Brighter Green

Beyond the Impossible

The Futures of Plant-based and Cellular Meat and Dairy

Brighter Green is a New York–based public policy action tank that aims to raise awareness and encourage dialogue on and attention to issues that span the environment, animals, and sustainable development both globally and locally. Brighter Green's work has a particular focus on equity and rights. On its own and in partnership with other organizations and individuals, Brighter Green generates and incubates research and project initiatives that are both visionary and practical. It produces publications, websites, documentary films, and implements programs to illuminate public debate among policy-makers, activists, communities, influential leaders, and the media, with the goal of social transformation at local and international levels. Brighter Green works in the United States and internationally, with a focus on the countries of the global South.

This paper is part of the Vegan America Project (VAP), a conceptual space that employs veganism as a heuristic to examine the social, economic, psychological, and cultural changes that will both occur and be necessary as the United States and the world confront climate change. VAP is an independent project of Brighter Green. VAP is funded by VegFund (https://vegfund.org). For more information, visit veganamericaproject.com.

Report Credits

Writer and researcher: Martin Rowe

Design and layout: Emily Lavieri-Scull

Thanks for editorial input to: Mia Macdonald, executive director of Brighter Green; Suzanne Lipton; and Ken Swensen; along with the assistance of Kyrillos Rizk

Thanks also for their contribution to: Friends of the Earth, Good Food Institute, GRAIN, Kadim *et al.*, Ocean Hugger Foods, New Harvest, Wild Earth, and the World Resources Institute.

Much appreciation to VegFund for its ongoing support of the Vegan America Project.

Photo and Illustration Credits

Blue Nala: 12:1 (used with permission. For more, visit: https://oceanhuggerfoods.com/ahimi)

Emily Lavieri-Scull:* Pages 1, 2:1, 4, 5, 7, 8, 9, 10:1, 10:2, 11, 16, 17, 19, 28 (bottom), 31, 34, 35, 37, 39, 55 (© Emily Lavieri-Scull 2018)

Friends of the Earth: 29 (cover of report)

Good Food Institute: 6 (© GFI 2017), 18 (© GFI 2018), 21 (© GFI 2017) (used with permission)

GRAIN and IATP: 26 (to access images, paper, visit: https://www.iatp.org/emissions-impossible)

Kadim: 22 (Kadim, Isam T., *et al.* "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* [2015] 14[2]: 222–233.) © 2015, CAAS. All rights reserved. Published by Elsevier Ltd. doi: 10.1016/S2095-3119(14)60881-9

Martin Rowe: 2:2, 12:2, 14, 20

Nic D on Unsplash: 15 (https://unsplash.com/@trancisky)

Wild Earth: 28 (top) (used with permission. For more, visit: https://wildearth.com/)

World Resources Institute: 32 (from Ranganathan, Janet. *et al.* Shifting Diets for a Sustainable Food Future: Creating a Sustainable Food Future, Installment Eleven: https://www.wri.org/publication/shifting-diets) (Creative Commons)

* For a description of all the vegan food in the photos by Emily Lavieri-Scull, see the "Food Details and Locations" section on p. 55.

Brighter Green, 165 Court Street, #171, Brooklyn, NY 11201. 212-414-2275 x 15

Printed on 30% recycled paper

www.brightergreen.org

Beyond the Impossible explores the current landscape in the U.S. of plant-based meat and dairy products and cellular agriculture. (See "Terms of Reference" on p. 18) for a discussion of the term *cellular agriculture*.) It examines the opportunities opened up by, and the challenges that face, their widespread manufacture and adoption, and places both within the contexts of a longstanding discussion of a "natural" diet in the West, the stark questions posed by an increasingly globalized industrial animal agriculture system, and the looming catastrophes of climate change and biodiversity loss. The paper is designed for those interested in knowing more about the science and rapidly evolving technological, business, and social-change dimensions of plant-based and cellular meat and dairy products. It also offers a larger philosophical and imaginative framework within which to consider how we balance the sometimes competing values that animate advocates for a healthy diet and sustainable food systems, food technologists, and those committed to veganism and animal rights.

