Alternative meats and alternative statistics: What do the data say?

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OVERVIEW ON THE TECHNOLOGY

The alternative animal product arena is complex and quite varied. Some products are entirely plant product derived and employ only plant origin proteins or metabolites. Other endeavors are using cells of animal origin to derive a more structurally similar meat yet still with animal genomes. Most of the analysis and discussion, though, has focused on bovine alternatives because of the iconic position of cattle in many climate and sustainability discussions.

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 type product. They are currently being sold at some fast food restaurants, and in supermarkets. Impossible Burger recently received safety approval for its genetically engineered heme as a color additive in ground beef analogue products, opening the way for its sale in supermarkets.

These are DIFFERENT to cultured meat, which is the term I am going to use today 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" (Van Eenennaam, 2018) 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 in what a viable, animal-free, growth media may look like (Stephens et al., 2018).

If cultured meat is to match or exceed the nutritional value of conventional meat products, nutrients found in meat not synthesized by muscle cells must be supplied as supplements in the culture medium. Conventional meat is a high-quality 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 B_{12}, an essential vitamin found solely in food products of animal origin. Vitamin B_{12} can be produced by microbes 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 woman of reproductive age that is also high in beef.

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 is that all of the biological structures avoided 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" (Mattick et al., 2015).

The start-to-end environmental footprint – called a life cycle assessment (**LCA**) – of cultured meat at large scale is not available as no group has yet achieved this feat. I have tried to summarize the literature in Table 1 on the basis of kg of final product, but note there are differences in a kg milk versus a kg of beef, and even a two-fold difference in the assumptions made as to the protein content of cultured meat. It is therefore close to impossible to do an apples to apples comparison. The values vary dramatically depending upon the assumptions made, and the boundaries of the LCA.

The functional unit (i.e. metric of the comparison) matters - whether kg carcass weight, kg product, kg of nutritional value (e.g., protein), and then of course the quality of that protein. Changes in the functional unit (**FU**) alters the results quite dramatically, and therefore, the development of a FU which would reflect the complete integrative nutritional function of meat substitute is needed. It is obvious that meat substitutes have different nutritional profiles and, therefore, nutritional value. At the same time, different aspects of nutritional quality (protein and amino acid content, vitamins, fat and fatty acids, etc.) vary in different proportion in meat substitutes. Therefore, it is necessary to develop a complex nutritional value estimate, which would reflect the qualities of meat and meat substitutes for further studies.

Some general rules always apply: the carbon footprint per kg product increases as you go from one tropic level to the next (i.e. plants to animals that eat plants), and from monogastrics to ruminants (chickens/pigs to cattle and sheep). However, ruminants can eat forage than monogastrics, humans included, cannot. Ruminants consume byproducts (e.g. distiller's grains) and crop residues (e.g. almond hulls) that would otherwise go to waste or into landfills.

Eighty-six (86%) of the global livestock feed DM intake consists of feed materials that are not human edible. Producing 1 kg of boneless meat requires an average of 2.8 kg human-edible feed in ruminant systems and 3.2 kg in monogastric systems (Mottet et al., 2017).

Table 1. Carbon Footprint CO_2-eq, land use (m^2), and energy use (MJ) per kg product for different products in a number of different studies. *Qantis (https://quantis-intl.com/).

Product (Number of studies)	**per kg product (not necessarily nutritionally equivalent)**			
	Carbon Footprint CO_2-eq	**Land use (m^2)**	**Energy Use (MJ)**	**Reference**
Beef (15)	**9-129**	7-420		(Nijdam et al., 2012)
Industrial systems (11)	9-42	15-29		(Nijdam et al., 2012)
Meadows, suckler (8)	23-53	33-158		(Nijdam et al., 2012)
Extensive pastoral systems (4)	12-129	286-420		(Nijdam et al., 2012)
Culled dairy cows (3)	9-12	7		(Nijdam et al., 2012)
Beef Burger	**30.6**	62		**Qantis***
	30.5-33	92-113	78.6-92.6	(Mattick, 2018)
	28.6			(Lynch and Pierrehumbert, 2019)
	42.45			(Lynch and Pierrehumbert, 2019)
	43.7			(Lynch and Pierrehumbert, 2019)
Mutton/lamb (4)	10-150	20-33		(Nijdam et al., 2012)
Milk (12)	1-2	1-2		(Nijdam et al., 2012)
Cheese (12)	6-22	6-17		(Nijdam et al., 2012)
Pigs (8)	4-11	8-15		(Nijdam et al., 2012)
	9			**Qantis***
	4.1-5	16-18	16-19.6	(Mattick, 2018)
	6.88	16.3	48	(Tuomisto and Teixeira de Mattos, 2011)
	14.25	16.6	37	
		22.4		
	8.46	20.4		
Poultry (4)	2-6	5-8		(Nijdam et al., 2012)
	6			**Qantis***
	2.3	9.5	26.6	(Mattick, 2018)
	8.9	20.5	23.2	Tuomisto and Teixeira de Mattos, 2011)
Eggs (4)	2-6	4-7		(Nijdam et al., 2012)
Seafood –fishery (18)	1-86	--		(Nijdam et al., 2012)
Seafood – aqua (7)	3-15	2-6		(Nijdam et al., 2012)
Impossible Burger	**3.5**	2.5		**Qantis***
Soy burger (1)	1-2	2-3		(Nijdam et al., 2012)
Soybeans	**2**			**Qantis***
Pulses (2)	1-2	3-8		(Nijdam et al., 2012)
Cultured Meat	1.69 (19% protein)	0.2	26.64	(Tuomisto and Teixeira de Mattos, 2011)
	3.67 (19% protein)			(Tuomisto et al., 2014)
	7.5 (7% protein)	4		(Mattick et al., 2015)
	25 (7% protein)	4		(Mattick et al., 2015)
	4-25 (7-19% protein)	2-8	50-359	(Lynch and Pierrehumbert, 2019)

