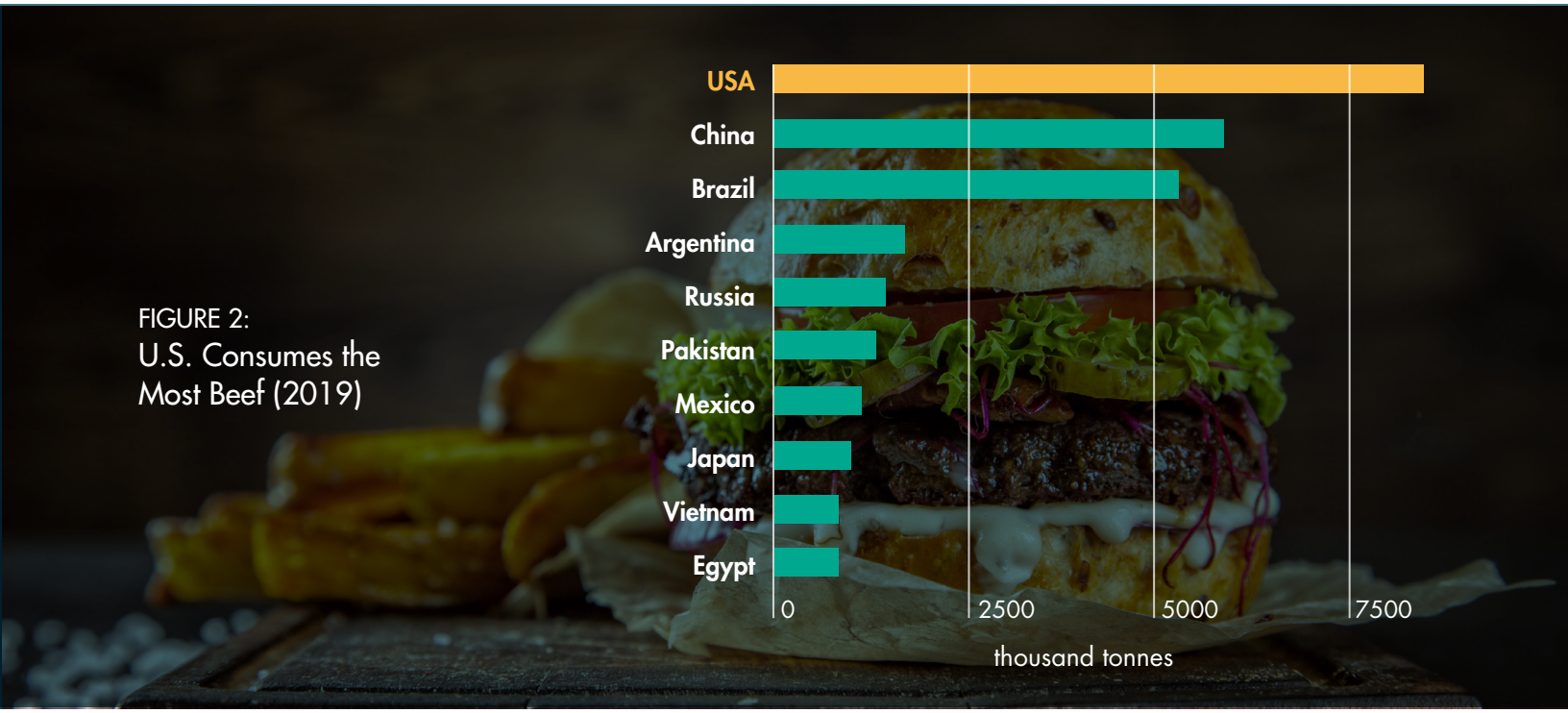


FIGURE 2:
U.S. Consumes the Most Beef (2019)

Source: OECD-FAO

This massive amount of meat consumption presents numerous problems, ranging from GHG emissions to antibiotic resistance and pandemic disease risk. A 2016 study estimates that a global shift to less meat-intensive, healthier diets could save between $1 and $31 trillion U.S. dollars, or roughly half a percent to 13 percent of the global gross domestic product (GDP) — depending on the extent of meat consumption reduction.[41]

Simply put, the negative impacts associated with meat production provide more than enough rationale for the federal government to invest in and fund alternative protein R&D.

Public investment in R&D and innovation is warranted in cases of market failures — where the market does not produce the optimal outcome and the price of a good does not reflect the true consequences of its production, such as high externalities.[42]

In addition to taxes or subsidies that incentivize meat producers to reduce impacts, public investment in R&D for alternative proteins is a central tool for addressing conventional meat's negative externalities.

Public investment in research remains critical for reducing the impacts of agriculture in general.[43] Although large corporations spend billions on agricultural R&D, which has increased

productivity,[44] the profit motive of these investments means that the resulting technological advances often fail to address environmental and public health impacts.[45] The public sector must therefore pick up the slack.

Alternative proteins provide an important means of combating the externalities related to meat production. This is not to say that alternative protein production does not have externalities of its own. Rather, the environmental and ethical externalities of alternative meat production simply have much less impact than those of animal agriculture, which are considerable.

Greenhouse Gas Emissions

Meat, especially beef and lamb, are some of the most emissions-intensive foods, producing almost a half of all GHG emissions from agriculture globally.[46]

Cows, sheep, and goats are ruminants that digest plants through enteric fermentation. Methane emissions from enteric fermentation makes up close to 29 percent of total U.S. agricultural emissions.[47] In addition, methane and nitrous oxide emissions from manure add up to roughly 13 percent of total U.S. agricultural emissions. This means that direct livestock emissions related only to livestock farms, but not their feed production or land use, add up to roughly 42 percent of U.S. agricultural emissions, or almost 4 percent of total GHG emissions from the United States.[48]

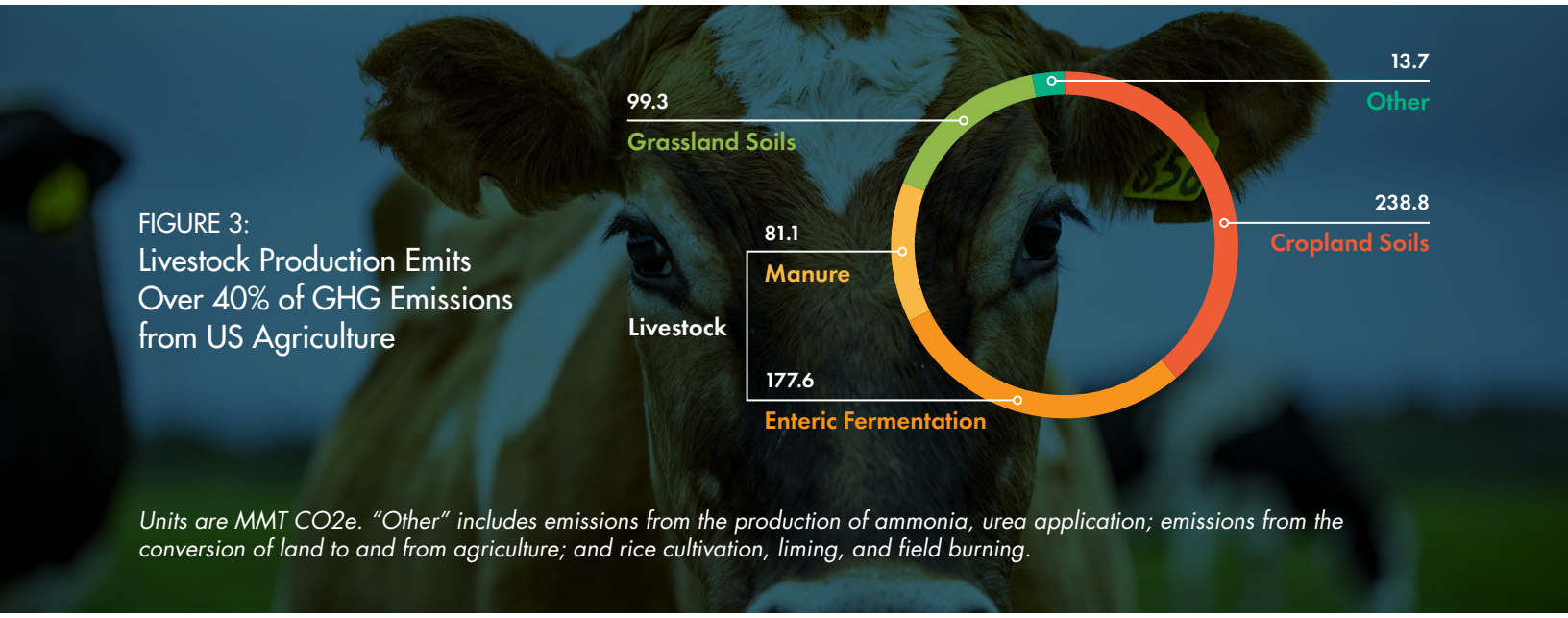


FIGURE 3:
Livestock Production Emits Over 40% of GHG Emissions from US Agriculture

Units are MMT CO2e. "Other" includes emissions from the production of ammonia, urea application; emissions from the conversion of land to and from agriculture; and rice cultivation, liming, and field burning.