Beyond the Impossible owes much of its information and many of its voices to New Harvest and the Good Food Institute, two non-profit organizations at the forefront of providing research in, information on, and discussion about plant-based and cellular meat and dairy. Speakers and presenters at New Harvest's 2017 and 2018 and Good Food Institute's 2018 conferences, as well as the organizations' websites, videos, and documents proved invaluable in presenting a snapshot of these industries at a nascent stage of development. Also helpful were several other events—including the Ivy League Future of Food Conference, Food Loves Tech, and Food Tank's Food Waste Conference (all in 2018)—and the Cultured Meat and Future Food Podcast hosted by Alex Shirazi, which began in 2018.[1]

The paper is designed for those interested in knowing more about the science and rapidly evolving technological, business, and social-change dimensions of plant-based and cellular meat and dairy products.

Precisely because much of the research and technology and many of the companies in these industries are relatively new, and because a substantial body of third-party research and long-view sociological analysis is not yet available, skepticism regarding outcomes and possible developments is warranted. This approach is reflected in this paper. That said, for those of us (the author of this paper included) who despair at the trajectories for meat and dairy consumption globally in the context of biodiversity loss,[2] runaway climate change, and the huge numbers of animals who suffer now and are killed for meat and dairy products at the moment (and will in the future), genuine opportunities to lessen the most damaging consequences of industrial animal agriculture presented by plant-based and cellular agriculture technologies offer some hope to change these trajectories and remediate the worst. This attitude is also reflected in this paper.

As an undertaking of the Vegan America Project,[3] *Beyond the Impossible* also asks whether cellular and plant-based meat and dairy products may be useful tools to help us transition from an agriculture centered on monocultures of feed crops and industrial animal farming toward a more diverse, plant-based agriculture, where many fewer farmed animals supply the cells and proteins that allow cellular agriculture to thrive, without having to be killed. In producing *Beyond the Impossible* within the context of the Vegan America Project, this writer is aware that some readers will expect more emphatically drawn ideological lines, while others will be leery of any judgments expressed lest they emerge from an ideological commitment they do not share. This balance, readers will find in this paper, is deliberate: not as a result of a lack of conviction, but because, as you will read, the complexities and nuances of the arguments require a more supple and imaginative response if we are to meet the considerable challenges facing the future of food security *and* that of our planet.

The paper begins with an outline of the historical and conceptual background to both plant-based and cellular meat and dairy products. It then lays out the specific challenges (technological, knowledge-based, regulatory, and consumer-based) confronting the development of plant-based meat and dairy products and cellular agriculture. The paper then outlines concerns expressed by those advocating for broad adoption of a whole-foods, plant-based diet, as well as criticisms from social and environmental researchers and activists, and presents a vision of the future that, this author believes, offers a way through the conceptual, socio-political, and perhaps even technological complexities that await both sectors.

The paper concludes with recommendations for how people in all these spaces might open up discussion, bring more stakeholders on board, and hold the competing values together, so we might chart a way forward, with maximal impact and minimal delay, toward a genuine and lasting climate resilience.

CONTEXT

Plant-based versions of animal-food products have existed for centuries. Tofu (bean curd) has origins dating to at least a thousand years ago in China and seven centuries[4] back in Japan. Its fermented form, tempeh, may have been present in Indonesia as early as the sixteenth century.[5] Wheat gluten may have been eaten in East Asia as early as the sixth century,[6] even though the term for its popular flavored iteration, *seitan*, was coined only in 1961. John Harvey Kellogg[7] made wheat gluten and various nut-based meat analogues at his sanitarium in Battle Creek, Michigan, in the early 1900s.[8] Non-dairy milks have also existed for centuries. Almond milk was drunk in the Middle East and Europe in the 1300s, and soymilk was consumed in China in the 1500s.[9] Kellogg also developed his own soymilk.