It should also be noted that land use numbers in Table 1 do not differentiate between arable land, and land that has no other human food purpose. Many ruminants graze marginal land, or crop residues, and convert that otherwise inedible forage into milk and meat. Conversely, cellular meat will require the provision of food grade nutrients supplied directly to the cells growing in the bioreactor, and waste streams will need to be disposed of following production of the cultured product. The LCA of this aspect of cellular meat remains unknown.

It is worth noting that the very favorable cultured meat LCA (Tuomisto and Teixeira de Mattos, 2011), oft-cited by proponents of cultured meat, was funded by New Harvest, a non-profit research institute accelerating breakthroughs in cellular agriculture, and has been especially criticized for assuming cultured mammalian meat will be able to be grown using cyanobacteria hydrolysate as the nutrient and energy source for muscle cell growth, as this medium is more commonly used for yeast cells; and for ignoring the environmental impacts of growth factors and vitamins, as the cells cannot grow without these supplements and they are both difficult to isolate and synthesize (Ricky, 2014).

WHO HAS INVESTED IN CULTURED MEAT (& PLANT-BASED VEGAN MEAT)?

There has been more funding available for plant-based alternatives, referred to as "novel vegan meat replacement" brands in Figure 1, than there has for cultured meat companies

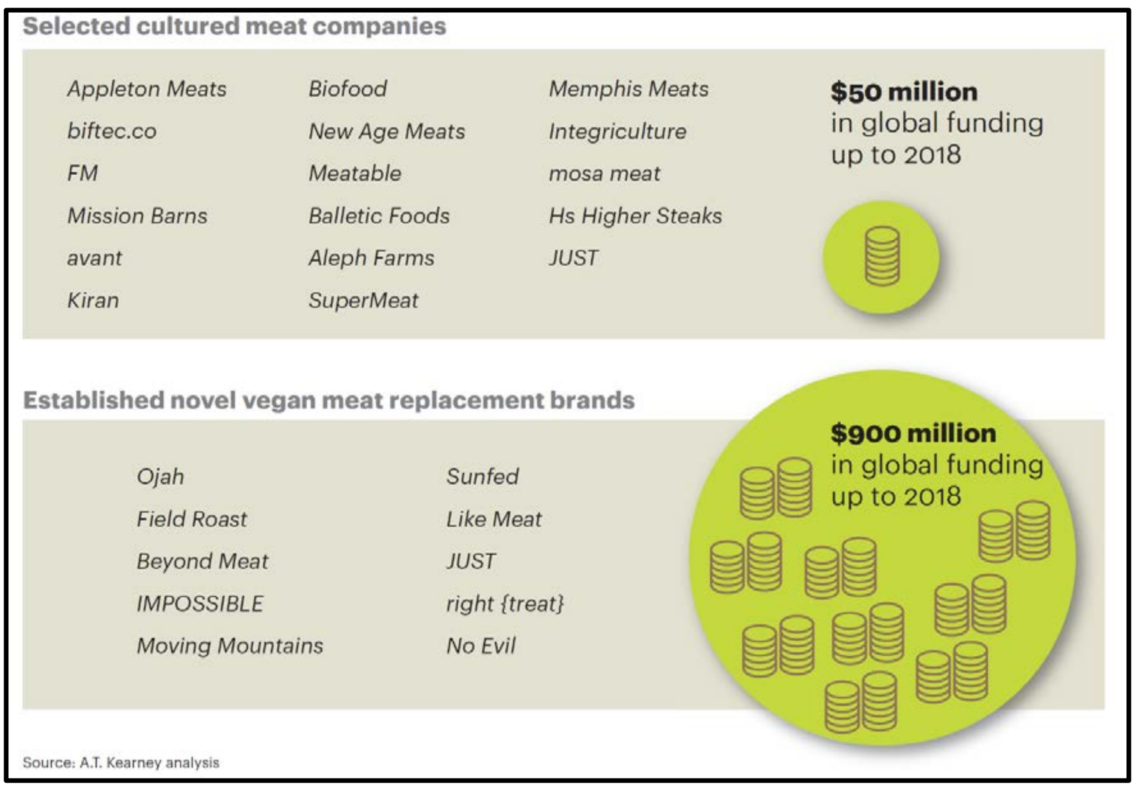

Figure 1. The meat replacement industry is attractive for venture capital. A.T. Kearney (2019).

Plant-based burger producer Beyond Meat is sometimes known as the 'Bill Gates backed veggieburger' in the press (Giammona, 2017). Leonardo DiCaprio is also a funder of Beyond Meat (Shieber, 2017). 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 in May 2019, and its shares have increased in value ~ 8 fold. Beyond Meat shares fell sharply in trading July 29^{th}, 2019 following news the company would embark on a secondary offering of 3.25 million shares only three 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 plan to sell 3 million shares, while 250,000 shares will be offered by the company itself. Based on value of $222.13 per share, the offering could raise $721.9 million for Beyond and selling shareholders. According to a July, 2019 report by CNBC, Beyond 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 (Lucas, 2019).

Impossible Foods has raised rounds of $75 million and $108 million from investors including Google Ventures, Khosla Ventures, Viking Global Investors, UBS, Hong Kong billionaire Li Ka-shing's (Net Worth: $29.4 Bn) Horizons Ventures, and Bill Gates (Net Worth: $105.4 Bn). In August 2017, $75 million in additional financing was raised after reaching key objectives, with Bill Gates investing additional money. 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. The total valuation of the company raised to $2 billion. The total market for plant-based meat alternative products was $4.6 billion in 2018 (A. T. Kearney Analysis), less than one percent of the $1,000 billion global market (this number does not include wholesale or resale). 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.