Source: EPA (2020).

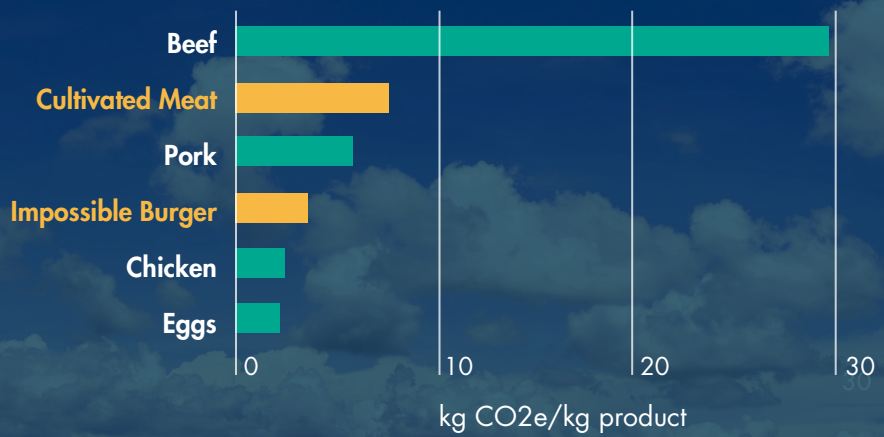
Importantly, the emissions intensities of meat and animal products vary widely depending on the animal, production practices, and the feed they eat. Beef and lamb are particularly emissions intensive, mostly due to the methane emitted from enteric fermentation. Whether measured by emissions per calorie or emissions per unit of protein, beef and lamb are much more GHG intensive than other widely consumed meats or plant products and also use more land per unit of meat.[49]

Although consistently less emissions intensive than beef, sheep or goat, alternative protein sources cannot yet match the lower emissions externalities of chicken. For example, both Impossible and Beyond burgers have an emissions intensity of roughly 3.5 kilogram (kg) carbon dioxide equivalent (CO2e)/kg product,[50,51] compared to 29.6 kg CO2e/kg functional weight for beef,[52] 5.4 kg CO2e/kg for pork,[53] or roughly 2.0 kg CO2e/kg for chicken.[54]

Current estimates for cultivated meat are highly speculative because they are based on hypothetical production processes. But some studies estimate 7.5 kg CO2e/kg product, with a very wide margin of error, meaning emissions may be much lower or higher depending on energy usage requirements and assumptions about energy production methods.[55]

Any step towards reducing the negative externalities of animal agriculture could go a long way to improving the environmental and climatic impacts of U.S. agriculture. For example, replacing 45 percent of U.S. beef consumption with Impossible or Beyond burgers would lower emissions in the U.S. by around 101 MMT CO_2e/year, or close to a sixth of U.S. GHG emissions from agriculture.[56,57,58,59]

FIGURE 4:
Meat Alternatives Have a Low Carbon Footprint



Source: Poore and Nemecek (2018), Rotz et al. (2019), Putnam et al. (2018), Putnam et al. (2017), Pelletier et al. (2014), Impossible Foods (2019).

Land Use and Conservation

Alongside GHG emissions, land use for meat production is one of the most significant challenges facing agriculture, biodiversity conservation, and climate change mitigation. Currently, production of ruminant meat uses almost 80 percent of all agricultural land in the world.[60] In the United States, grassland pasture and rangeland make up more than a quarter of total land, making ruminant meat production by far the largest category of human land use. This is true even after excluding the cropland used to grow livestock feed and land used for feedlots, processing plants, and factory farms.[61]

Alternative proteins are far less land intensive. Plant-based meat alternatives are 98 percent less land intensive than beef per 100 grams of protein.[62] Plant-based substitutes are even 77 percent less land intensive than pork production and 82 percent less land intensive than chicken production.[63] According to projections, cultivated meat production would have lower land-use requirements than beef or pork, but it would be roughly similar to the land-use intensity of chicken.[64]

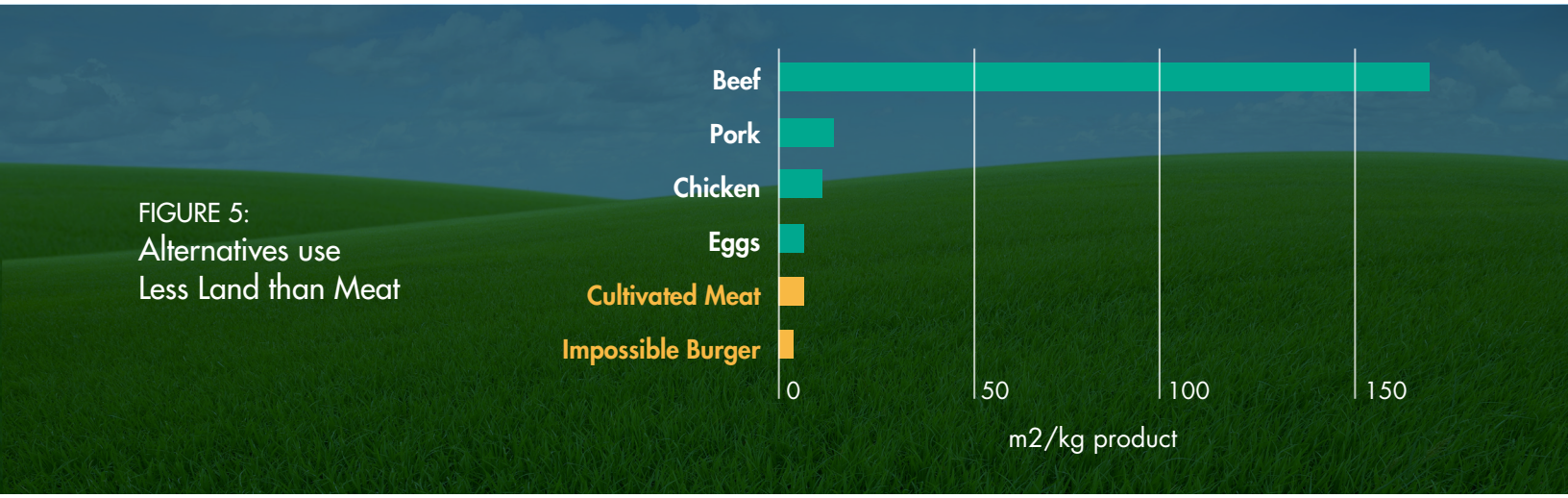


FIGURE 5:
Alternatives use
Less Land than Meat

Source: Poore and Nemecek (2018), Khan et al. (2015), and Mattick et al. (2015).

Overall, a shift in consumption from meat to plant-based and cultivated alternatives has the potential to massively change land use. This is especially true for the replacement of beef and other ruminant consumption. Although some dry and remote rangeland has limited or negligible alternative uses, more than 680 million hectares or roughly a third of global pasture and rangeland could be shifted to crop agriculture.[65] Demand reductions in developed countries from increased adoption of alternative meats could lower pastureland and grazing land use.[66]

A recent paper outlines the "carbon opportunity cost" of land used for animal agriculture. If global diets shifted to plant-based diets by 2050, the authors argue that native vegetation regrowth on pasture and land that's currently growing feed crops could sequester somewhere between 332 and 547 GtCO2e, depending on how much humans reduce their meat consumption.[67] Such a broad return to native vegetation would also have major benefits for wildlife populations and biodiversity.

