Alternative meats and alternative facts

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Abstract

The alternative animal product arena is complex and quite varied. Some plant-based alternative meat products are derived entirely from plants. Other entrepreneurs are using cultivated cells of animal origin to derive a product structurally similar to meat and milk and comprised of animal proteins. Many of these endeavors use a combination of both approaches with the plant-based product providing filler for the cultivated meat or milk product. Most of the discussion around alternative meats has focused on bovine alternatives because of the iconic position of cattle in many climate and sustainability discussions. A considerable amount of capital has been raised based on the

envisioned market share of these products, although estimates vary widely, and the high profile initial public offering of Beyond Meat shares in May 2019 which saw share prices soar from $75 to $235, has this year seen share prices plummet to about one-tenth of that highest price. Proponents of alternative meats suggest these production systems are more sustainable based on anticipatory greenhouse gas emission (GHG) and land use life-cycle assessment (LCA)/kilogram (kg) of product, as compared to LCA metrics for ruminant meat. Much of the rationale

invokes a simplistic narrative around GHG/kg of protein. The GHG "sustainability" metric will invariably reflect poorly on ruminants as they are uniquely able to digest cellulose through their rumen microbes, and the methanogens produces methane which is a potent but short-lived greenhouse gas. And because ruminants are typically grazing in marginal land unsuitable for producing crops, they also have a high land use m2/kg of protein. However, there is no reason to conclude that food production on well-managed pasture and rangeland is, a priori, less sustainable than food production of well-managed arable cropland. Moreover, the other sustainability externalities of ruminant meat production systems such as the provision of ecosystem services and biodiversity conservation, the consumption of inedible food waste and cellulose, manure, transportation, contributions to the livelihoods and food security of 1.3 billion livestock keepers, the fact that meat provides nutrients in addition to protein, and that existing harvesting systems utilize everything but the "moo" are often ignored or simply disregarded.

Key words: sustainability, alternative meat, culture meat, plant-based meat, greenhouse gas (GHG) emissions

Plant-based meats

There are two "alternative meat" sources that are often confused. One is so called "plant-based" or "vegan" meat replacements (e.g. Beyond Burger). These types of "veggie" burgers have been around a long time (e.g. Morningstar Farms®, Boca Burgers), and now have some bells and whistles like genetically-engineered heme to make them bleed (e.g. Impossible™ Burger), but at the end of the day, they consist of plant-sourced material being molded into a meat substitute product. Impossible Burger received U.S. Food and Drug Administration safety approval for its genetically- engineered heme as a color additive in its ground beef analogue products. Plant-based burgers are currently being sold at some fast food restaurants, and in supermarkets. According to a May 2019 Barclay's report, 2018 meat substitute sales were valued at $1.3 billion which was about 4% of all U.S. meat retail sales ($270 billion). The annual retail value of the frozen/refrigerated meat sector is $15 billion, of which $700 million (~5%) was meat

alternatives. MorningStar Farms (owned by Kellogg's®) is the largest company in this space with $292 million in sales. There are also nut and legume plant-based milks (soy, almond, hemp, coconut, oat, etc.). In 2018, plant-based milk substitutes represented 13% ($1,932 million) of U.S. milk category retail sales, although only 5% of the volume.

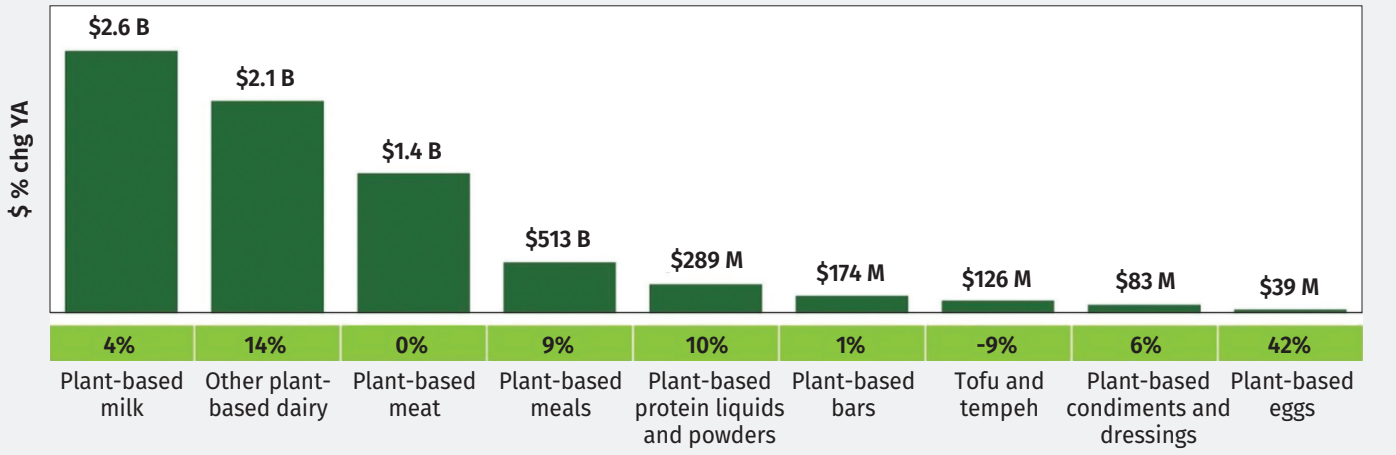
U.S. retail sales of plant-based food grew 6.2% to $7.4 billion in 2021 vs 2020. While most major categories such as plant-based milk and eggs reported positive growth in 2021, growth of the plant-based meat sector was flat with $1.4 billion in sales for 2021, and accounted for just 2.7% of total packaged meat sales (Figure 1). While alternatives to milk and other dairy have captured about 15% of total sales, sales of vegan meat products have barely scratched the surface of total meat volume, comprising less than 1% of all meat consumed in the U.S.[1]