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 proof-of-concept burger (Post, 2012) featured at the August 2013 £250,000 (US $330,000) lab-grown burger unveiling event in London. According to an article by Mouat and Prince (2018), “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 Bn). The event was simulcast on the web and included a celebrity chef live-cooking the burger, a three-person tasting panel, and a live studio audience (Murray, 2018). 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 (Post, 2013).

Memphis Meats made meatballs from cultured meat at $18,000 per pound in 2016 (Swerdloff, 2016) Somewhat ironically given the environmental footprint of airplane travel, Virgin Airlines founder Richard Branson (Net Worth: $3.8 Bn) 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 (2018), 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 as mentioned previously Impossible Foods. There has also been some state investment in these technologies (Stephens, 2015).

A list of the companies I could find is in Table 2 using data from this list maintained at Cell based tech (https://cellbasedtech.com/lab-grown-meat-companies) among other media sources – along with their location and the product they are trying to mimic.

Table 2. Listing of companies formed to produce cellular animal-based products, and their location. Estimates of total capital raised is listed when known.

Company	Total Capital Raised	Location	Product
Aleph Farms	??	Israel	Meat (steak)
Appleton Meats	??	Canada	Beef (ground)
Avant	??	China	Meat (unsure of specifics)
Balletic Foods	??	USA	Meat (unsure of specifics)
Blue Nalu	$4.5 million	USA	Fish/seafood
Biftek	??	Turkey	Beef
Biofood systems	??	Israel	Beef
Bond Pet Food	??	USA	Pet food
Cubiq Foods	$13.6 million	Spain	Omega-3 fats
Finless Foods	$3.8 million	USA	Fish (bluefin tuna)
Future Meat Technologies	$14 million led by Tyson ventures	Israel	Chicken
Higher Steaks	??	UK	Beef
Heuros	??	Australia	Meat (unsure of specifics)
Integriculture	$2.7 million	Japan	Meat (unsure of specifics)
JUST	$220 million	USA	Beef (waygu), eggs, milk
Kiran Meats	??	USA	Beef
Meatable	$3.5 million	Netherlands	Beef
Memphis Meats	$20.1 million + ?? $$ from Tyson Ventures.	USA	Meat (general meats)
Mission Barns	$3.5 million	USA	Meat (general meats)
Modern Meadow		USA	Leather
Mosa Meats	$8.8 million	Netherlands	Beef
Motif Ingredients	$117.5 million	USA	Dairy, eggs, meat proteins
New Age Meats	$250,000	USA	Pork
New Culture	??	USA	Cheese
Perfect Day (Muufri)	$24.7 million	USA	Ice cream (whey proteins)
SeaFuture	??	Canda	Fish
Shiok Meats	??	Singapore	Seafood
Super Meat	$4.2 million	Israel	Chicken
VOW	??	Australia	Meat (general meats)
Wild Earth	$4.5 million	USA	Mouse cells for pet food
Wild Type	$3.5 million	USA	Meat (unsure of specifics)