In fact, land use and deforestation from agricultural production is one of the main drivers of biodiversity loss, and animal agriculture is one of the main culprits. Especially in low- and middle-income tropical countries, livestock production is the single largest contributor to biodiversity loss through habitat destruction and deforestation.[68] In the United States, both cattle grazing and intensive confined operations impact biodiversity, the former through habitat destruction and fragmentation, and the latter through nitrogen pollution that contaminates waterways and makes them uninhabitable for wildlife.[69,70]

Because land-use requirements of protein alternatives are drastically lower than those of animal agriculture, large-scale replacement of animal-based meat with alternatives would greatly reduce wildlife and biodiversity impacts stemming from agriculture. At the same time, reducing U.S. meat consumption while maintaining high feed production could still help limit habitat and biodiversity loss in countries like Brazil. That's because Brazilian deforestation is driven in part by soy production for domestic and international animal feed. Cheap U.S. imports providing feed for Brazilian animal agricultural facilities and other international destinations would help limit habitat loss in the Amazon and other sensitive areas.[71]

Conventional protein consumption also heavily impacts wild fisheries. Overfishing has long decimated fish populations around the world. The Northwest Atlantic Cod fishery has long been a central example of overfishing driven by consumer demand.[72] Reduced consumption of fish, replaced by alternatives produced by companies like BlueNalu, could help fisheries return to healthy populations, making them resilient to future fishing and restoring ecosystem health.

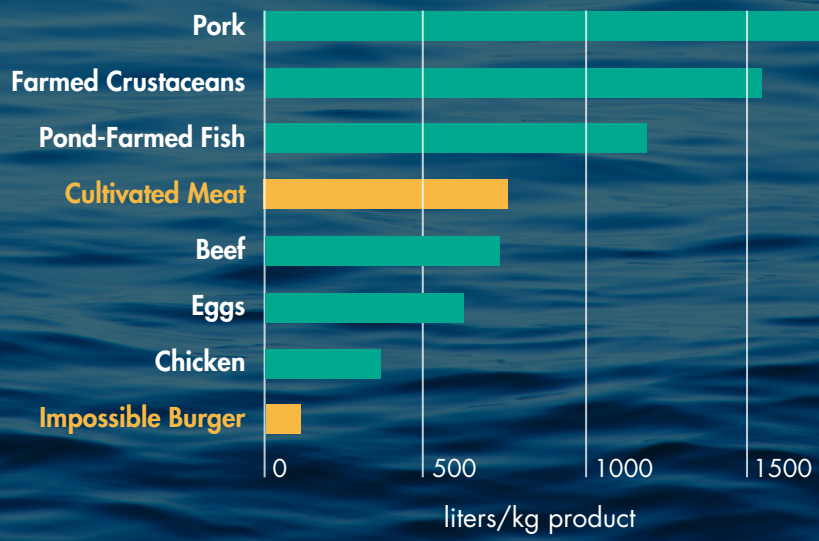
Overall, adoption of alternative meats would have a major positive impact on wildlife and biodiversity. There is little research to demonstrate the potential impact of alternatives on wildlife, habitats, and biodiversity. But the net benefits of a shift from animal meat to alternatives would be overwhelmingly positive because cell- and plant-based meat have lower land-use intensities than most meats.

Water Use

Like greenhouse gas emissions and land use, water use for animal agriculture presents an important challenge for environmental mitigation. Plant-based meats beat almost every other protein source in terms of water use, utilizing 89 percent less water than pork production per 100 grams of protein, 77 percent less than beef, and 76 percent less than chicken.[73]

Although anticipated to use less water than pork and beef production per 100 grams of protein, cultivated meat could potentially be quite water intensive compared to vegetarian protein sources and plant-based alternatives.[74] This may be due to the novelty of and lack of an efficient production system for cultivated alternatives. But making sure production has low water use intensity will be an important question for cultivated meat producers and researchers as they establish their production processes.

FIGURE 6:
Alternatives Use Less Water than Beef or Pork



Source: Poore and Nemecek (2018), Khan et al. (2019), and Tuomisto et al. (2014).

Air and Water Pollution

Animal agriculture, especially concentrated animal feed operations (CAFOs), is responsible for air pollution that impacts local and more dispersed communities. Manure from animal agriculture generally pollutes the air with ammonium compounds, which can have significant health impacts, such as higher risks of lung cancer.[75] Animal agriculture, including dairy, is one of the top five sources of air pollution deaths globally.[76]

Air pollution from pork CAFOs in rural communities is linked to increased rates of sore throat, coughing, and asthma, disproportionately impacting those in close proximity, often poor communities and communities of color.[77,78] The negative impact of pork CAFOs on poor Black communities in North Carolina, for example, has been particularly well studied.[79]

Although there is little research on the air pollution impacts of protein alternatives, the impacts will assuredly be lower. Plant-based meat production is based on crops, which produce some air pollution from fertilizer application and other sources, but far less than conventional meat.[80]

Conventional meat production also produces considerable water pollution, stemming from animal manure, fertilizers and pesticides from feed production, and antibiotics used by livestock operations. Excess nitrogen in waterways — from both manure and fertilizer runoff — causes eutrophication, which can lead to dead zones in fresh and marine water bodies, suffocating fish and causing economic harm to fisheries.

While nitrogen runoff occurs from crop production for alternative meat as well, early estimates of the difference between animal agriculture's and alternative proteins' impact on eutrophication suggests that plant-based alternatives would be one to two orders of magnitude smaller than pork and beef or chicken, respectively.[81]

Nutrition and Public Health

Consumption of meat also has negative consequences for individual and public health. Although links between meat consumption and obesity, cardiovascular disease, and diabetes are hard to assess, there are well-established links between the consumption of red and processed meat and colorectal cancer, one of the most common and deadliest cancers for older American men.[82,83]

As with conventional meat, the long-term health and nutrition consequences related to the consumption of alternatives are hard to assess and substituting plant-based meats does not automatically produce a healthy diet. But there is no evidence that it would be worse than the consumption of animal-based meats.[84] In fact, early studies suggest that reducing heavily processed meat consumption with plant-based alternatives could improve fiber consumption and help to lower risks of colorectal cancer and cardiovascular disease.[85,86]

Still, research is needed to better understand the nutritional health ramifications of a consumption shift towards cultivated meat products. This research should occur simultaneously with the development and formulation of cultivated meats.

Beyond nutrition, replacing meat consumption with plant-based and cultivated alternatives would have other positive public health impacts.

First, animal agriculture's reliance on antibiotics, which has helped breed antibiotic-resistant bacteria, could be mitigated by consumption shifts away from meat.[87] While plant-based alternatives use no antibiotics, questions remain about whether or not cultivated meat production would also include antibiotic use, but the extent of use will be nowhere near that of animal agriculture, inevitably lowering the associated risks.[88]

Second, animal agriculture increases the risk of zoonotic pandemics by driving deforestation and habitat loss and by reducing biodiversity and increasing the transmissibility of influenza.[89,90] The epidemics of HIV, Zika Virus, and Ebola all exemplify how deforestation and biodiversity loss can precipitate zoonotic diseases.[91]

Any shifts in consumption from animal-based meat to plant-based and cultivated alternatives might reduce the misuse of antibiotics and deforestation, which could help mitigate the risk of future pandemics.

Animal Welfare

In 2018, more than 70 billion animals were slaughtered for meat, excluding fish, shellfish, and wild game or bushmeat.[92] Almost 69 billion of those animals were chickens — not even counting the "unproductive" chicks killed close to their birth.[93] In 2017 alone, close to 9.5 billion animals were killed in the United States, or roughly 29 animals slaughtered for every person in the country.[94] At the same time, animals that are raised for consumption are often subjected to cruel and painful conditions and procedures such as overcrowding, debeaking, castration, and the removal of weaning young from mothers.[95]

Any shift toward alternative protein consumption would improve animal welfare. Plant-based meat production does not generally involve animal use and therefore does not involve the harms associated with animal agriculture.[96,97] Current technologies prevent cultivated meat producers from completely removing animals from their production cycle. Cultivated meat production still involves deriving cells from livestock. But by default, far fewer animals are involved than with conventional animal agriculture and the use of animals has been almost entirely eliminated.[98]

Externalities in Totality — Estimating the Costs of Animal Agriculture

Seen apart, the externalities related to animal agriculture are devastating. Seen together, they are motivating. High GHG emissions; increasing land use leading to deforestation, biodiversity loss, and loss of wildlife; air and water pollution that threatens both human and non-human lives; high rates of colorectal cancer; the continued threat of novel zoonotic diseases and the increased virulence of existing diseases from the misuse of antibiotics; the incalculable cruelty of treating billions of animals poorly and ultimately slaughtering them for our food.