Cultured meats

Plant-based or vegan meats are different to cultured meat, which is the term used to refer to animal cells grown in cell culture. This technology has other terminology – some appealing (e.g., in vitro meat, cellular meat, fermented meat, or slaughter- free meat, clean meat), and some derogatory (e.g. artificial meat, synthetic meat, zombie meat, lab-grown meat, non-meat, or artificial muscle proteins). This is discussed in my article "Why cows are getting a bad rap in lab-grown meat debate"2 which appeared in The Conversation. Cultured meat requires the initial collection of stem cells from living animals and then greatly expanding their numbers in a bioreactor, a device for carrying out chemical processes. These living cells must be provided with nutrients in a suitable growth medium containing food-grade components that must be effective and efficient in supporting and promoting muscle cell growth. A typical growth medium contains an energy source such as glucose, synthetic amino acids, antibiotics, fetal bovine serum, horse serum and chicken embryo extract. Some of these components are problematic for consumers wishing to avoid animal products. The status quo for culturing tissue involves the use of fetal bovine serum, a byproduct of the livestock industry collected from fetuses in pregnant cows that are being slaughtered. Large uncertainties remain as to what a viable, animal-free, growth media may look like.[3] If cultured meat is to match or exceed the nutritional value of conventional meat products, nutrients found in meat that are not synthesized by muscle cells must be supplied as supplements in the culture medium. Conventional meat is a highquality protein, meaning it has a full complement of essential amino acids. It also provides a source of several other desirable nutrients such as vitamins and minerals, and bioactive compounds.

Therefore, to be nutritionally equivalent, cultured meat medium would need to provide all of the essential amino acids, along with vitamin B12, an essential vitamin found solely in food products of animal origin. Vitamin B12 can be produced by microbes

Figure 1: Value ($USD) of U.S. plant-based food retail sales in 2021 by product type, and percent change from 2020 (Food Navigator, and Good Food Institute).[1] $ % chg YA – absolute change vs. year ago.



in fermentation tanks, and could be used to supplement a cultured meat product. It would also be necessary to supplement iron, an especially important nutrient for women of reproductive age.

The process for making cultured meat has technically challenging aspects. It includes manufacturing and purifying culture media and supplements in large quantities, expanding animal cells in a bioreactor, processing the resultant tissue into an edible product, removing and disposing of the spent media, and keeping the bioreactor clean. Each are themselves associated with their own set of costs, inputs and energy demands. Cultured meat production will likely require more industrial energy than do livestock to produce equivalent quantities of meat. The reason for this is that all of the biological structures not involved in cellular agriculture play important roles in meat production. An animal's skin regulates temperature; internal organs digest food, circulate nutrients, and distribute oxygen;

and the immune system destroys pathogens. When meat is grown in a bioreactor, all the same functions must still be accomplished, but at the expense of industrial energy. A bioreactor regulates temperature, food is predigested and fed to cells as simple sugars and amino acids, oxygen is pumped into the bioreactor, and all equipment is sterilized to prevent the growth of pathogens. Hence, a shift from livestock production to cellular agriculture could be a transition toward greater reliance on industrial energy.

One study concluded that "in vitro biomass cultivation could require smaller quantities of agricultural inputs and land than livestock; however, those benefits could come at the expense of more intensive energy use as biological functions such as digestion and nutrient circulation are replaced by industrial equivalents".[4]

Who has invested in alternative meats?

Plant-based burger producer Beyond Meat® is sometimes known as the "Bill Gates-backed veggie burger" in the press. Leonardo DiCaprio is also a funder of Beyond Meat. Tyson took a 5% stake in this plant-based vegan meat replacement in 2016, but sold it in April 2019. Beyond Meat had its initial public offering (IPO) in May 2019, and its shares have increased in value ~8-fold. Beyond Meat shares fell sharply in trading July 29, 2019, following news that the company would embark on a secondary offering of 3.25 million shares only 3 months after its IPO. That report followed the release of mixed second-quarter results and a raised 2019 revenue forecast. It was reported that shareholders planned to sell 3 million shares, while 250,000 shares would be offered by the company itself. Based on a value of $222.13 per share in July 2019, the offering could raise $721.9 million for Beyond Meat and its selling shareholders. According to a July 2019 report by CNBC, Beyond Meat CEO Ethan Brown planned to sell 39,130 shares, which could net him $8.7 million. CFO Mark Nelson planned to sell 55,530 shares, potentially earning him $12.3 million. Since May 2019, the stock value has dropped below its $75 IPO valuation to around one-third of that amount (Figure 2). Part of the recent drop in stock prices was due to a July 2022 announcement by McDonald's® that they will end the pilot program for McPlant™ which used Beyond Meat plant-based patties. An early report from BTIG analysts Peter Saleh and Ben Parente found that the McPlant was only selling about 20 sandwiches per day in many test markets in California and Texas.

Stock of Beyond Meat (BYND) dropped by more than 6% immediately after the announcement was made. In July 2019, Beyond Meat was valued at nearly $15 billion. Now it's just under $2 billion. The alternative meat market has already had a rough 2022, falling by nearly 52% since the start of 2021.5 Impossible Foods vegetarian patties are featured in Burger King® plant-based burgers, and it has raised investments of $75 million and $108 million from companies including Google Ventures, Khosla Ventures, Viking Global Investors, UBS, Hong Kong billionaire Li Ka-shing's (Net Worth: $34.4 B) Horizons Ventures, and Bill Gates (Net Worth: $106B). In August 2017, $75 million in additional financing was raised after reaching key objectives, including additional money invested by Bill Gates.