New Harvest, a 501(c)(3) research institute accelerating breakthroughs in cellular agriculture, 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" (Mouat and Prince, 2018). 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 sum of total capital raised in Table 2 is well north of USD$400 million. The Good Food Institute, a non-profit that promotes plant-based and cultured meat alternatives to meat, dairy, and eggs; estimated that in the five years leading up to 2018, USD$17.1 billion had been invested in plant-based food; with a further USD$73.3 million in cell-based meat companies. Just for comparison, in 2016 the U.S. public investment in all animal agriculture research was approximately USD$38 million (Table 3).

Table 3. Number of USDA NIFA grant applications, awards, success rate, and funded $ for Animal Health and Production and Animal Products research (https://nifa.usda.gov/table-3).

Animal Health and Production and Animal Products (2016)	**# applications**	**# Awards**	**Success rate (%)**	**Amount funded ($)**
Animal Breeding, Genetics, and Genomics	30	9	30%	2,980,000
Animal Reproduction	65	17	26%	6,237,383
Animal Health and Disease	154	35	23%	12,379,358
Ecology and Evolution of Infectious Diseases	4	4	100%	4,644,700
Tools and Resources	3	1	33%	500,000
Improved Nutritional Performance, Growth, and Lactation of Animals	94	18	19%	6,509,027
Dual Use of Animals for Dual Benefit	3	2	67%	3,246,109
Animal Well-Being	19	3	16%	1,500,000
2016 USDA funding for Animal Agriculture competitive grants				**37,996,577** (12.4%)
TOTAL 2016 USDA NIFA funding for all competitive grants				**$307,146,458**

Animal production is a critical component of the U.S. economy, with more than 1 million farms producing $182 billion in products in 2011 (National Agricultural Statistics Service (NASS), 2012) while employing more than 2.3 million people and representing 63.7 percent of farm income. In 2014, animal agriculture yielded $440.7 billion in economic output, with $76.7 billion in earnings, $19.6 billion in income taxes, and another $7.4 billion in property taxes (Rexroad et al., 2019). In 2016, the latest year for which data is available USDA, animal agriculture research obtained approximately $38 million in public sector grants, 12.4% of USDA's competitive grant portfolio (Table 3), or 0.01% of the annual economic output.

Mouat and Prince (2018) use the term **biocapitalism** to describe the investment in cultured meat**.** They reflect that fundraising for companies trying to produce animal-free food – depends to varying extents on "a venture capital industry with a culture that celebrates 'disruption'; a set of biotechnical materials and relations that are being pacified into a marketable object; an existing community of concern worried about the effects of animal agriculture; and the construction of ethical agency for animal-free food to solve the problems that this community is so concerned with. It is all of these things that enable value to be leveraged off the biological material that makes up animal-free food, and so constitutes it as biocapital."

WHO IS SELLING CULTURED MEAT?

Nobody yet, at least as far as cultured meats go, because no one has reduced this to practice. But the concept is being sold hard. According to the June 2019 report by consulting firm A.T. Kearney (2019), they predict that "In 20 years, only 40% of global meat consumption will still come from conventional meat sources". They posit that "Cultured meat will win in the long run. However, novel vegan meat replacements will be essential in the transition phase". In their estimation by 2040, cultured meat will make up 35 percent of meat consumed worldwide, while plant-based alternatives (e.g. Impossible, Beyond Burger) will compose 25 percent. Or at least of the value of meat consumed worldwide, as all of their numbers are in billion US$ (Figure 2). 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" (RethinkX, 2019). Others like Rabobank are not so bullish on the growth, and think that collectively plant-based and cultured meat might take more like a 13% market share, similar that that portion of the milk market that is currently occupied by plant-based milk substitutes.