Economic assessments do not provide a complete portrayal of the issues raised above. However, the economic costs of animal agriculture's externalities may add considerable weight to the arguments of those advocating dietary shifts for ethical and environmental reasons.

One study estimates that a global reduction of meat consumption could reduce costs for the global economy related to GHG emissions and public health issues by as much $1.6 trillion per year, adding up to about $31 trillion in total by 2050.[99] If the U.S. population were to limit meat consumption based on internationally accepted dietary recommendations, it could save about $197 billion in social costs of emissions and burdens on the healthcare system. That figure would be about $289 billion per year if the entire population became vegan.[100]

Combined with the total estimated cost of air pollution from animal agriculture, the price tag of externalities related to meat production goes up to at least $388 billion.[101] This figure does not take into account losses to existing industries, opportunity costs, or costs associated with biodiversity loss, land use, water use, and water pollution — for example, nitrogen pollution from agriculture costs the U.S. public between $59 and $340 billion per year.[102] But the cost savings from reducing meat consumption is clearly staggering. Again, this does not even include the moral dilemma of animal welfare at the center of modern animal agriculture.[103]

These costs — whether social, economic, environmental, or ethical — ought to motivate federal investment in alternatives to animal-based meat. By investing in alternative protein R&D, the federal government can reduce cost burdens from animal agriculture and work towards a better, more ethical future.

PUBLIC INVESTMENT IN ALTERNATIVE MEAT CAN DRIVE ECONOMIC GROWTH

There is no question that the economic, environmental, and ethical costs of animal agriculture present the strongest case for public investment in alternative meat. Yet, mitigating the costs of conventional meat does not encompass the full benefit of alternative meat. With the help of the federal government, the U.S. alternative meat industry can be a driving force for domestic economic growth by becoming an international leader in the fast-growing market for alternative proteins.

As we show in the first section of this report, the alternative meat industry has grown by leaps and bounds, and industry experts are happy to point out the potential for future growth. Despite the COVID-19 pandemic and the resulting economic downturn, consumer interest in clean and ethical meat has become further entrenched in the second half of 2020.[104] The U.S. market for alternatives has continued to grow, but not as fast as international markets. In 2019, domestic consumers purchased $1 billion worth of plant-based meat, compared to $1.1 billion in the UK, which has a population roughly one fifth the size of the US.[105]

Similarly, plant-based meat and protein alternatives have seen tremendous growth in Asia.[106] The outbreak of the novel coronavirus, as well as the long-running devastation of African swine fever among China's pig population, has spurred Chinese demand for meat alternatives.[107,108] At the same time, Singapore has invested in alternative protein R&D through their Agency for Science, Technology and Research, signaling a national interest in food security.[109]

Singapore is not alone among national governments interested in funding alternative protein R&D. Earlier this year, the Canadian government invested $100 million in Merit Functional Foods, an alternative protein producer based in Winnipeg.[110]

The growing international demand for and interest in alternative meat signals the potential of the U.S. plant-based and cultivated meat industry. To become internationally competitive and take advantage of growing international demand, however, the U.S. alternative meat industry must overcome the barriers described above.

Of course, alternative protein is not without tradeoffs — large-scale shifts from animal meat to alternative meat could have large economic impacts, particularly on those working in livestock agriculture and meat processing.[111] But a few factors could mitigate the impacts.

First, alternative protein growth may not eat into existing markets for meat, but rather, limit the rate of growth for animal-based meat demand, functionally growing a new industry while keeping the existing meat industry relatively intact.

Second, growth of the plant-based and cultivated meat industries will create jobs. These jobs would be fundamentally different from existing jobs in ranching and livestock agriculture, but would be fairly familiar to workers in meat processing and packaging plants.[112] For example, if the U.S. domestic benefit of alternative meat investment matches that of previous Canadian investments, a $50 million investment by the U.S. federal government in alternative meat R&D could create more than 2,000 jobs and add nearly $1.5 billion to the U.S. economy over 10 years.[113] Another estimate suggests that if the alternative meat sector can grow tenfold — measured by market valuation — it could create up to 200,000 jobs in the United States.[114]

Third, the alternative meat industries may create demand for different crops, such as peas, that farmers growing livestock feed could produce.[115] However, there is currently little research on the topic and it is not clear what the net impact on jobs and the agricultural economy would be.

Ultimately, the success of alternative meats in replacing some or all conventional meat consumption depends on customer demand for certain products. If demand for alternatives does not continue to grow, and alternatives can only maintain the same portion of the total meat market, animal agriculture is unlikely to see any economic losses. But, if demand does continue to grow, and the U.S. does not have an alternative industry capable of meeting that demand, U.S. animal agriculture is likely to see economic losses that will not be mitigated by economic gains in other sectors of the U.S. economy.

Overall, we need more research to understand the relationship between the growth in alternative meats and negative consequences for the conventional meat industry. To justify federal spending on alternative R&D, it's essential to understand the potential impacts from and transitions necessitated by alternative meat demand, especially given the millions of Americans employed by conventional meat producers and the political power of animal agriculture groups. If advocates can provide an alternative vision for the livelihoods of those employed by conventional meat, the politics of alternative meat become dramatically simpler.

THE FEDERAL GOVERNMENT IS UNIQUELY SUITED TO FUND THE NECESSARY RESEARCH

High-risk, pre-competitive and multidisciplinary R&D is key to the alternative meat sector overcoming its barriers to growth and widespread adoption. Such research often necessitates public intervention.[116] Despite popular narratives of "lone inventors" or individualistic entrepreneurship leading to technological breakthroughs, U.S. history shows the necessary role of the federal government in driving innovation.[117,118]

For example, the success of U.S. innovation in renewable energy demonstrates the need for federal investment to drive clean technologies. Advocates of clean energy have successfully motivated federal action on renewable energy research and development for the past two decades. From 2005 to 2015, the U.S. federal government spent $4 billion on R&D, combined with $45.8 billion on tax incentives and $1.3 billion on credit incentives for the wind and solar energy industries.[119] This investment has led to long-term cost reductions for solar, wind, and new technological breakthroughs in small modular nuclear power, among other innovations.

Government investment can aid in overcoming technological barriers for alternative meats, helping to lower costs of production and consumer prices, ultimately driving adoption rates. For clean innovation to be successful, the U.S. government clearly must take an active role.

Governments Fund High-Risk and Pre-Competitive R&D

Federal investment is very likely to prove synergistic and complementary to existing and future private investment focused on less-risky research and commercial ventures. Across industries and sectors, public R&D investment has been shown to "crowd in" private investment by tackling high-risk research, lowering costs of production, spurring innovation, and improving expectations of future growth.[120] Public agricultural R&D, for example, complements private R&D spending by targeting research topics that private firms are less likely to invest in.[121,122]

Public investment in cultivated meat has the potential to drive large-scale growth. Despite differences in final end products and starting species of cells, all companies across the industry have roughly the same needs for technological development, bioprocess design, and feedstock and raw materials. This widespread demand is due to the novelty of the field and the breadth of research needed.[123] Research topics unlikely to be funded by private investment could be addressed by federal investment, thereby driving price reductions that allow the industry to compete with animal agriculture.

For plant-based alternatives, public R&D can help develop production processes that drive price reductions and help generate the scientific knowledge and technologies needed for firms to develop new product types such as plant-based fish and alternatives to whole cuts.

Government Funding Solves Network Failures

Researchers working on technological innovation, as well as firms seeking to bring new technologies to market, often face network failures due to the need for collaboration with multiple partners, such as other researchers, firms, institutions, or public agencies.[124]

Alternative meat firms and researchers also face risks of network failures due to the multidisciplinary and collaborative approach of their work. This is especially true for the development of production processes, the improved data resources and analysis needed, and the required basic scientific breakthroughs central to the field.

Cultivated meat producers, in particular, face challenges with collaboration. Because research is necessary at so many different levels, cultivated meat producers must maintain collaborative relationships across institutions, geographies, and disciplines. Similarly, plant-based producers need to bridge gaps between private firms, academic researchers, and data scientists aiming to automate ingredient discovery.