Other meat analogues, such as vegetarian burgers of textured vegetable protein (TVP, invented by ADM),[10] soy, or other beans (such as in Sosmix)[11] have been available[12] in the West since the late 1960s. Plamil Foods in the U.K. was founded in 1965 to sell soymilk, and branched out in the 1970s to sell other vegan foodstuffs.[13] Seth Tibbott started the soy and seitan meat company Tofurky in 1980,[14] and non-meat patties from Gardenburger (owned by Kellogg's) and Boca Burger (now a division of Kraft foods) followed in 1981

and 1982 respectively. Quorn, a protein made from fungus, was released in the U.K. in 1985.[15]

Until recently in the West, meat analogues were predominantly marketed to (and eaten by) consumers concerned with their health and/or committed to animal protection. Although the ecological burden on and the calorie-delivery inefficiencies of a meat-intensive diet have been known to the general public since Frances Moore Lappé issued *Diet for a Small Planet* in 1971,[16] neither the environmental movement nor animal advocates, nor (for that matter) dietitians have made them the central plank for changing hearts and minds about how we raise animals for food. Nor was how the meat and dairy substitutes tasted a major component of their marketing pitch.

The reasons for this relative indifference among activists to gastronomy in the West may have partly been that the faux meat pucks, powders, or plant-based milks didn't taste like the real thing (or weren't meant to). They weren't attractively packaged and they were hard to produce at scale. These realities were, in turn, perhaps the cause and effect of at least some vegetarians and vegans (hereafter veg*ns[17]) presenting their diet as self-denying,[18] purifying/cleansing,[19] and an expression of individual (self-)righteousness[20]—a deliberate rejection of the trope of meat-eating as unhealthy and self-indulgent.

Throughout the long tradition of Western veg*ism, stretching back to Pythagoras, eating and not eating meat have existed in a kind of symbiotic dialectic. Some veg*ns as well as meat-eaters have acknowledged that eating animals is symbolic of festivity or tribal bonding,[21] gendered identities *and* virility,[22] and can lead to the arousal of animal spirits (aggression, strength), as well as gluttony and excess.[23] Both veg*ns *and* meat-eaters have claimed that the choice of whether to eat or not eat animal flesh is a facet of our distinctive human identity.[24]

These often contradictory social and ethical associations inevitably color responses from both groups on how closely analogues should mimic meat's social and culinary (re)presentations, or whether they should do so at all. These incongruities are themselves embedded in complex attitudes toward food that exist on a continuum between those who see food essentially as a nutrient delivery system governed by taste, price, and convenience on the one end and those who value it as a multilayered and interconnected set of personal, familial, religious, emotional, and cultural expressions on the other.[25]

Finally, the extent to which you consider food a biological necessity or ultimate expression of human uniqueness is wrapped in a millennia-long discussion on what constitutes a "natural" diet—and, as the highly gendered hunter/gatherer paleo-anthropological *mythos* suggests, the "natural" relation between men and women; between men, women, and nature; and cooking, and who prepares and eats which food.[26] This pursuit is itself a facet of humankind's quest for our appropriate, often divinely mandated relationship with Nature and other animals, which is in turn framed by various taboos, circumscriptions, and hieratic obligations that surround the use and killing of animals—including pollution/sanctification, in-group/out-group identities, and food choices. These are inevitably reflective of gendered attitudes over which animals are to be raised and killed by whom.[27]

For cultural anthropologist Nick Fiddes, author of *Meat: A Natural Symbol*, food is always more than nutrition, taste, or affordability: "Our attitudes to different foods are conditioned by the associations which we invest in them and we learn these from the day we are born."[28] Furthermore, "[t]he foods we select reflect our thought, including our conception of our actual or desired way of life and our perceptions of the food choices of people with whom we wish to identify."[29]

These conceptions are reinforced, Fiddes argues, with animal flesh, which is rich with meanings, many of which were enumerated above. These meanings, Fiddes observes, mirror how we view economics, technology, and society:

> Each meaning, and countless others, is true for the individuals concerned, extending the significance of the name of a particular meat, or of meat in general, far beyond its function as a foodstuff. It is the totality of these ideas which combine to form a language, and which constitute culture."[30]

As Fiddes summarizes, meat is, therefore, both compartmentalizing and encompassing: "[Meat] is about what parts of which animals we habitually eat, when we eat meat, where we eat it, and with whom we eat it."[31]