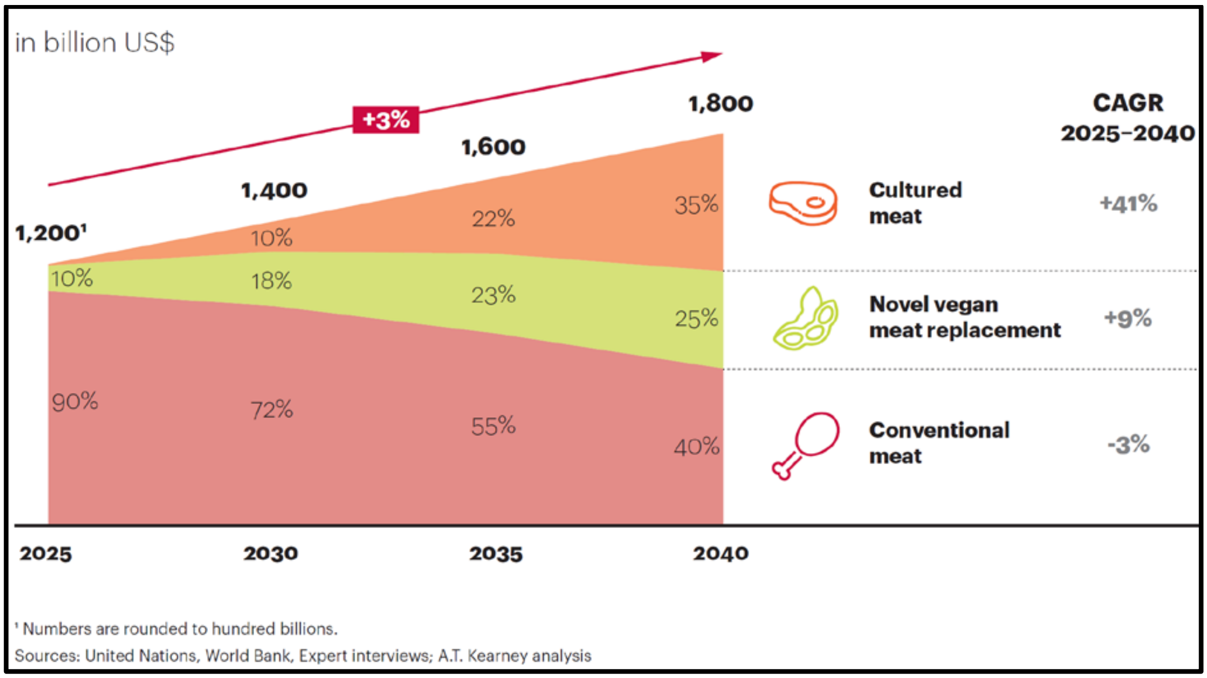

Figure 2. Projected breakdown of global meat production by 2040 according to a June 2019 A. T. Kearney (2019) Analysis.

By 2040 the FAO predicts 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 1751 MMT (compared to 1430 in 2020). Doing the simple math, and assuming that only the 402 MMT of land-based meat production is replaced with "quarter pounders" of the alternative source that would be [(.25 x 402 MMT) X (1,000,000,000/0.1133981)] = **886,258,235,367** plant-based burgers (Eight hundred and eighty-six billion, two hundred and fifty-eight million, two hundred and thirty-five thousand, three hundred and sixty-seven), and (.35 x 402 MMT)X(1,000,000,000/0.1133981) = **1,240,761,529,514** cultured meat burgers (one trillion, two hundred forty billion, seven hundred & sixty-one million, five hundred and twenty-nine thousand, five hundred & fourteen) by 2040. **That is a big ask in 20 years for an industry that does not yet have a single product on the market**!

WHO IS BUYING CULTURED MEAT?

Nobody yet, at least as far as cultured meats go. According to the Good Food Institute, sales of plant-based meat in the U.S. grew more than 23% in 2018, exceeding $760mn. Figure 3 was for the year ending June 2018 and is for plant-based aka vegan meat replacements. Just for perspective, looking at the US number for beef - 14 billion pounds – that would be 56 billion quarter pounders annually if all beef was hamburgers. In March 2017, Impossible Foods announced it would build its first large-scale plant in Oakland, California to produce 1 million pounds of plant-based burger meat a month, i.e. 12 million pounds per year. Nestlé, which sells a meatless burger in Europe, plans to introduce a US version this fall. And big meat producers like Tyson and Perdue are putting their own spin on the trend with blended products made with real meat and vegetables. They may launch closer alternatives to Impossible's protein, as well.