In April 2018, an additional $114 million was raised, led by Singapore's Temasek Holdings and Hong Kong-based Sailing Capital, bringing the total to $372 million. In May 2019, the company raised $300 million of investment. In November 2021, Impossible Foods secured $500 million in funding, bringing its total raise to nearly $2 billion since its founding in 2011. The most recent deal valued the company at $7 billion. Stanford University biochemist and Impossible Foods founder Pat Brown handed over the CEO job to "professional manager," former Chobani® chief operating officer Peter McGuinness in April 2022. Brown

Figure 2: Beyond Meat (BYND:NASDAQ) share value over time since May 2019 IPO ($75) captured 9/6/2022.

is now known as the "chief visionary officer" and says he is committed to the same goal as always: eliminating animal meat by 2035.[6] Just for perspective, U.S. beef production alone is around 14 billion pounds – that is equivalent to 56 billion Quarter Pounders® annually if all beef was made into hamburgers.

In March 2017, Impossible Foods announced it would build its first large-scale plant in Oakland, Calif. to produce 1 million pounds of plant-based burger meat a month, i.e. 12 million pounds per year. It is unclear how the company plans to produce enough product to achieve its stated goal of displacing allanimal meat by 2035.

In 2021, Colorado-based Meati™ revealed it had secured $150 million to build a new 80,000 sq. ft. factory. When complete, the facility will be in a position to manufacture tons of its proprietary fungi-based meat alternative. The company estimates its products require less than 1% of the land and water of traditional beef ranching. Similarly, Zikooin announced it is building one of the biggest plant-based protein factories in the whole of Asia. Twenty-three million dollars was raised to support construction of the new 95,800 sq. ft. facility. The location is due to open later in 2022.

The global market for plant-based substitutes is projected to reach $24.8 billion (USD) by 2030,5 up from $4.6 billion in 2018,[7] which at the time was less than 1% of the $1.4 trillion global market. In June 2019, Tyson Foods announced a plan to expand its line of plant-based meat alternatives, including the launch of a new brand devoted solely to those products. According to Forbes,[5] 2021 was the first year there was a decrease in investment in plant-based startups. The sector raised $2.1 billion in 2020, according to the Good Food Institute, and $1.9 billion in 2021. Deal-making has slowed even further in 2022. When it comes to cultured meat, venture capital funds are funding startups in California, Israel and the Netherlands. Some of the first work in this area was done by Mark Post at Maastricht University in the Netherlands to produce the proofof- concept burger featured at the August 2013 £250,000 (US $330,000) lab-grown burger unveiling event in London.[8] According to an article by Mouat and Prince,[9] "Before the hamburger event, the mystery benefactor that financed the burger was unknown." Later it was revealed that the funder was Google co-founder Sergei Brin (Net Worth: $53.8 B). The event was simulcast on the web and included a celebrity chef live-cooking the burger, a 3-person tasting panel, and a live studio audience.[10] At this event, Post estimated that if the process can be scaled up it would take 10-20 years to produce "beef", likely still at relatively high cost.[11] Memphis Meats made meatballs from cultured meat at $18,000 per pound in 2016.12 Somewhat ironically given the environmental footprint of airplane travel, Virgin Airlines founder Richard Branson (net worth: $3.8 B) joined Bill Gates in financing cultured meat leader Memphis Meats in part of a $17 million fundraising round in 2017. Ground beef is not the only product that is being attempted in cell-based culture. There are a number of companies springing up making everything from ice-cream to egg whites to cowless milk. In 2014, Perfect Day (Muufri prior to August 2016) was offered USD $2 million in seed money from Horizons Ventures. According to Mouat and Prince,9 one of the partners at Horizons Ventures, Li Ka-shing "loves disruptive innovations and

sees it as kind of predictive lenses into the future. He loves to meet and geek with the founders and CEOs of companies within our disruptive portfolio, to understand their concepts and missions." Horizons Ventures have also invested in Facebook, Spotify, Skype, Modern Meadow (lab-grown leather for disrupting the $90 billion per year leather industry) and New Harvest, a 501(c)(3) research institute accelerating breakthroughs in cellular agriculture, that collects and directs charitable donations and grants in the industry. There is no doubt that "the association of this iteration of biological technology with super-rich celebrity investors and venture capital is significant."[9] Next to venture capital funds, large corporations such as Cargill, Merck, Google, UBS and PHW Group have invested in these companies. Cargill invested in Memphis Meats. The Good Food Institute, a non-profit that promotes plant-based and cultured meat alternatives to meat, dairy, and eggs, estimated that in the 5 years leading up to 2018, $17.1 billion had been invested in plant-based food, with a further $73.3 million in cell-based meat companies.

Who is selling cultured meat?

Nobody has yet produced an edible cultured meat product at scale. But the concept is being sold hard, especially by think tanks and venture capitalists. According to a June 2019 report by consulting firm A.T. Kearney,[7] they predicted that "In 20 years, only 40% of global meat consumption will still come from conventional meat sources." They posited that "Cultured meat will win in the long run. However, novel vegan meat replacements will be essential in the transition phase." They estimated that by 2040 cultured meat will make up 35% of the global "meat" market, while plant-based alternatives (e.g. Impossible, Beyond Burger) will comprise 25% (Figure 3).

On the other hand, the Food and Agriculture Organization (Reference) predicts that by 2040 there will be 402 million metric tons (MMT) of land-based meat consumed worldwide (169 chicken, 143 pork, 90 beef). That does not include eggs (98 MMT), fish (200 MMT), or milk (1,051 MMT). The total of animal-based products in 2040 is therefore predicted to be 1,751 MMT (compared to 1,430 MMT in 2020).