The inherently ambivalent constructs around meat likewise carry echoes of imaginary Golden Ages and aspirations for ideal human and human/animal communities. These might take the form of the prophet Isaiah's eschatological vision of animals and humans in concord (Isaiah 11) in the Hebrew Bible, which is itself a restoration of the prelapsarian diet of Genesis 1:29. Or they may hearken to bucolic notions of the (inherently noble or ennobled) farmer working in concert with his livestock—an idealized representation of republican values of modesty, piety, and discipline in contrast to the personal and political corruption of urban life. They might accompany the refinement of the animal body through astringent practices or through progressive cycles of reincarnation—until there is no body at all.[32]

Although the various arguments for a "natural" diet with or without meat have existed for centuries, and proscriptions surrounding meat may be based in protective sensory mechanisms to avoid contaminated or rotten food, whether or which parts of which animals to eat is (as Fiddes suggests) freighted with symbolic and moral import.[33] Religio-ethical principles on what makes a body inviolable (for instance, sentience, natural rights, *ahimsa* or nonviolence, metempsychosis, God's law) perhaps inevitably foster a sectarian or even separatist identity (Essenes, Brahmins, Jains, Seventh-Day Adventists, Jews, Muslims).[34] In such situations, not eating flesh or specific animals becomes a means for a group to distinguish itself from, and yet remain in critical relationship with, a larger or external society.[35]

THE SPREAD OF FACTORY FARMING

In the last fifty years, two considerations have broadened interest in veg*sm beyond worries about meat's inflammatory effects on individual human health or the soul. These are the growth and spread of Concentrated Animal Feeding Operations (CAFOs)—so-called factory farming—and, more recently, the realization of animal agriculture's outsized contribution to environmental degradation and climate change.

The deaths of animals for human food has long drawn the attention of philosophers, writers, and artists, but it was Upton Sinclair's novel *The Jungle* (1908) that first brought to public attention the mechanized, industrialized mass slaughter, and life-threatening, degrading, and demoralizing conditions for immigrant workers (mainly of Eastern European heritage) on the disassembly lines of Chicago's meatpacking industry.[36] Sinclair hoped his book would encourage labor reform; instead, the public demanded and received new federal food safety laws.[37]

Since then, and particularly following the Second World War, animal agriculture has further industrialized and consolidated, and multinational conglomerates have made possible its expansion beyond the West.[38] Ever greater numbers of poultry, pigs, dairy cows, and (for much of their lives) beef cattle are raised in pens, cages, or stalls in large sheds, often unable to turn around or step outside.[39] Slaughter-lines have sped up, and working conditions are still some of the most dangerous, both physically and psychologically.[40]

One reason for a growing emphasis on farmed animal suffering among animal protectionists has been this dramatic rise in the number of animals raised and killed, as well as the conditions in which they live and die.[41] Of the 10 billion animals killed in the U.S. each year, for instance, 95 percent were raised and slaughtered for food (not including fish), dwarfing the numbers of those used in experimentation or entertainment, hunted for fur or sport, or killed by automobiles.[42] Despite some federal legislation in the U.S. that offers some animals some protection on their way to slaughter and on their arrival,[43] many abuses are exempt from oversight because they are considered "standard industry practice." Indeed, poultry (which constitute over 90 percent of all animals slaughtered for food) receive no protections at all.[44]

The welfare of farmed animals in CAFOs and at slaughterhouses was the subject of Ruth Harrison's *Animal Machines* (1964), Peter Singer's *Animal Liberation* (1975), and Peter Singer and Jim Mason's *Animal Factories* (1980), as well as sections of *The Animals Film* (1980).[45] These works in turn inspired the founding of new organizations—such as People for the Ethical Treatment of Animals (1980), Farm Sanctuary (1986), Compassion Over Killing (1995), and Mercy For Animals (1999). The last three focus exclusively on the welfare of farmed animals and promoting veganism.