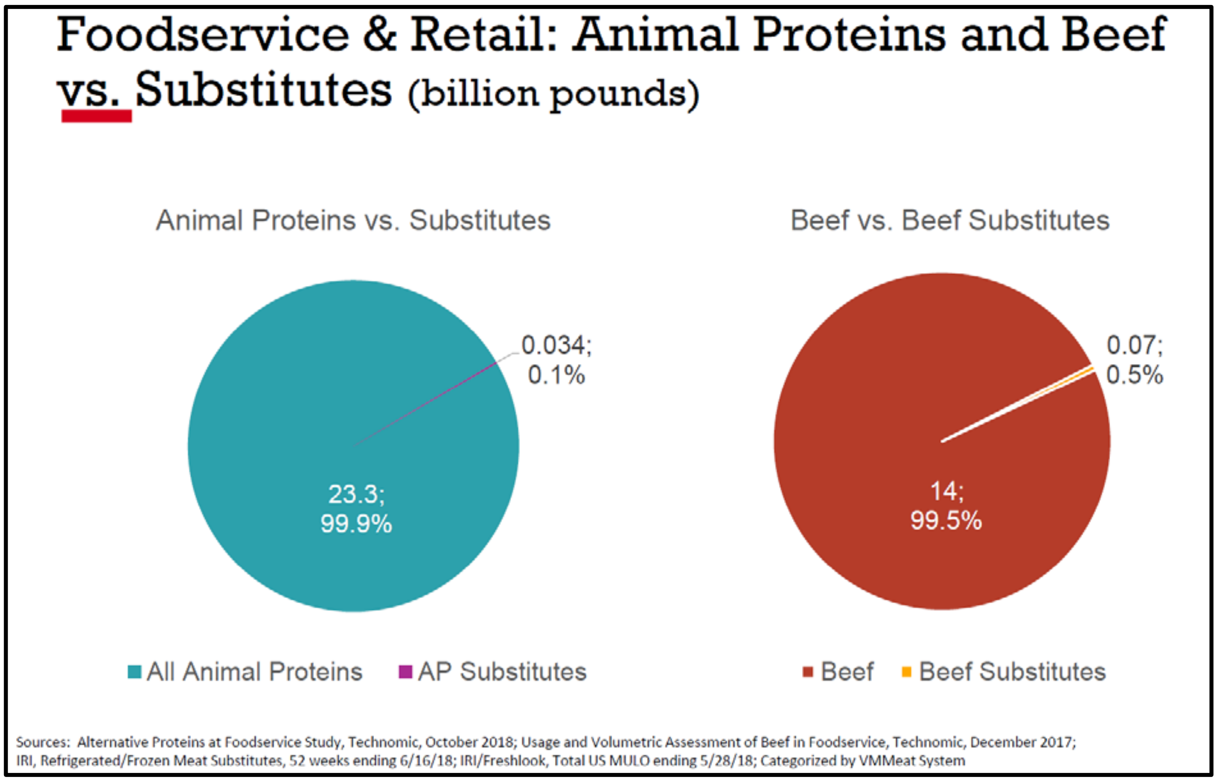

Figure 3. Foodservice and Retail: Animal proteins and beef versus substitutes (2017 data).

HOW IT CULTURED MEAT CURRENTLY REGULATED?

The regulation of cultured meat in the United States is currently split between the FDA and the USDA. According to a 2018 press release (FDA, 2018). The statement reads:

"Both the USDA and the FDA should jointly oversee the production of cell-cultured food products derived from livestock and poultry. Drawing on the expertise of both USDA and FDA, the Agencies are today announcing agreement on a joint regulatory framework wherein FDA oversees cell collection, cell banks, and cell growth and differentiation. A

transition from FDA to USDA oversight will occur during the cell harvest stage. USDA will then oversee the production and labeling of food products derived from the cells of livestock and poultry. And, the Agencies are actively refining the technical details of the framework, including robust collaboration and information sharing between the agencies to allow each to carry out our respective roles."

The Food and Drug Administration also has a legal standard for what can be called "ice cream". Officially, ice cream must contain no less than 10 percent milk fat (or cream) from a cow. Perfect Day ice cream products have none; they contain coconut oil and sunflower oil instead, to remain animal-free, and must therefore be labeled as a "frozen dairy dessert".

WHAT WILL BE THE IMPACTS OF CULTURE MEATS ON CATTLE INDUSTRY?

This is a hard question to answer. I look at the projected increase in demand. Beef is projected to go from 63 MMT in 2018 to around 90 million in 2040, and milk from 828 MMT to 1051 MMT in 2040 (Figure 4). I do not foresee the demise of grazing ruminants as a food production system, and contend that at the current time there is no viable substitute for animal agriculture.