Doing the simple math, and assuming that 25% of the 402 MMT of land-based meat production is replaced with "quarter pounders" of the plant-based alternative, that would be([.25 × 402 MMT] × [1,000,000,000/0.1133981]) = 886,258,235,367 plant-based burgers produced in 2040. Replacing 35% of 402 MMT of meat would take (.35 x 402 MMT) × (1,000,000,000/0.1133981) = 1,240,761,529,514 cultured meat burgers in the year 2040. That is a big ask in 20 years for an industry that does not yet have a single product on the market!

In September 2019, a team of "technology, finance and market sector experts" forecast that, "By 2030, the number of cows in the U.S. will have fallen by 50% and the cattle farming industry will be all but bankrupt. All other livestock industries will suffer a similar fate".[13] Others like Barclays are not so bullish on the growth, and think that collectively plant-based and cultured meat might take more like a 10% of global market share by 2029, similar to the portion of the U.S. milk market currently occupied by plant-based milks. According to an Acumen Research and Consulting report,14 the cultured meat market size was US $134 million in 2021, whereas an Allied Market Research reports estimated it to be only $1.64 million.[15] Some prominent players in the global cultured meat market include: Aleph Farms Ltd., Avant Meats Company Limited, Balletic Foods, Bluenalu, Inc., Biofood Systems LTD., Finless Foods Inc., Fork & Goode, Future Meat Technologies Ltd., Higher Steaks, Integriculture Inc., Lab Farm Foods, Meatable, Upside Foods (formerly Memphis Meats), Mission Barns, Mosa Meat, New Age Meats, Shiok Meats, Supermeat and Wild Type.

Who is buying cultured meat?

Nobody yet, at least as far as cultured meats go. In 2020, Singapore approved sale of U.S. California-based start-up Eat Just's lab-grown "chicken" meat. This blended product (meaning it contains some cultured chicken cells and plant-based filler) is being sold at the "1800" restaurant and social club for $23. Eat Just is a California-based company developed by vegan mayo and liquid egg creator Josh Tetrick, who has been dubbed the "Elon Musk of Condiments".[16]

According to their June 2021 press release, Future Meat Technologies opened of the world's first industrial cultured meat facility with the capability to produce 500 kg of cultured products a day. According to the press release, the facility can produce cultured chicken, pork and lamb without the use of animal serum or genetic modification (non-GMO) with the production of beef coming soon. The company plans to introduce hybrid products into the market, combining plant proteins for texture with cultured fats to create the aroma and flavor of meat. While existing costs are $150 per pound of chicken and $200 per pound of beef, it aims to market its hybrid (i.e. blended with plant filler) products at a "competitive cost level" from its pilot production facility by this year 2022. At the time of printing, no products were available for purchase.

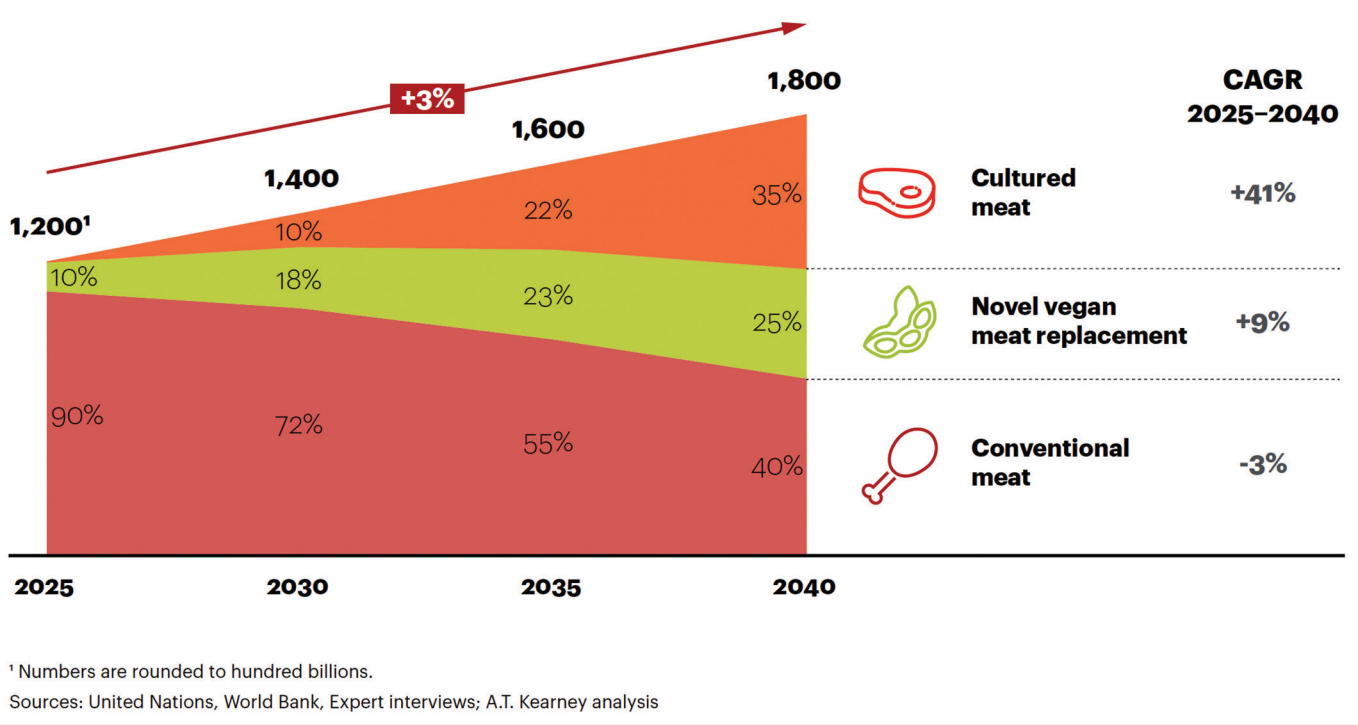
In October 2020, plans to build an alternative protein production facility in Singapore to serve the Asian market were announced. Mung-bean-based whole egg substitutes and cultivated meat products will be manufactured at the plant. Singapore has now approved two cultivated chicken products, branded as GOOD Meat. And, in November 2021, Upside Foods opened EPIC, a 53,000-sq. ft. cultivated meat production facility in Emeryville, Calif. designed to produce any species of meat, poultry and seafood - directly from animal cells.