THE "FAILURE" OF ADVOCACY

Nevertheless, in spite of decades of advocacy (education, provocation, "open rescues,"[46] demonstrations, and boycotts), as well as publications offering more insight into the emotional and social lives of farmed animals,[47] extensive academic work in animal ethics,[48] and many exposés, books, articles, and films documenting the cruelties of factory farming, the number of those who no longer eat animal products has remained below five percent of the population in industrialized nations,[49] with perhaps the exception of Israel.[50] In 2018, the U.S. ate more meat (222 lbs per person) than ever before.[51] Furthermore, as

the world's population has risen, grown richer, and become more urbanized, intensive animal agriculture has spread to emerging markets to promote and meet the demand for meat and dairy products. This has occurred in regions, such as China, India, and some countries in Africa, where, respectively, meat was considered a condiment, there was a strong vegetarian tradition, or animals may have been worth more to people alive (as labor, chattel, or providers of dung and urine) than dead.[52]

These realities have led some animal advocates to conclude that efforts to convince consumers about the immorality of eating animals or highlighting the cruelty of CAFOs have failed, or at least are no match for the convenience, tastiness, or affordability of farmed animal meat and dairy.[53] Bruce Friedrich, a long-time animal advocate and vegan who is now executive director of the Good Food Institute, a non-profit that promotes plant-based meat and cellular agriculture, is succinct about his organization's aim:

> Our goal is to take ethical considerations off the table, and to make the best choices from the perspective of sustainability, climate change, global health, and animal welfare.
>
> In other words, we want to make the best choices the default choices because the products are delicious, price competitive, and convenient.[54]

This shift in approach has been accompanied and spurred by an influx of philanthropic interest underpinned by the utilitarian philosophy of effective altruism (EA). In its response to animal agriculture, EA seeks to pivot from an absolutist-abolitionist stance that calls for an end to all animal farming and the promotion of veganism to one that reduces animal suffering by improving farmed animal welfare and increasing the numbers of those who consume less meat and dairy.[55,56]

CLIMATE CHANGE

Mounting awareness of and alarm about the spread of factory farming has run in tandem with awareness of and concern about climate change. The 2006 publication of the United Nations Food & Agriculture Organization's (UNFAO) report *Livestock's Long Shadow*[57] concluded that animal agriculture's contribution to greenhouse gas (GHG) emissions is significant (at least 14.5 percent or 7.1GtCO_2 equivalent),[58] perhaps as extensive as that of the global transportation sector. Recently, environmental organizations such as Greenpeace,[59] the international World Wildlife Fund,[60] and the Center for Biological Diversity[61] have called for reducing meat consumption to conserve wildlife, lower GHG emissions, protect watersheds, and cut down on deforestation and biodiversity loss.

It is within this socio-historical, ethical, and climatological context that the considerable interest in and emergence of a new generation of plant-based meat and dairy products and cellular agriculture should be understood. Their advantage consists in that both plant-based and cellular products could form, as Friedrich notes in the quotation above, a default architecture of food choices without anyone having to adopt any of the perceived social, political, or ethical "baggage" they or others might assign to veg*ism, or even meat or dairy reduction.

As Paul Shapiro, founder of Compassion Over Killing and author of *Clean Meat* puts it, weighing advocacy and social reform against entrepreneurship and technology:

> There's no doubt to me the former are important (I have, after all, spent the bulk of my career as a policy advocate), but the fact of the matter is, as long as people demand real meat, the market is going to supply it, and globally demand for meat is only going up.[62]

These products, therefore, could theoretically bypass or even co-opt values such as sociality, familial and cultural loyalty, religious fealty, aspirations to wealth and success, and even masculinity that are still given considerable valence by animal products. Indeed, as some have argued, the social acceptability of plant-based or cellular meat and dairy could provide an entry-point for consumers to retroactively season their food choices with moral clarity. As vegan social theorist Tobias Leenaert remarks: "If it were, for instance, to become profoundly inconvenient or expensive to eat animals, people

would eat fewer of them and start to think of themselves as the sort of person who eats little or no meat. They'd even be likely to come up with stories about how they'd wanted to eat fewer animals all along."[63]

