The Challenges and Potential Benefits of Animal-Free Meats

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Innovations in food science have led to the emergence of plant-based substitutes for animal meat products. This article provides an overview of some of the emergent products and argues that their diffusion may be gradual and dependent upon technological improvements and consumer preferences. These products have the potential to reduce greenhouse gases and the environmental side effects of agriculture, but further research is required to quantify their impacts.

Plant-based meat alternative, Impossible Burger, is available in more than 1,000 locations in the U.S., including fast-food restaurants such as Burger King.

Food systems around the world account for about 30% of the world's total energy consumption. As the human population continues to rise, food production would be a significant contributor to an estimated 80% increase in global agricultural greenhouse gas (GHG) emissions. An increase in energy conversion efficiency in the food production system will have a crucial impact on food security, global health, climate, and the environment.

Recently, innovations in food production make producing plant-based meat, substitutes that closely mimic the taste and appearance of meat, possible for the first time in human history. Pound for pound, a plant-based diet has higher conversion efficiency than an animal-based diet as it removes an extra step of energy conversion from sunlight. Thus, replacing meat consumption with plant-based meat products would improve the efficiency of use of feed inputs based on the percentage of energy input utilized in the production.

The notion of improved input use efficiency is a key element of modern agriculture. For example, both modern irrigation and precise fertilizer application technologies increase the fixed cost of production. By increasing the efficiency of inputs, they have increased yields and decreased total costs, making them ubiquitous in modern agriculture. For example, most animal meats require more legumes like soybean than that needed to produce legume-based meat. The diffusion of these new technologies has been gradual, and the early adoption occurred at locations and applications where the technologies had a relative advantage. If consumers eventually embrace animal-free meat, its cost savings could result in a significant expansion of the dietary options of consumers.

The introduction of animal-free meat systems will require investment in research, but may result in cost and environmental savings over time. Impossible Meats, a leading producer, spent nearly five years on the research and development before releasing a product, then needed three more years before they received the FDA's permission to sell their product in grocery stores rather than just restaurants. The investors believe that low-cost production in the future and improved quality resulting from research make these investments profitable.

The current innovations are the culmination of advancements in molecular biology, biochemistry, and cell biology. The production methods follow two approaches: simulating meat products using plant components (plant-based meat) and culturing muscle cells using plant-based media (cultured meat).

Plant-based meat alternatives: These products closely mimic the unique tastes and textures for real meat by creating molecules that closely resemble those present in meat by using pea proteins or fermenting soy. They much more resemble the real thing than tofu (soybeans) and seitan (wheat).

Cultured Meat: These are actual muscle tissues grown in labs using stem cell biology and tissue engineering. The technology involves the extraction of stem cells from the organism and transferring them onto or into a suitable growth medium. The product can be modified to contain proper fat and water compositions and color, so it mimics the texture and flavor of meat derived from animals. The result is nearly identical to conventional meat but avoids much of the

Table 1. Plant-based Meat, Cell-culture Based Animal Products and Cultured Meat Companies