Greenhouse gas emissions (GHGs)

Much of the rationale behind alternative meats invokes a simplistic narrative around greenhouse gas emission/unit weight of product. This is used to contrast cultured/alternative meats negatively against ruminant products – especially beef. Figure 4 shows a comparison of different sources of protein and the greenhouse gas emissions/kg of protein. This functional unit i.e. kg of protein – doesn't consider other micronutrients embodied in meat, nor protein quality. Many authors do this type of calculation using the weight of the product at the functional unit which doesn't make a lot of sense. A pound of lettuce clearly has a vastly different nutritional profile to a pound of beef.

A typical pattern can be seen in Figure 4 –beef and sheep, as ruminants, have higher global warming/kg of protein because they ruminate and produce methane which goes into the GWP100 metric which makes them high relative to their monogastric comparators – pork and poultry. Invariably, insects, pulses (legumes with high levels of oil in their seeds), and spirulina (an algae) are lowest on all of these metrics. If you're really concerned about the environment, then these products are what you should be eating. But, in general, there isn't a huge difference in terms of GHG/unit of protein between these products and monogastric products (i.e. pork and poultry). In the ruminants, you see a big number. That is because

Figure 3: Projected breakdown of global meat production by 2040 according to a June 2019 A. T. Kearney[7] Analysis. The compound annual growth rate (CAGR) is the rate of return (RoR) that would be required for an investment to grow from its beginning balance to its ending.



they are consuming cellulose. There isn't any way to get around that. This metric is inherently high for ruminants. There is also some discussion of using metrics other than the GWP100 calculation (e.g. GWP*)18 based on the fact that methane is a short-lived GHG in that it breaks down more quickly (10 yr) as compared to CO2 (1,000 yr), and so it shouldn't be weighted as heavily as it is in the GWP100 calculation.

Land use

Ruminants graze on more land when compared with the area of crop land required to grow feed for monogastrics (Figure 5). This land usage metric is also an awkward metric for pastoral systems because not all land is arable. This metric is inherently slanted against extensive, rangeland-based production systems. There is no reason to conclude that food production on well-managed pasture and rangeland is less sustainable than food production of well-managed arable cropland. The former achieves lower yields and therefore requires more land/unit of production. Is the alternative that all animal products should be produced using feed produced on the most intensive production systems on arable lands? Or, is there a benefit to having extensive pasture and rangeland systems that capture carbon? Which sustainability metrics are being optimized? Livestock production, especially extensive cattle grazing, maintains various habitats and species and can be beneficial for biodiversity. Tuomisto[17] writes "a complete elimination of all livestock production is not reasonable from the perspective of biodiversity conservation. Another argument for the importance of livestock in sustainable agricultural systems is their role in nutrient recycling and the ability to utilize plants that humans cannot consume as food".

Energy use

And finally, comes energy – where the picture changes a little for cultured meats and meat substitutes too – and the impacts will vary depending upon whether the source of energy can be decarbonized. I am not going to dwell on this one environmental metric because the discussion needs to be more complex than this, but at the current time, electricity and factories have a large carbon footprint in the U.S. Until power is decarbonized, cultured meat may be substituting so-called "factory farming" for another undertaken in an actual factory with no net benefit in GHG/unit of product.

Mattick, et al.[4] writes of cultured meat, "These energy dynamics may be better understood through the analogy of the Industrial Revolution: Just as automobiles and tractors burning fossil fuels replaced the external work done by horses eating hay, in vitro biomass cultivation may similarly substitute industrial processes for the internal, biological work done by animal physiologies." Meaning external energy sources will be used to replace the work of the biological processes that take place in the cow. The authors continue, "That is, meat production in animals is made possible by internal biological functions (temperature regulation, digestion, oxygenation, nutrient distribution, disease prevention, etc.) fueled by agricultural energy inputs (feed). Producing meat in a bioreactor could mean that these same functions will be performed at the expense of industrial energy, rather than biotic energy. From this perspective, large-scale cultivation of in vitro meat and other bioengineered products could represent a new phase of industrialization with inherently complex and challenging trade-offs."

Figure 4: The greenhouse gas emissions (CO2eq100/kg protein) of different protein sources.[17]