The federal government needs to fund collaborative R&D networks for the alternative meat industry to reach its full potential. Recent research into the historical patterns of innovation has demonstrated the role that governments can play in mitigating network failures. This has been especially apparent in the United States over the past few decades.[125]

For example, the Advanced Manufacturing Institutes (AMIs) created by the Obama administration both funded R&D and provided network support and direction for the technological development of highly innovative industry research. They helped organize workforce development, connecting researchers to firms and helping to set R&D agendas based on future industry needs.[126]

SECTION III: HOW FEDERAL INVESTMENT SHOULD BE SPENT TO MAXIMIZE IMPACT

How the world produces and consumes protein is central to any discussion of climate and society. In the United States, animal agriculture dominates the protein production landscape and, accordingly, dominates its externalities. Scaling up plant- and cell-based meat alternatives would mitigate these externalities while also contributing to economic growth.

But shifting consumption towards alternative proteins requires significant investments in R&D as the industry faces a multitude of unanswered questions. The federal government is best suited to fund the needed research because private investors are unlikely to focus investment in places that can lead to long-term price reductions, improved quality, and real innovation.[127]

At the same time, the novelty of these fields, the lack of existing public funding, and the need for interdisciplinary expertise means that alternative protein industry members struggle to find capable partners in R&D. Investment into alternative protein R&D can easily solve these network failures, helping to accelerate innovation and increase adoption of alternative meats.

However, we need the right institutional arrangements to guarantee the needed technological developments and overcome barriers to alternative meats. Federal funding should go to funding networks, expanding basic and more advanced research into alternative meats and creating mission-oriented approaches that target specific challenges for R&D. Together, these arrangements can drive the innovation and growth necessary for large-scale alternative meat adoption.

FUND NETWORKS

To avoid network failures, the federal government should fund cooperative research projects, consortiums, and interdisciplinary research institutes focused on cell- and plant-based alternatives. Because of the interdisciplinary nature of alternative proteins research, firms may face limitations related to finding capable partners, employees, and researchers. Funding networks related to alternative protein R&D could drive innovation and help firms and researchers establish impactful relationships and agendas.

One avenue for this is to expand funding for the Foundation for Food and Agriculture Research (FFAR) to develop a pre-competitive, public-private R&D consortium on plant-based and cultivated meat production. FFAR already works to coordinate R&D by managing and holding convenings and consortiums related to agricultural issues. FFAR can also utilize existing networks — such as those created and maintained by The Good Food Institute (GFI) or New Harvest — to ensure that both public and private funding work together towards innovative R&D goals.

EXPAND EXISTING R&D PROGRAMS TO INCLUDE ALTERNATIVE MEAT

The U.S. government should expand funding for ARS, NIFA, NSF, and other agencies capable of doing cell- and plant-based alternatives research and provide language directing these agencies to fund said research. These agencies can fund research projects that private firms are unlikely to invest in, reducing the impacts of negative externalities and ensuring the long-term growth of the alternatives industry. For a list of possible research and funding opportunities, please see Appendix 1.

Although each of these agencies has the license and capabilities to fund research into alternative meats, they have different relevant pathways towards funding and research. ARS already has the infrastructure and expertise to begin plant-based and cultivated meat research projects, while NIFA and NSF have networks and grant-making apparatuses to reach capable scientists and firms to perform relevant research. The kind of research that is being targeted should dictate which agencies take the lead. For example, ARS's in-house research and federally funded laboratories and infrastructure would provide an ideal environment for the creation of an open-source cell line or plant-ingredient genomic database. On the other hand, NIFA or NSF would be ideal pathways to targeting federal funding on cost-cutting production innovations that would most likely involve public-private cooperation, like bioprocess designs that could reduce costs, and product integrity for cultivated meat companies.

APPLY A MISSION-ORIENTED APPROACH TO INNOVATE TOWARDS PRICE REDUCTIONS AND CELL LINE DEVELOPMENT

Applying a mission-oriented approach to alternative protein R&D, most likely through the creation of a cross-agency initiative, would go a long way towards solving the pressing problems of the field. Such a program should focus on innovation related to general cost reduction — such as innovations in production processes and ingredient optimization — strategies, cell line development for cultivated meats, and technological innovation aimed at the development of whole-cut meat alternatives.

Mission-oriented programs such as the Department of Defense's Defense Advanced Research Projects Agency (DARPA) and its historical antecedents, or the U.S. AMIs, which foster networks, provide connections between academic and industry positions, and incentivize collaborations that are crucial to creating innovation-friendly environments.[128,129]

Mission-oriented approaches also bring high returns on investment for the public sector. For example, DARPA has secured higher economic returns than other forms of either public or private innovation spending.[130] This is true for a few reasons. First, mission-oriented approaches help produce networks capable of long-term innovation. Second, they lead to technological and knowledge spillover within and outside of the sector of interest. DARPA has led to high economic returns in part because of the breadth of sectors that their defense projects impacted.

At the same time, mission-oriented innovation policy potentially incentivizes increased private funding, catalyzing further innovation and acceleration. The Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E), for example, directly connects researchers to private sector investors and entrepreneurs who can invest in and provide other resources to researchers in the field.

Such a program could be created at existing agencies like ARS, NIFA, or NSF. Or it could be tied to the creation or funding of a new agency such as the Agricultural Advanced Research and Development Authority (AGARDA), approved in the 2018 Farm Bill.

Altogether, limiting the social, monetary, and ethical costs of animal agriculture and ensuring American competitiveness in the growing global market for alternative meats requires large-scale, organized public investment in plant-based and cultivated meats.

APPENDIX 1

OPPORTUNITIES FOR PUBLIC INVESTMENT IN SPECIFIC RESEARCH QUESTIONS

CULTIVATED MEAT

Opportunity #1: Establish and Bank Cell Lines

There are currently few developed and available cell lines for animals consumed as food. Cell-line development has historically been centered around model organisms in biology or biomedical research and applications. Therefore, there are few food-relevant options for cultivated meat companies to work from to produce products that resemble commonly consumed meat.[131] Existing cell lines are often proprietary and difficult or impossible to obtain.

The lack of developed and available cell lines creates a high barrier to entry for new firms and for academic researchers.[132] This problem will continue to grow as more researchers, laboratories, and firms become interested in working on the development of cultivated meats.

As the problem grows, there may be a need for a centralized, third-party, cell-line bio-banking and maintenance service. Such a facility could reduce barriers to entry for interested firms and lower the cost of academic, public, and private research on cellular agriculture. Recently, GFI partnered with Kerafast to host a cell-line repository for early-stage firms and researchers interested in breaking into the cultivated meat industry.[133]

While GFI and Kerafast's work is laudable, a federally funded, open-access cell-line repository would have greater benefits, both to private sector innovation and to government agencies. Although a repository would help realize the economic, environmental, and other public benefits associated with cultivated meat, the private sector has little incentive to develop one as it would be very costly and pre-commercial. Therefore, the federal government should. In addition, a federally funded, open-access cell-line repository could reduce the cost of federal grants and other R&D funding that might otherwise go toward developing cell lines.

Opportunity #2: Develop Serum-Free Media Formulations

Media represents the main cost impediment for many cultivated meat firms. The elimination of animal sera from media is a major limitation and barrier to product development and manufacturing when moving from early-stage product demonstration to at-scale production. Currently, most of the work on serum-free media is under the purview of private firms hoping to patent and privatize research findings.

Because of the novelty of the field, increased public investment in serum-free media ingredient research could have long-term impacts that are currently unknown. At the heart of this question is uncovering the essential components of fetal bovine serum and being able to replicate it. Not only would serum-free media allow for cultivated meat production to be completely animal free, but it would also allow for more consistency in both product processing and further research into cultivated production.

Opportunity #3: Develop New Scaffolding Technologies

Scaffolding technology is another area ripe for innovation. Scaffolding is a crucial element of the cultivated meat production process but it remains a bottleneck in R&D. Production of cell-based whole cuts will require improved scaffolding technologies that allow multiple kinds of cells to grow together. Such technological innovation could help improve the consistency and quality of cultivated products.[134]

Public investment is warranted since advances in scaffolding technologies would have broad applications across the industry but require fundamental research that universities and other public actors are often best suited to conduct. Answering some of the largest research questions about the structuring and fabrication of effective scaffolding would enable improved cell attachment, nutrient penetration, and improve the form of a finished product. Increasing funding for scaffolding technologies would benefit both researchers and private firms who hope to scale up production of cultivated meats. Because so many questions remain unanswered, public funding will both improve the potential of the industry and provide large returns for the federal government.

Innovation in biomedical research is also a co-benefit of scaffolding research. Advancing scaffolding technology could allow for improved whole-tissue replacements for medical operations.