	Technology	Product	Technological Challenges	Capital
Beyond Meat	**Plant-based Meat Alternatives (Use pea as the source of protein)**	Imitating ground meat product (hamburger, taco, sausages). Available in restaurant and supermarkets	Mimicking appearance, texture, and flavor to meat products	IPO in 2019 Market cap in December 2019 is valued at $4.65 billion
Impossible Foods	**Plant-based Meat Alternatives** Heme mixed with soy-based structured patty (wheat, coconut oil, and potatoes)	Burger available in more than 1,000 locations in the US, including fast-food restaurants such as Burger King.	Mimicking appearance, texture, and flavor to meat products	Funding estimated: $600 million
LightLife	**Plant-based Meat Alternatives**	Plant-based burger and sausages available in select supermarkets	Mimicking appearance, texture, and flavor to meat products	Acquired by Maple Leaf Foods in 2017 for $140 million
Raised and Rooted (Tyson Foods)	**Plant-based Meat Alternatives**	Plant-based nuggets and burgers available in select supermarkets	Mimicking appearance, texture, and flavor to meat products	Privately owned by Tyson
Sophie's Kitchen	**Plant-based Seafood Alternative**	Available in some health food stores and select supermarkets	Developing attractive flavor and texture imitating seafood	Established 2011 Investors: Spring Singapore and Food Future Co.
Memphis Meats	**Cultured Meat**	Not available on the market	Commercially viable scale	Raised $161 million led by Japan Soft Bank (A big investor in new technologies)
JUST (Hampton Creek)	**Cultured Meat**	Not available on the market	Commercially viable scale	$220 million led by Khosla Venture
Finless Foods	**Cultured Fish** (Bluefin tuna)	Not available on the market	Fish cell culture	Seed funding $3.5 million USD by Draper Associates
Mosa Meat	**Cultured Meat**	First Demo August 2015, lab grown meat. Not available on the market	Commercially viable scale	Partnership with Nutreco and Lowercarbon Capital
Shiok Meats	**Cultured Seafood**	Founded in 2018 in Singapore. Not available on the market	Develop Cell-based Shrimp not available in the market	Raised $4.6 million seed money

Source: Center for Sustainable Systems, University of Michigan (2019)

emissions associated with raising livestock. Cultured meats need to cross cost and regulatory challenges before being ready for the market.

The State of the Industry and Its Future

The two approaches to produce animal-free meat are at different stages of commercialization. Table 1 provides a list and details of companies employing these approaches. Beyond Meat and Impossible Foods are two leading new plant-based meat companies. The traditional American meat giants, Tyson and Purdue, have announced plans to release their plant-based meat products, and Canadian meat giant Maple Leaf has already entered the market via acquisition of LightLife. In addition to meats, seafood alternatives are becoming available in grocery stores under brand names like Sophie's Kitchen.

As a technology, cultured meat is still in its early stages. Currently, only a small-scale "proof of concept" has been demonstrated for publicity; however, the prospect of making meat from authentic animal muscle cells without slaughter has attracted significant investment from venture capital firms and large industry players like Cargill. Mosa Meats, JUST and Memphis Meats are some of the early pioneers in this space. Cultured seafood pioneers are motivated by the decline of the wild stocks (Finless for Bluefin tuna) or enormous market demands (Shiok for shrimp).

Figure 1 presents results of life cycle assessments (LCA) showing that sheep and beef meats have high rates of CO_2 emissions per kg of protein. The GHG emissions of extensive beef (grazing) are smaller than that of intensive meat (feedlot). Meat substitutes have relatively low CO_2 emissions (10-40% of beef products), but we lack LCA estimates for the newer products, which makes comparisons challenging.

There are significant differences in emissions among different beef categories, suggesting opportunities for reduction in emissions. Replacing beef has been the focus of work by both plant-based and cultured meat technologies. Both Beyond Meat and Impossible Foods offer burger patties with the look and taste of the conventional product. Other ground meat products, such as taco ground beef and meatballs, are also available, as well as deli meats, sausages, and bacon. Imitation or cultured chicken is a focus of investments by chicken giants like Tyson and Purdue, and Beyond and Impossible have announced their intent to enter the

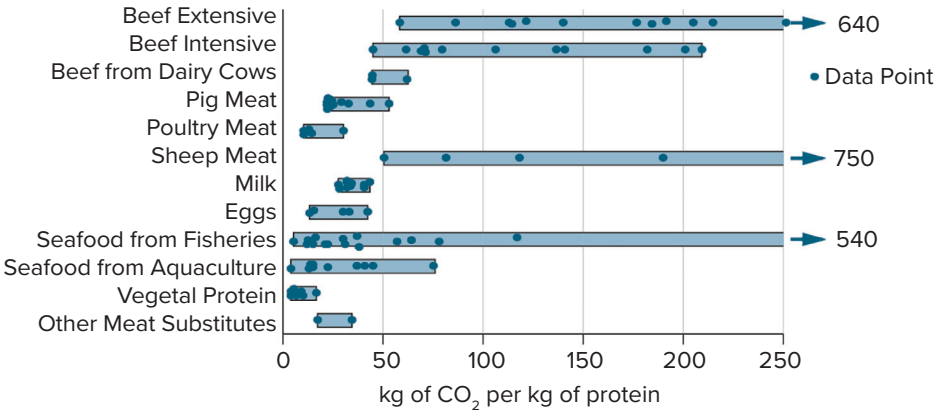
market as well, focusing on sausages and "nuggets" that lack bones or other skeletal structures. Some analysts believe chicken will be the first commercially available cultured meat product.