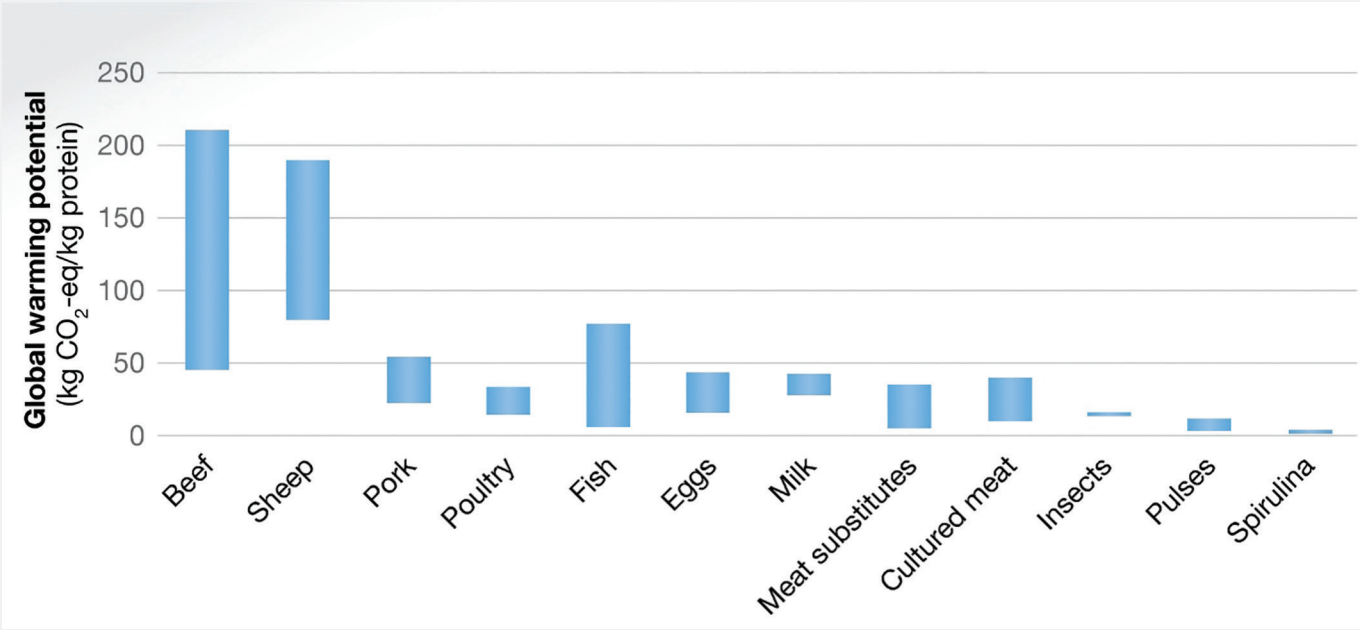
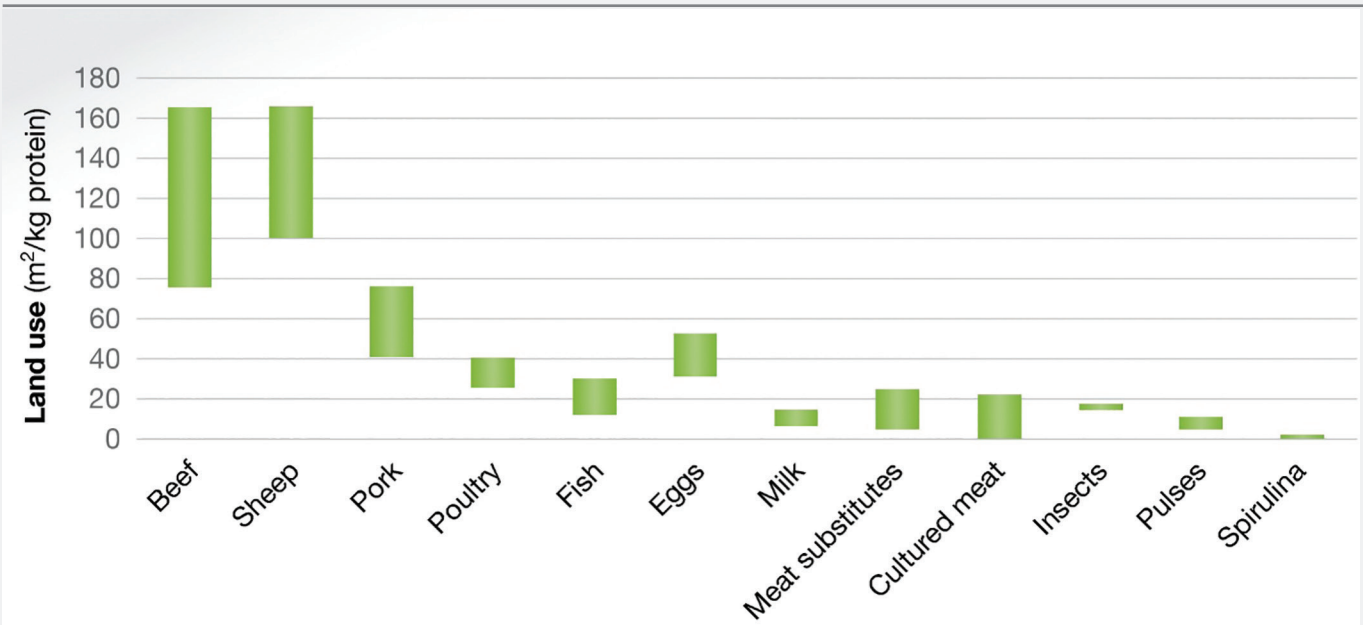


Figure 5: The land use (m2/kg protein) of different protein sources.[17]



Some other thoughts

As with all "disruptive innovations", there is a need to consider the pros and cons of the system that is being proposed as compared to the existing system. There will always be tradeoffs, some good, some bad. Some of the nuances that seem to be lacking in the discussion around cultured meats is that proponents tend to use the worst possible life-cycle assessment (LCA) metrics, often from a single study related to extensive animal protein production in terms of GHG emissions, land and water use to justify their solution, based on anticipatory LCA figures for a system that is not yet operational. The positive externalities of ruminants such as ecosystem services, consumption of inedible food waste and cellulose, manure, transportation, the livelihoods and food security of the 1.3 billion livestock keepers, the fact that cows produce more than just hamburgers, and that existing harvest systems utilize everything but the "moo".