Opportunity #4: Develop New Bioreactor Designs

Bioreactors are the central equipment in the cell culturing process to produce cultivated meat. Currently, bioreactor technology capable of large-scale production of intact meat tissues is purely hypothetical.[135]

Further R&D related to bioreactor design and efficiency is necessary for cultivated meat to scale up and compete with animal agriculture.[136] Bioreactor design R&D must incorporate research and scientists from cell biology, bioengineering, and mechanical engineering, among other fields. Because of this interdisciplinarity, the federal government is uniquely suited to intervene and provide research ecosystem support through research funding and organization.

PLANT-BASED MEAT

Opportunity #1: Develop Novel Plant Protein Processing and Manufacturing Methods

Costs associated with plant-based meat ingredient processing and manufacturing remain a challenge for reaching cost parity with ground beef, pork sausage, and other meat products.[137] For early-stage firms, processing and production equipment remain the central barrier to cost reductions. Even if test products are high quality and relatively cheaply made in laboratories, the cost of scaling production and maintaining quality are likely to limit firms' abilities to compete with meat.

The development of improved production frameworks and manufacturing methods requires interdisciplinary work that ranges from biochemistry and food science to mechanical and chemical engineering.

Opportunity #2: Develop Public Functionality Database of Plant Ingredients

Plant-based meat companies and researchers have access to few ingredients that exhibit reliable, sufficient performance in plant-based meat products while fulfilling desired sensory attributes. Historically, plant-based meat alternatives have relied on soy and wheat as main ingredients. However, companies need new protein, flavor, and ingredient sources to appeal to meat eaters.

Although many species of plants, vegetables, legumes, nuts, and fruits can be used as flavoring, bulking, or protein-rich ingredients, few have been sufficiently validated to provide meat-like texture and taste. Currently, plant-based producers use pea proteins, potato proteins, and other flavoring and color-based ingredients such as beets. Researchers currently have the ability to isolate flavor compounds and functional fractions, and to test them for functional properties such as emulsification, gelling capacity, and water-binding and fat-binding capacity, but a standardized, comprehensive public database for this information is missing.

The federal government can fund and maintain a database of sensory, compositional, and functional profiles for specialty crops and their various fractions across U.S. agriculture. One benefit of a federally funded open-access database is that it would help prevent costly duplication of research. If the federal government can establish the database and research infrastructure, researchers and scientists across the country can help populate the characterization data, allowing other researchers to build upon their work and ultimately benefit the industry.

At the same time, such a database could be a significant boon for researchers aiming to breed, engineer, or otherwise modify crops to produce ingredients best suited for alternative protein production. Plant genomics researchers and breeders have the opportunity and capability to improve both the productivity and usability of specific crops, thus raising their market value and profiting farmers. By including genetic data in the ingredient characterization database, the federal government would foster broad innovations up the value chain, both within the field of plant-based meat and beyond.

ENDNOTES

1 "Meat Consumption," OECD, accessed January 4, 2021, https://data.oecd.org/agroutput/meat-consumption.htm.

2 "Research Funding Database," Good Food Institute, accessed January 8, 2021, https://www.gfi.org/fundingdatabase.

3 Andy Fell, "UC Davis Establishes Research, Training in Cultivated Meat," UC Davis, September 23, 2020, https://www.ucdavis.edu/news/uc-davis-establishes-research-training-cultivated-meat/.

4 Fred Block and Matthew R. Keller, "Where do Innovations Come From? Transformations in the U.S. Economy, 1970-2006," Socio-Economic Review 7, no. 3 (2009): 1-32.

5 Nate Crosser et al., *2019 U.S. State of the Industry Report: Plant-Based Meat, Eggs, and Dairy*, (The Good Food Institute, 2019): 1–73.

6 Zafer Bashi et al., "Alternative proteins: The race for market share is on," McKinsey & Company, August 16, 2019, https://www.mckinsey.com/industries/agriculture/our-insights/alternative-proteins-the-race-for-market-share-is-on#.

7 Crosser et al., *2019 U.S. State of the Industry Report Plant-Based Meat, Eggs, and Dairy:* 25.

8 David Yaffe-Bellany, "The New Makers of Plant-Based Meat? Big Meat Companies," *The New York Times*, October 14, 2019, https://www.nytimes.com/2019/10/14/business/the-new-makers-of-plant-based-meat-big-meat-companies.html.

9 Crosser et al., *2019 U.S. State of the Industry Report Plant-Based Meat, Eggs, and Dairy:* 9.

10 Emiko Terazono, "Alternative meat moves beyond the burger," *Financial Times*, March 9, 2020, https://www.ft.com/content/3e484b96-5ef7-11ea-b0ab-339c2307bcd4

11 Allison Aubrey, "Ready for Meat Grown From Animal Cells? A Startup Plans a Pilot Facility," NPR, January 22, 2020, https://www.npr.org/sections/thesalt/2020/01/22/798515259/ready-for-meat-grown-from-animal-cells-a-startup-plans-a-pilot-plant.

12 Celia Sepulveda, "BlueNalu Announces First-of-its-Kind Commercialization Strategy and Facility Designs for Large-Scale Production of Cell-Based Seafood," BlueNalu, August 22, 2019, https://www.bluenalu.com/pr-82219.

13 Sam Danley, "Cell-based meats approaching scalability," *FoodBusinessNews*, January 27, 2020, https://www.foodbusinessnews.net/articles/15286-cell-based-meats-approaching-scalability

14 Megan Poinski, "Mosa Meat raises $55M for cell-based meat," *Food Dive*, September 25, 2020, https://www.fooddive.com/news/mosa-meat-raises-55m-for-cell-based-meat/585884/

15 Chloe Servino, "Tyson Invests in Lab-Grown Protein Startup Memphis Meats, Joining Bill Gates and Richard Branson," *Forbes*, January 29, 2018, https://www.forbes.com/sites/chloesorvino/2018/01/29/exclusive-interview-tyson-invests-in-lab-grown-protein-startup-memphis-meats-joining-bill-gates-and-richard-branson/#71022f123351.

16 Megan McSeveney, "USDA and FDA Announce a Formal Agreement to Regulate Cell-Cultured Food Products from Cell Lines of Livestock and Poultry," *FDA*, March 7, 2019, https://www.fda.gov/news-events/press-announcements/usda-and-fda-announce-formal-agreement-regulate-cell-cultured-food-products-cell-lines-livestock-and.

17 "*Appetite for Disruption: A Second Serving*, FAIRR (July 2020): 1–61.

18 Michelle J. Saksena et al., *America's Eating Habits: Food Away From Home*, USDA ERS, 196 (September 2018): 1–163.

19 Wayne Pacelle, "Compass, Aramark work with the HSUS to introduce plant-based options at universities, hospitals," Humane Society of the United States, September 8, 2017, https://blog.humanesociety.org/2017/09/compass-aramark-work-hsus-introduce-plant-based-options-universities-hospitals.html.

20 Jenny Splitter, "Lightlife Calls on Impossible And Beyond To Make Cleaner Plant-Based Food," *Forbes*, August 25, 2020, https://www.forbes.com/sites/jennysplitter/2020/08/25/lightlife-letter-impossible-beyond/?sh=1a4548d02b65.

21 Jenny Splitter, "The Name Game: Cultured Meat Could Suffer the Same Fate as GMOs, New Research Suggests," *Forbes*, July 11, 2019, https://www.forbes.com/sites/jennysplitter/2019/07/11/cultured-meat-could-suffer-the-same-fate-as-gmos-new-research-suggests/?sh=31b9f2294a4c.

22 Jan Dutkiewicz and Gabriel N. Rosenberg, "Burgers Won't Save the Planet," *Wired*, August 7, 2020, https://www.wired.com/story/opinion-burgers-wont-save-the-planet-but-fast-food-might/.

23 Alex Trembath, "The Fake Backlash to Fake Meat," OneZero, August 12, 2019, https://onezero.medium.com/the-fake-backlash-to-fake-meat-f53098bfb71b.

24 Keri Szejda, *Cellular Agriculture Nomenclature: Optimizing Consumer Acceptance*, (The Good Food Institute, Updated January 2020): 1–44.

25 Christopher Bryant et al., "A Survey of Consumer Perceptions of Plant-Based and Clean Meat in the USA, India, and China," *Frontiers in Sustainable Food Systems*, 3, no. 11 (February 2019): 1–11.