The development of plant-based and cultured meat technologies has followed the familiar stages of technological advancements—basic research, testing, upscaling, commercialization, and development of a supply chain. The cost of these products is likely to decline over time as a result of "learning by doing," and their value to consumers may rise due to "learning by using."

The introduction of plant-based meat alternatives is the culmination of many years of research in food sciences and molecular biology. The critical ingredient of Impossible Burger, recombinant heme from soy, was discovered by its founder during a sabbatical from biomedical research at Stanford. Similarly, cultured meat technology started from stem cell biology initially developed for therapeutic applications. The journey from proof-of-concept in labs to the commercial products has taken both Impossible and Beyond Meat four to five years. In both cases, small-scale processes produced novel products that impressed both consumers and investors, which drove a virtuous product development cycle to improve the quality and quantity of the product.

Impossible Burger was initially (2016) available in select restaurants before it became a popular item in fast-food chains, and in 2019 was added to the menu at Burger King. Through research and learning by doing, the company recently released a new version of their signature burger, the Impossible Burger 2.0, which more closely resembles 80/20 ground beef from cows. Beyond Meat first sold chicken products in 2013 at Whole Foods, but then pivoted to a more

Figure 1. Carbon Footprints per Kilogram of Protein



Source: Nijdam et al., 2012.

successful ground beef product line in 2017 at many more supermarkets before expanding to fast-food restaurants in 2019. The first movers invited imitation. It is hard to imagine that large conglomerates like Cargill and Tyson would have made their investments without Beyond and Impossible demonstrating the viability of the product first.

Consumer Demand and Political Economy

The success of the novel meat alternatives ultimately hinges on their acceptance by consumers. Cooking and consuming meat is culturally rooted and not likely to change overnight. While plant-based meat products may appeal to vegetarians and vegans, only 5% of Americans identify as such. Analysts believe that companies must attract meat-eaters, which may be a tall order.

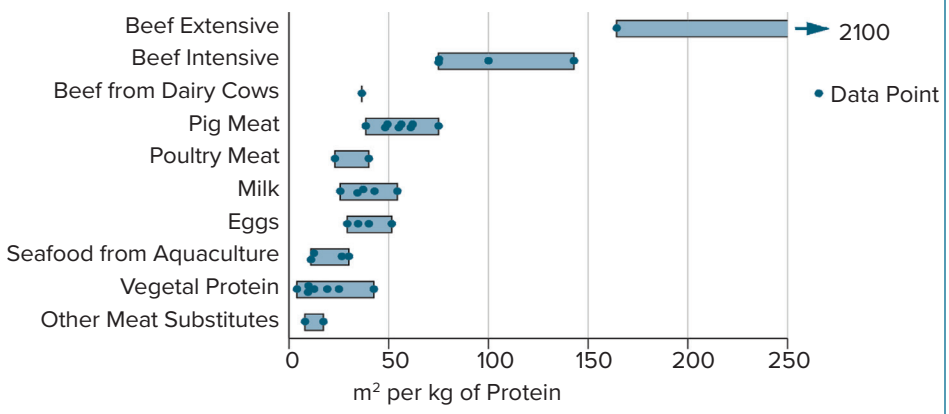
Plant-based burgers may be able to gain cost advantages as they perfect their processes, but they are challenged by meeting consumer perceptions and taste requirements. Even if plant-based meats can match real burgers on taste, it may take much effort to attract customers to try the product if they have negative attitudes towards vegan foods. Producers aimed to attract customers by making their products as cheap and ubiquitous as possible at fast-food outlets.