Globally, animal agriculture is estimated to account for 14.5% of anthropogenic GHG emissions which can be broken down into beef (5.9%), cattle milk (2.9%), pork (1.3%), buffalo milk and meat (1.2%), chicken meat and eggs (1.2%), and small ruminant milk and meat (0.9%).19 In the U.S., all of agriculture was responsible for 9.9 % of the total U.S. GHG emissions in 202020, although this was a bit of an exceptional year as there was an 11% decrease in CO2 emissions from fossil fuel combustion as

Figure 6: The energy use (MJ/kg protein) of different protein sources.[17]

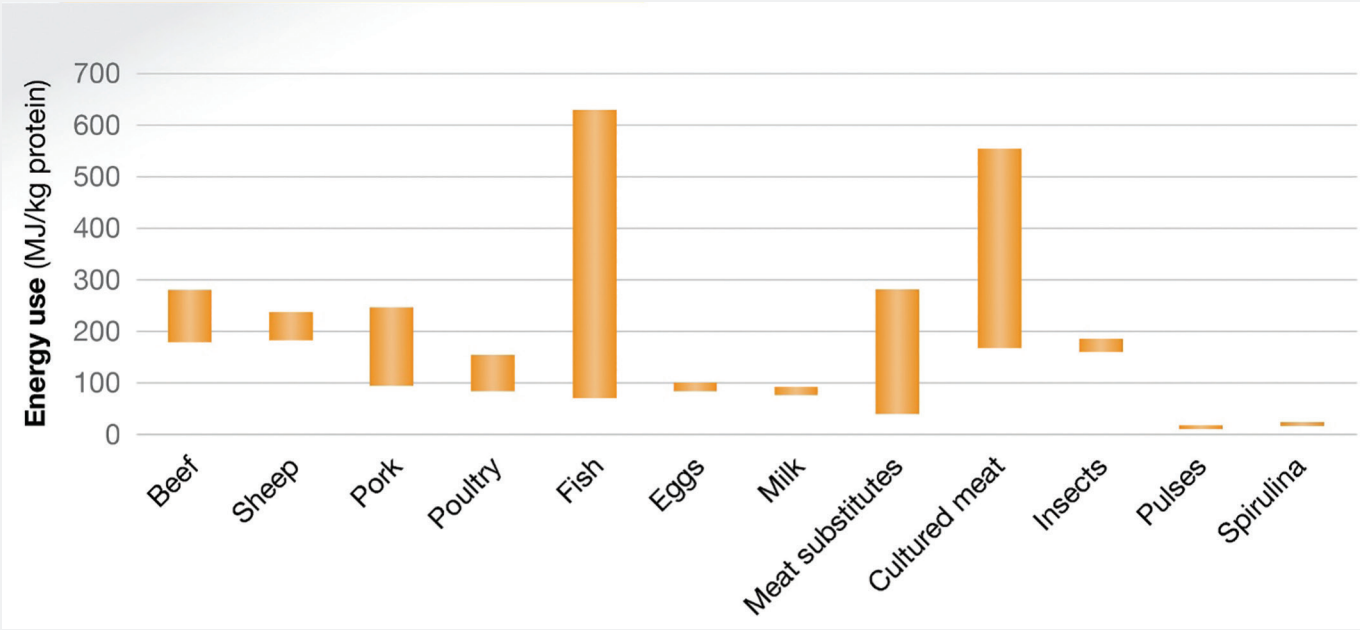
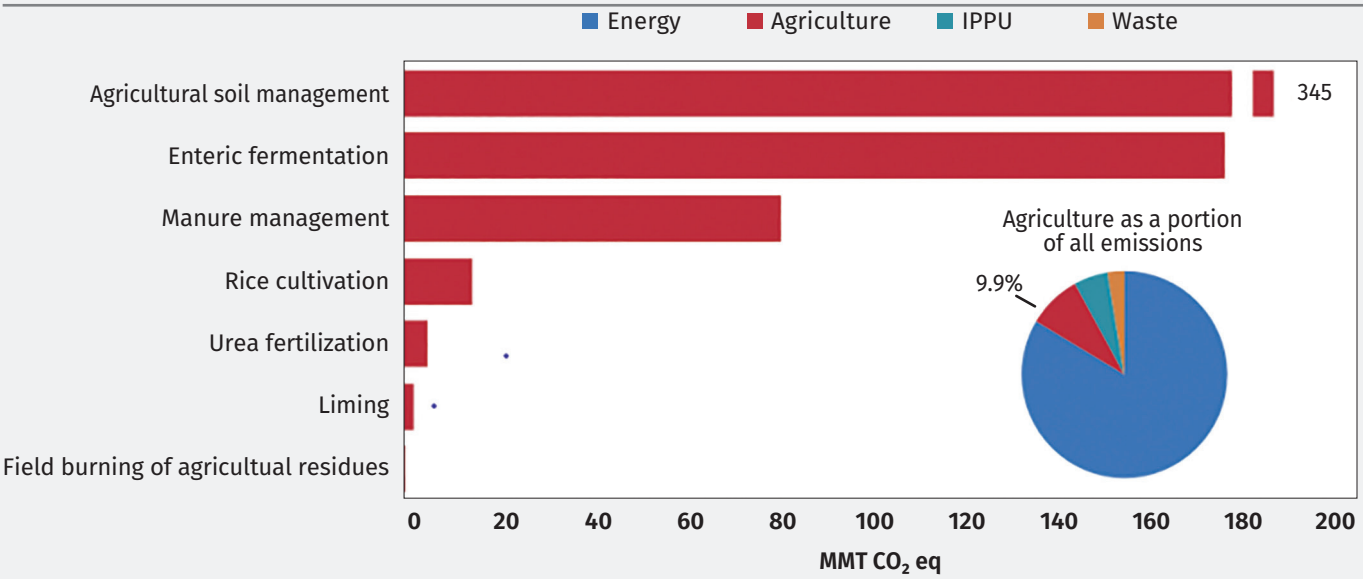