26 Bryant et al., "A Survey of Consumer Perceptions of Plant-based and Clean Meat," 4.

27 James Parry and Keri Szejda, *How to Drive Plant-Based Food Purchasing: Key findings from a Mindlab study into implicit perceptions of the plant-based category*, (The Good Food Institute, October 2019): 1–25.

28 Emiko Terazono, "Alternative meat industry moves beyond the burger," *Financial Times*, March 9, 2020, https://www.ft.com/content/3e484b96-5ef7-11ea-b0ab-339c2307bcd4.

29 Wes Ishmael, "Feeding the demand for ground beef," *Beef Magazine*, July 13, 2020, https://www.beefmagazine.com/beef/feeding-demand-ground-beef.

30 Jan Dutkiewicz and Gabrial N. Rosenberg, "Burgers Won't Save the Planet." *Wired*, August 7, 2020, https://www.wired.com/story/opinion-burgers-wont-save-the-planet-but-fast-food-might/.

31 Joshua Specht, *Red Meat Republic: A Hoof-to-Table History of How Beef Changed America*, (Princeton, NJ: Princeton University Press, 2019).

32 Kelsey Piper, "The next challenge for plant-based meat: Winning the price war against animal meat," Vox, August 18, 2020, https://www.vox.com/future-perfect/21366607/beyond-impossible-plant-based-meat-factory-farming

33 Impossible Foods, "Impossible Family Pack," accessed October 19, 2020, https://buy.impossiblefoods.com/products/impossible-burger-family-pack.

34 U.S. Bureau of Labor Statistics, "Average Retail Food and Energy Prices, U.S. and Midwest Region," accessed January 13, 2021, https://www.bls.gov/regions/mid-atlantic/data/averageretailfoodandenergyprices_usandmidwest_table.htm.

35 "Beyond Meat Burger," Target, accessed January 17, 2021, https://www.target.com/p/beyond-meat-burger-2pk-4oz-patties/-/A-53332974#lnk=sametab.

36 "Beyond Meat Cookout Classic Plant Based Burger Patties," Target, accessed January 17, 2020, https://www.target.com/p/beyond-meat-cookout-classic-plant-based-burger-patties-frozen-10pk-2-5lb/-/A-80209782.

37 "Beyond Meat Second Quarter 2020 Financial Results, Beyond Meat, accessed January 17, 2021, https://investors.beyondmeat.com/news-releases/news-release-details/beyond-meatr-reports-third-quarter-2020-financial-results.

38 Damian Carrington, "No-kill, lab-grown meat to go on sale for first time," *The Guardian*, December 1, 2020. https://www.theguardian.com/environment/2020/dec/02/no-kill-lab-grown-meat-to-go-on-sale-for-first-time.

39 Johnston, Jeremiah, in discussion with the July 17, 2020.

40 See Appendix 1, "Opportunities for Public Investment in Specific Research Questions."

41 Marco Springman, et al., "Analysis and valuation of the health and climate change cobenefits of dietary change," PNAS 113, no.15 (2016): 4146–4156.

42 Jeffrey M. Perloff. *Microeconomics with Calculus*, 3rd ed. (San Francisco: Pearson, 2013), 620.

43 Sun Ling Wang et al., *Agricultural Productivity Growth in the United States: Measurement, Trends, and Drivers,* USDA Economic Research Service, 189 (July 2015): 1–72.

44 Keith Fuglie, "The growing role of the private sector in agricultural research and development world-wide," *Global Food Security* 10 (2016): 29–38.

45 John King, Andrew Toole, and Keith Fuglie, "The Complementary Roles of the Public and Private Sectors in U.S. Agricultural Research and Development," *USDA ERS Economic Brief* 19 (September 2012): 1–8.

46 Tim Searchinger et al., *Creating a Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050*, World Resources Institute (July 2019): 9.

47 EPA, *Overview of Greenhouse Gas Emissions*, accessed January 14, 2021, https://www.epa.gov/ghgemissions/overview-greenhouse-gases

48 EPA, *Overview*.

49 Searchinger et al., "Creating a Sustainable Food Future," 76.

50 Sofia Khan et al., *Comparative environmental LCA of the Impossible Burger with conventional ground beef burger*, Quantis (2019): 1–64.

51 Martin Heller and Gregory Keoleian, *Beyond Meat's Burger Life Cycle Assessment: A detailed comparison between a plant-based and an animal-based protein source*, University of Michigan, Report No. CSS18-10 (September 14, 2018):1–46.

52 C. Alan Rotz et al., "Environmental footprints of beef cattle production in the United States," Agricultural Systems 169 (2019): 1–13.

53 Ben Putnam et al., "A Retrospective Assessment of U.S. Pork Production: 1960 to 2015, Final Report," *Pork Checkoff*, University of Arkansas (July 7, 2018): 42.

54 Putnam et al., "A retrospective analysis of the United States poultry industry," 107–117.

55 Carolyn Mattick et al., "Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States," *Environmental Science & Technology* 49, no.19 (2015): 11941–11949.

56 C. Alan Rotz et al., "Environmental footprints of beef cattle production in the United States." Agricultural Systems 169 (2019): 1–13.

57 Sofia Khan et al., Environmental Life Cycle Analysis: Impossible Burger 2.0, Impossible Foods, accessed January 14, 2021, https://impossiblefoods.com/sustainable-food/burger-life-cycle-assessment-2019

58 OECD (2020), Meat consumption (indicator). doi: 10.1787/fa290fd0-en, accessed January 14, 2021, https://data.oecd.org/agroutput/meat-consumption.htm

59 This estimate does not take into account

60 Hannah Ritchie, "Half of the world's habitable land is used for agriculture," *Our World in Data* November 11, 2019, https://ourworldindata.org/global-land-for-agriculture.

61 Daniel Bigelow, "A Primer on Land Use in the United States," USDA ERS, 2017, https://www.ers.usda.gov/amber-waves/2017/december/a-primer-on-land-use-in-the-united-states/.

62 Raychel E. Santo et al., "Considering Plant-Based Meat Substitutes and Cell-Based Meats: A Public Health and Food Systems Perspective," *Frontiers in Sustainable Food Systems* 4 (August 2020): 1–20.

63 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat:" 5.

64 Peter Alexander et al., "Could consumption of insects, cultured meat or imitation meat reduce global agricultural land use?" *Global Food Security* 15, (2017): 1–11.

65 Anne Mottet et al., "Livestock: On our plates or eating at our table?" *Global Food Security*, 14 (2017): 1–8.

66 Raychel E. Santo et al., "Considering Plant-Based Meat Substitutes and Cell-Based Meat," *Frontiers in Sustainable Food Systems* 4 (August 2020): 1–20.

67 Matthew Hayek et al., "The carbon opportunity cost of animal-sourced food production on land," *Nature Sustainability* 4 (September 7, 2020): 21–24. Hayek et al., use the EAT-Lancet diet as lower end of their analysis, which would see roughly a 70% reduction in meat consumption. Please see Walter Willett, MD et al., "Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems," Lancet 393, no. 10170, (January 16, 2019): 447–492

68 Brian Machovina, Kenneth J. Feeley, William J. Ripple, "Biodiversity conservation: The key is reducing meat consumption," *Science of the Total Environment* 536 (2015): 419–431.

69 Rob Alkemade et al., "Assessing the impacts of livestock production on biodiversity in rangeland ecosystems," PNAS 110, no. 52 (December 24, 2013): 20900–20905.

70 Henning Steinfeld et al., *Livestock's long shadow: Environmental Issues and Options*, (New York City: FAO, 2006), 212-213.

71 Santo et al., "Considering Plant-Based Meat Substitutes and Cell-Based Meats," 11.

72 Dean Bavington, *Managed Annihilation: An Unnatural History of the Newfoundland Cod Collapse*, (Vancouver: UBC Press, 2011).

73 Santo et al., "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 11-12.

74 Santo et al., "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 11-12.

75 S. E. Bauer et al., "Significant atmospheric aerosol pollution caused by world food cultivation," *Geophysical Research Letters*, 43 (2016): 5394–5400.

76 Sumil K. Thakrar et al., "Reducing Mortality from Air Pollution in the United States by Targeting Specific Emissions Sources," *Environmental Science & Technology Letters* 7, no. 9 (2020): 639–645.