Thus far, Burger King increased total sales by adding the Impossible Burger, but there was no significant impact on the consumption of meat burgers. While Impossible Foods boasts that 90% of their customers are meat-eaters, it is not apparent that these consumers are substituting for meat or older meat alternatives like tofu or veggie burgers.

Many customers may try plant-based meats because they perceive them to be healthier, but while plant-based burgers are lower in cholesterol, they are still just as high in fat, calories, and sodium as the real thing. Plant-based alternatives are not able to provide the necessary amino acids found in beef. Also, there has been a backlash against these products by consumers who eschew highly processed foods. Advocates claim that plant-based diets are better for the environment and animal welfare, but such claims require further evaluation. On the surface, they may provide meat with lower GHG emissions and a smaller agricultural footprint. However, their claims do not consider GHG emissions from alternative land uses, and rangelands provide essential environmental services.

The meat industry is also responding to the threat of this technology. For example, the Real MEAT Act of 2019 requires labeling plant-based meat

Figure 2. Land Use per Kilogram of Protein



Source: Nijdam et al., 2012.

products as 'imitation' meat. In 2018, Missouri enacted a law requiring that only products that come from slaughtered animals can be marketed as meat. Furthermore, the listing of ingredients used in plant-based meats may raise consumer concerns about the alteration of natural foods.

Economics of the Industry

The plant-based meat market is experiencing an explosive growth rate. The market has been estimated to be worth $12.1 billion worldwide in 2019, with an annual growth rate of 15% and projected $27.9 billion sales by 2025. The Swiss investment banking company, UBS, forecasts that the market could grow to reach $85 billion by 2030. However, these projections are subject to much uncertainty.

The current price of plant-based meat is frequently more than twice as high as an equivalent meat. The Impossible Whopper produced by Burger King costs about 70% more than a regular Whopper. With the scale-up, improved supply chain, "learning by doing," and maturation of food technology, the price of the plant-based meat alternative and cultured meat is likely to go down. These products may become competitive on price due to smaller variable costs and improved technology. The plant-based meat alternative may enjoy a price advantage over conventional beef if and when there will be penalties for the GHG emissions of the production processes. However, we lack rigorous computation of whether and to what extent these technologies are reducing GHG emissions, taking into account land-use effects and life cycle analysis.

Figure 2 provides results of studies assessing the land-use effects of plant-based meats vs. traditional meats, suggesting that grain production for feed for meats is likely to be much bigger than production for animal-free meats that rely on legumes. Between pastures and cropland used to produce feed, 41% of U.S. land in the contiguous states revolves around livestock. Thus, animal feedstock acreage may decline—and lead to the emergence of alternative land uses such as biofuels, and some pasture land will revert to wild land. A large-scale switch from animal-based protein may slow deforestation and biodiversity loss in places like South America. Plant-based fish replacements could relieve pressure on wild stocks while feeding growing human demands at the same time, but it will increase demand for agriculture feedstock and agricultural land.

The new industry demands highly skilled workers who have advanced knowledge of chemistry and biology. The co-location of the high-tech talent pool ensures the adaptation of computational tools, including artificial intelligence, in the early phase of product development. These new technologies will require a well-compensated, high-skilled workforce, but reduce demand for agricultural labor in both grain and livestock production, and may negatively affect the economies of rural areas both domestically and globally.

Summary

Plant-based meat is only in its infancy. If consumers will accept it as a close substitute for meat, its seemingly lower input requirements, and GHG emissions contributions, it will change the structure of agribusiness, the economics of food and agriculture and rural regions, and the environmental impacts of food and agricultural production. Assessing these changes and developing policies to impact them will be the subject of substantial future research.

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For additional information, the authors recommend:

Nijdam, D., T. Rood, and H. Westhoek. "The Price of Protein: Review of Land Use and Carbon Footprints from Life Cycle Assessments of Animal Food Products and their Substitutes." *Food Policy* 37 (6) (2012):760-770.