Figure 7: US Agricultural Sector Greenhouse Gas Emission Sources 2020.[21]



a result of the Covid-19 pandemic. Fossil fuel-based energy is responsible for over 80% of total U.S. GHG emissions, as compared to slightly less than 4% from animal agriculture. To put this in perspective, it has been estimated that eliminating all of U.S. animal agriculture would decrease U.S. GHG by 2.6%, but would also create a food supply incapable of supporting the U.S. population's nutritional requirements.[22]

Summary

"Plant-based" or "vegan" meat replacements are products derived entirely from plants and vegan additives. Conversely, cultured meat is a term used to describe imitating a range of animal products from animal cells grown in a bioreactor. In 2021, alternatives to milk and other dairy captured about 15% of U.S. total sales whereas alternative meat products comprised < 1% of total meat volume consumed in the U.S. Although there is a lot of venture capital and celebrity investor buzz around these technologies, there is no company that is currently selling cultured meat at scale. There are a number of unknowns about the feasibility of large-scale animal tissue culture, and the true environmental impact of using energy to replace the biological functions carried out by the body of an animal (harvesting forage for energy and growth, waste removal, fighting off disease, etc.). Growing animal cells efficiently and keeping contaminants out of the system and end product requires attentive management and innovation, whether meat is produced in

a biotic system that is powered by solar energy and the physiology of a cow, or an industrial system using electricity and a bioreactor to produce cultured meat in a manufacturing plant.

References

1. Shoup ME. Plant-based food sakes: Plant-base meat sales stall while eggs, yogurt, and cheese gain ground. 2022; **https://www.foodnavigator-usa.com/Article/2022/03/25/Plant-based-foodssales-Plant-based-meat-sales-stallwhile-eggs-yogurt-andcheese-gain-ground-GFI-SPINS-PBFA#.**

2. Van Eenennaam AL. Why cows are getting a bad rap in lab-grown meat debate. **https://theconversationcom/why-cowsare-getting-a-bad-rap-in-lab-grown-meat-debate-103716 2018.**

3. Stephens N, Di Silvio L, Dunsford I, et al. Bringing cultured meat to market: Technical, socio-political, and regulatorychallenges in cellular agriculture. *Trends Food Sci Technol* 2018;78:155-166.

4. Mattick CS, Landis AE, Allenby BR, et al. Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States. *Environ Sci Technol* 2015;49:11941-11949.

5. Sorvine C. Lifeless Market for Meatless Meat. 2022; **https://www.forbes.com/sites/chloesorvino/2022/06/18/lifeless-market-for-meatless-meat.**

6. CNBC.com staff. 49. Impossible Foods. 2022; **https://www.cnbc.com/2022/05/17/impossible-foods-disruptor-50.html.**

7. Kearney AT. How Will Cultured Meat and Meat Alternatives Disrupt the Agricultural and Food Industry? **https://wwwatkearneycom/retail/article/?/a/how-will-cultured-meatand- meat-alternatives-disrupt-the-agricultural-and-foodindustry 2019.**

8. Post MJ. Cultured meat from stem cells: Challenges and prospects. *Meat Sci* 2012;92:297-301.

9. Mouat MJ, Prince R. Cultured meat and cowless milk: on making markets for animal-free food. *J Cult Econ* 2018;11:315-329.

10. Murray A. Meat cultures: Lab-grown meat and the politics of contamination. *BioSocieties* 2018;13:513-534.

11. Post MJ, Levenberg S, Kaplan DL, et al. Scientific, sustainability and regulatory challenges of cultured meat. *Nat Food* 2020;1:403-415.

12. Swerdloff A. No Animals Were Harmed in the Making of this $1,000 Meatball. **https://wwwvicecom/en_us/article/jpkgy8/noanimals-were-harmed-in-the-making-of-this-18000-meatball 2016.**

13. RethinkX. Rethinking Food and Agriculture 2020-2030: The Second Domestication of Plants and Animals, the Disruption of the Cow, and the Collapse of Industrial Livestock Farming. **https://wwwrethinkxcom/food-and agriculture 2019.**

14. Acumen Research and Consulting. Cultured Meat Market to Reach US$ 517 Million by 2030 - Exclusive Report by Acumen Research & Consulting. 2022; **https://www.globenewswire.com/en/news-release/2022/06/14/2462113/0/en/Cultured-Meat-Market-to-Reach-US-517-Million-by-2030-Exclusive-Report-By-Acumen-Research-Consulting.html.**

15. Kamble A, Deshmukh R. Cultured Meat Market by Type (Red Meat, Poultry and Seafood), End User (Household and Food Services: Global Opportunity Analysis and Industry Forecast 2022–2030. 2021; **https://www.alliedmarketresearch.com/cultured-meat-market-A06670.**

16. Smith K. VeganMayo and Liquid Egg Creator Josh Tetrick Dubbed The 'Elon Musk of Condiments'.2018; **https://www.livekindly.com/vegan-mayo-egg-josh-tetrick-elon-musk-condiments/.**

17. Tuomisto HL. The eco-friendly burger. EMBO Reports 2019;20:e47395.

18. Allen MR, Shine KP, Fuglestvedt JS, et al. A solution to the misrepresentations of CO 2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. *Npj Clim* 2018;1:1-8.

19. Gerber PJ, Steinfeld H, Henderson B, et al. Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities: Food and Agriculture Organization of the United Nations (FAO), 2013.

20. United States Environmental Protection Agency. Sources of Greenhouse Gas Emissions. 2020; **https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.**

21. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. 2022. Chapter 5. Agriculture Sector Greenhouse Gas Emission Sources. **https://www.epa.gov/system/files/documents/2022-04/us-ghg-inventory-2022-chapter-5-agriculture.pdf**

22.White RR, Hall MB. Nutritional and greenhouse gas impacts of removing animals from U.S. agriculture. *Proc Natl Acad of Sci* 2017;114:E10301-E10308.