77 Leah Schinasi et al., "Air Pollution, Lung Function, and Physical Symptoms in Communities Near Concentrated Swine Feeding Operations," *Epidemiology* 22, no.2 (2011): 208–215.

78 Steve Wing, Rachel Avery Horton, and Kathryn M. Rose, "Air Pollution from Industrial Swine Operations and Blood Pressure of Neighboring Residents," *Environmental Health Perspectives* 121, no. 1 (2013): 92–96.

79 Wendee Nicole, "CAFOs and Environmental Justice: The Case of North Carolina," *Environmental Health Perspectives* 121, no. 6 (2013): A183–A189.

80 Bauer et al., "Significant atmospheric aerosol pollution caused by world food cultivation," 5394.

81 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 12.

82 H.Charles J. Godfray et al., "Meat consumption, health, and the environment," Science, 361, no. 6399 (July 2018): 1–8.

83 Crystal Raypole, "Does Red Meat Really Cause Cancer?" *healthline*, April 30, 2019, https://www.healthline.com/health/does-red-meat-cause-cancer

84 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 6-8. See also, Frank Hu et al., "Can Plant-Based Meat Alternatives Be Part of a Healthy and Sustainable Diet?" *JAMA* (2019).

85 Santo et al., "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 8.

86 Anthony Crimarco et al., "A randomized crossover trial on the effect of plant-based compared with animal-based meat on trimethylamine-N-oxide and cardiovascular disease risk factors in generally healthy adults: Study With Appetized Plantfood—Meat Eating Alternative Trial (SWAP-MEAT)," *The American Journal of Clinical Nutrition* 112, no. 3 (August 11, 2020): 1188–1199.

87 Thomas P. Van Boeckel et al., "Global trends in antimicrobial use in food animals," PNAS 112, no.18 (2015): 5649–5654.

88 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 3,9.

89 Jesús Olivero et al., "Recent loss of closed forests is associated with Ebola virus disease outbreaks," *Scientific Reports 7*, no. 14291 (2017): 5.

90 Nathan D. Wolfe et al., "Bushmeat Hunting, Deforestation, and Prediction of Zoonotic Disease Emergence," *Emerging Infectious Diseases* 11, no.12 (2005): 1822–1827.

91 Wolfe et al., "Bushmeat Hunting, Deforestation, and Prediction of Zoonotic Disease," 1822–1827.

92 FAO Stats.

93 FAO Stats.

94 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 4.

95 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 4.

96 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 13.

97 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 13. This is with the possible exception of plant-based proteins that contain coconut oil produced using monkey labor.

98 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 13-14.

99 Springmann et al., "Analysis and valuation of the health and climate change cobenefits of dietary change," 4146.

100 Lauren Cassani Davis, "The Economic Case for Worldwide Vegetarianism," *The Atlantic*, March 28, 2016. https://www.theatlantic.com/business/archive/2016/03/the-economic-case-for-worldwide-vegetarianism/475524/.

101 Peter Tschofen, Inês L. Azevedo and Nicholas Z. Muller, "Fine particulate matter damages and value added in the U.S. economy," PNAS 116, no. 40 (October 2019): 19857–19862.

102 Daniel Sobota et al., "Cost of reactive nitrogen release from human activities to the environment in the United States," *Environmental Research Letters* 10, no. 2 (2015): 1–13.

103 Kelsey Piper, "What philosopher Peter Singer has learned in 45 years of advocating for animals," Vox, October 27, 2020. https://www.vox.com/future-perfect/2020/10/27/21529060/animal-rights-philosopher-peter-singer-why-vegan-book.

104 Kyle Gaan, "U.S. Plant-Based Meat Sales Growth Accelerates Despite COVID-19," (The Good Food Institute, July 22, 2020), https://www.gfi.org/blog-plant-based-sales-covid-19.

105 FAIRR, *Appetite for Disruption*, 13.

106 FAIRR, *Appetite for Disruption*, 13.

107 Farah Master, "Coronavirus has put plant protein back on the menu for China," *World Economic Forum*, (April 27, 2020).

108 FAIRR, *Appetite for Disruption*, 13.

109 "SIFBI's Capabilities in Food Science and Biotechnology," Singapore Institute of Food and Biotechnology, accessed 1-14-21, https://www.a-star.edu.sg/sifbi

110 Audrey Enjoli, "Canada Just Invested $100 Million into Vegan Meat," LiveKindly.co, June 22, 2020, https://www.livekindly.co/canada-invested-100-million-vegan-meat/.

111 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 14-15.

112 Santo et al. "Considering Plant-Based Meat Substitutes and Cell-Based Meat," 14-15.

113 Dan Blaustein-Rejto, *Accelerating Economic Recovery Through Agricultural Innovation*, (Breakthrough Institute, June 2020): 1–9.

114 Saloni Shah and Dan Blaustein-Rejto, *Federal Support for Alternative Protein for Economic Recovery and Climate Mitigation*, (Breakthrough Institute, May 2020): 1–62.

115 Peter Newton and Dan Blaustein-Rejto, *Social and economic opportunities and challenges of plant-based and cultured meat for rural producers in the US, Manuscript in preparation*, (Breakthrough Institute): 5-6.

116 Wang et al., *Agricultural Productivity Growth in the United States*, pp. 38–40.

117 Block and Keller, "Where do Innovations Come From? Transformations in the U.S. Economy, 1970-2006," 19-20.

118 Mariana Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths* (London, UK: Anthem Press, 2013).

119 Seth Kirshinger et al., "Examination of Federal Financial Assistance in the Renewable Energy Market: Implications and Opportunities for Commercial Deployment of Small Modular Reactors," Scully Capital (2018): es-4.

120 Matteo Deledi et al., "The macroeconomic impact of government innovation policies: A quantitative assessment," UCL Institute for Innovation and Public Purpose, Policy Report (2019): 1–52.

121 John King, Andrew Toole, and Keith Fuglie, "The Complementary Roles of the Public and Private Sectors in U.S. Agricultural Research and Development," USDA ERS 19 (2012): 4-5.

122 Wang et al., *Agricultural Productivity Growth in the United States*, 38-40.

123 Johnston, Jeremiah (New Harvest), in discussion with the authors. July 17, 2020.

124 Fred Block, Matthew R. Keller, and Marian Negoita, "Network Failure and the Evolution of the U.S. Innovation System," *Journal of Industry, Competition and Trade*, 20 (2020): 235–237.

125 Block and Keller, "Where do Innovations Come From? Transformations in the U.S. Economy, 1970-2006," 19-20.

126 Block, Keller, and Negoita, "Network Failure and the Evolution of the U.S. Innovation System," 13-14.

127 See Appendix 1: "Opportunities for Public Investment in Specific Research Questions."

128 Block and Keller, "Where do Innovations Come From?" 20.

129 Daniel Sarewitz, "Saving Science," *The New Atlantis*, (Spring/Summer 2016), https://www.thenewatlantis.com/publications/saving-science

130 Deledi et al., "The macroeconomic impact of government innovation policies," 31

131 Johnston, Jeremiah (New Harvest), in discussion with the author. July 17, 2020.

132 Arthurs-Schoppe, Sofia, (venture analyst at Stray Dog Capital), in discussion with the author. July 6, 2020.

133 Ahlam Rais, "Kerafast Partners with Good Food Institute to Make Cell Lines Available," Lab Worldwide July 2, 2020, https://www.lab-worldwide.com/kerafast-partners-with-good-food-institute-to-make-cell-lines-available-a-903284/.

134 Catherine Lamb, "For Cultured Meat, Scaffolding is the Next Big Hurdle. Could LEGOs Hold the Answer?" The Spoon, April 1, 2019, https://thespoon.tech/for-cultured-meat-scaffolding-is-the-next-big-hurdle-could-legos-hold-the-answer/.

135 Neil Stephens et al., "Bringing cultured meat to market: Technical, socio-political, and regulatory challenges in cellular agriculture," *Trends in Food Science & Technology*, 78 (2018): 155–166.

136 Scott J. Allan, Paul A. De Bank, and Marianne J. Ellis, "Bioprocess Design Considerations for Cultured Meat Production With a Focus on the Expansion Bioreactor," Frontiers in Sustainable Food Systems, 3, no. 144 (2019): 1–9.

137 Kelsey Piper, "The next challenge for plant-based meat: Winning the price war against animal meat." Vox, August 18, 2020, https://www.vox.com/future-perfect/21366607/beyond-impossible-plant-based-meat-factory-farming.

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