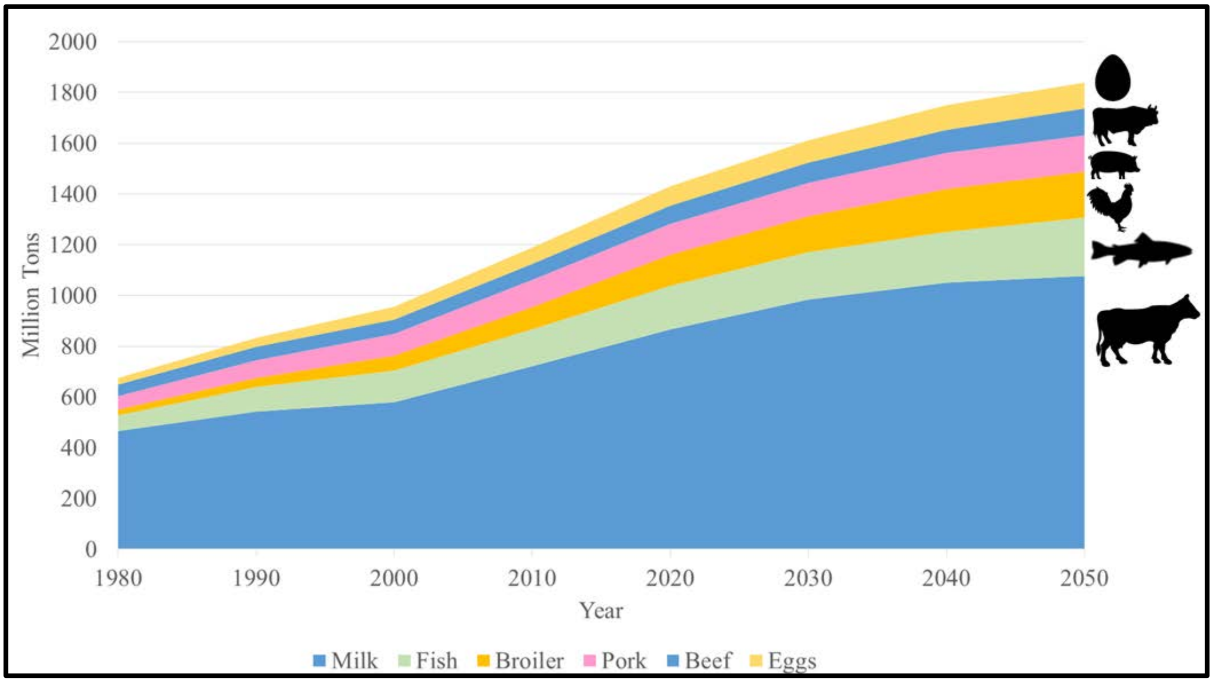

Figure 4. Projected demand (Million metric tons) for animal source foods through 2050

I personally think that we will need a multitude of approaches to address this demand for protein, but I am not remotely convinced by projections that meat substitutes will supply 60% of global meat production by 2040. Nor do I see a comprehensive consideration of the many other services provided by ruminants (ecosystem services, fire management, manure as fertilizer, draught power, scavenger of inedible crop residues and byproducts that otherwise waste), nor the many other products produced by cattle beyond ground beef. "Move fast and break things" might be a fitting adage in Silicon Valley for systems where no great harm results from upheaval. Making major changes in agricultural ecosystems should be undertaken with great care and a thorough understanding of the system-wide implications of such changes on the interconnected pillars of sustainability, especially when contemplating reforms to 40% of the global agricultural output of the world's food systems.

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 I see lacking in the discussion around cultured meats is that proponents tend to use the worst possible LCA metrics, often from a single study related to extensive beef production in terms of GHG, land and water use to justify their solution, based on highly variable anticipatory LCA figures. The positive externalities of ruminants such as ecosystem services, 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". It might also be worth asking whether all this alternative meats venture capital investment is focusing on the right problem.

Mattick et al. (2015) 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 with this train of thought, "*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***."

The functional unit (FU) of the alternative meat discussion to date has been, oddly enough, hamburger patties. The "leftovers" of the primal cuts (Figure 5). As mentioned previously, the FU used as the comparator can dramatically alter the sustainability metrics of any system (lb carcass weight is different to lb edible meat, and lb protein, and lb of animal source food – especially if the comparators differ nutritionally).

An average weight steer (1,300 lb) produces an 806 lb carcass which yields 639 lb edible beef, of which 38% is ground beef (i.e. 62% is not!). Primal cuts are obviously more valuable than ground beef, and the by-products of beef (including hides, offal, blood, tallow, bones, and bone meal) which represent approximately 11.7% of the value of a carcass are not factored into many LCA analyses. There are also offal products such as beef tongue and tripe, favorites of many ethnic communities, which are unlikely to be replicated via cell culture technology.

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%) (Gerber et al., 2013). In the United States, all of agriculture is responsible for 9% of the US GHG emissions (US EPA; https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions). Fossil fuel-based energy is responsible for over 80% of total US GHG emissions, as compared to slightly less than 4% from animal agriculture. The current focus on replacing dietary animal source foods seems to divert focus away from the biggest source of GHG – the burning of fossil fuel-based energy.

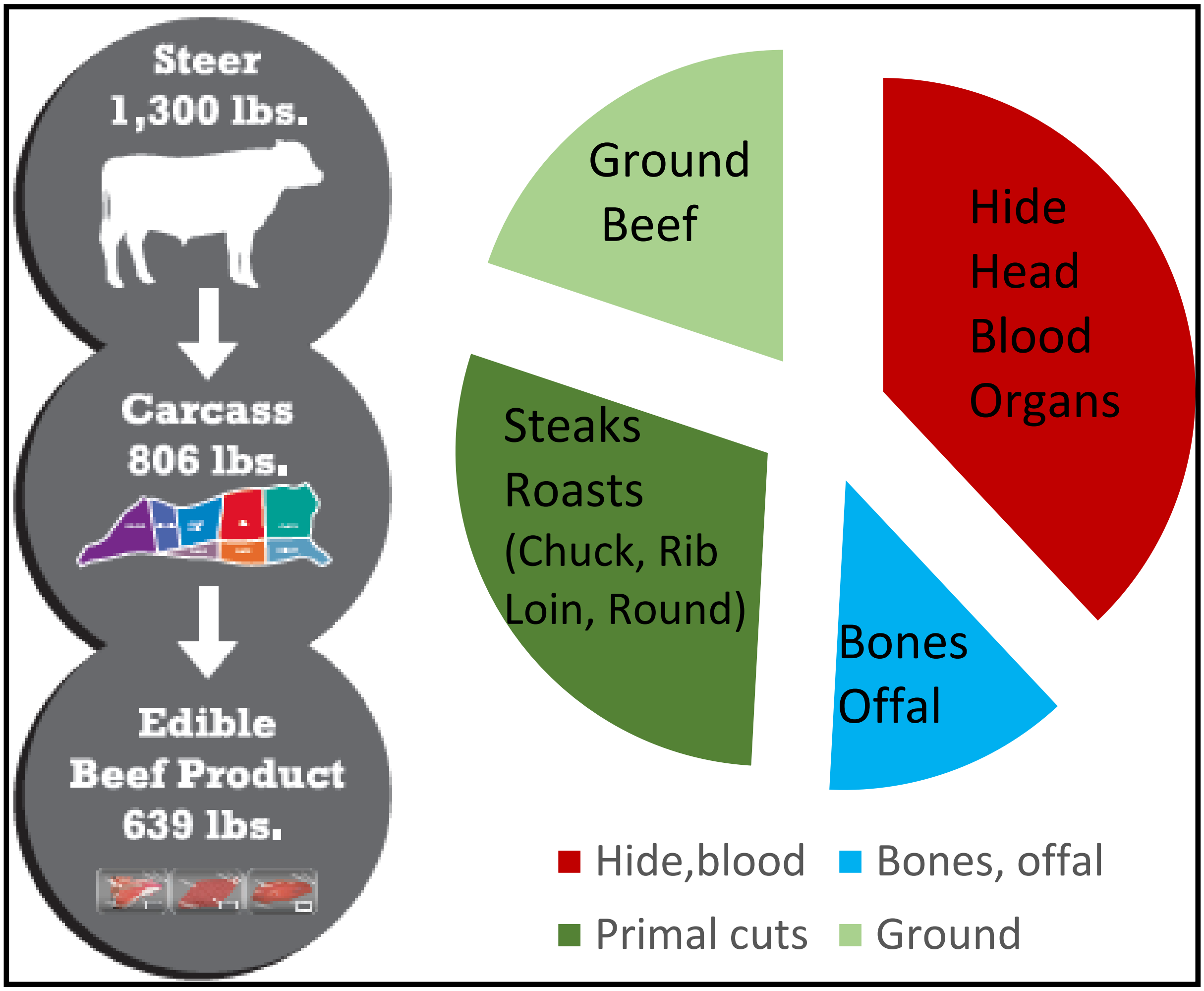

Figure 5: Breakdown of the multitude of different products from a 1,300 pound steer.

To put this in perspective, it has been estimated that eliminating ALL of US animal agriculture would decrease US GHG by 2.6%, but would also create a food supply incapable of supporting the US population's nutritional requirements (White and Hall, 2017). It would be refreshing to hear these numbers, and the likely evidence-based tradeoffs associated with growing animal cells at scale in a bioreactor included in the discussion around cultured meats, rather than improbable anticipatory LCA numbers seemingly designed to create an investor buzz

SUMMARY

Cultured meat is a term used to describe imitating a range of animal products from animal cells grown in a bioreactor. Although there is a lot of venture capital and celebrity investor buzz around this technology, there is no company that is currently selling cultured meat. There are a number of unknowns about the feasibility of culturing animal tissues at scale, 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.

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