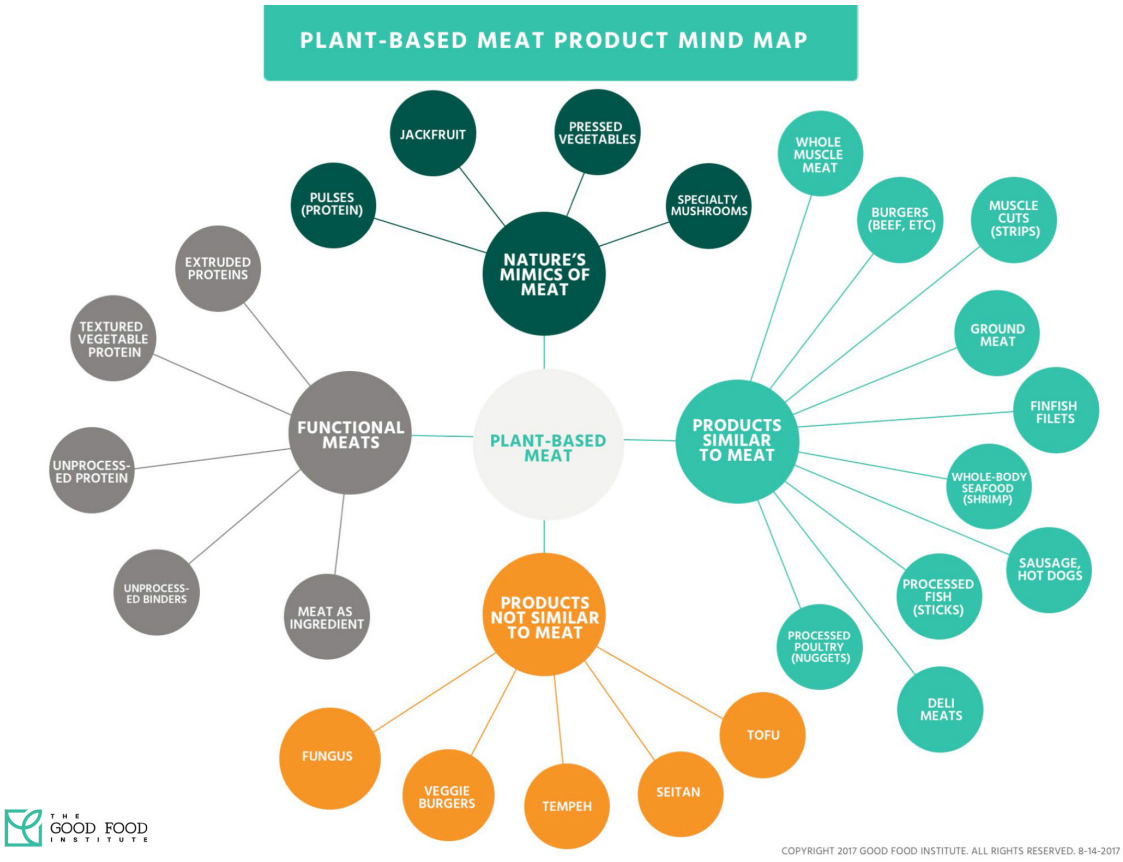
* * *

The paper starts with the origins of plant-based and cellular meat and dairy, and then moves specifically on to the technological, business, and consumer-acceptance challenges facing plant-based products. Following that, it explores cellular agriculture and the (more pronounced) conundrums and difficulties it faces in technological and business development, as well as consumer acceptance. It details those who have raised objections to both forms of meat and dairy products because of health and environmental concerns, and concludes with the voices of some of those who are imagining various futures for a combination of plant-based and cellular worlds. The paper ends with recommendations, both general and specific, for those within the various industries and also within the academy and in public policy looking to understand the ramifications of their development and expansion.

THE ORIGINS OF PLANT-BASED AND CELLULAR MEAT

As the Good Food Institute's plant-based mind map[64] indicates (below), it is possible to divide plant-based meats into four groups: those that serve the same function as meat, such as textured vegetable protein (TVP); naturally occurring foods that mimic meat's texture (such as the Asian jackfruit and fungi); analogues that act as a chewy filler but don't taste like meat (seitan, tofu, tempeh); and products that aim to replicate the total experience of eating a particular kind of meat in a particular form (such as a fish-stick, shrimp, or burger). This last category is the focus of this paper.

In only two decades, advances in molecular biology and biochemistry have enabled scientists to understand more fully how amino acids, proteins, carbohydrates, lipids, and salt—the building blocks of meat—interact on a molecular level to form the flavor and texture that we associate with the products we call "meat" and "dairy." Utilizing this science, entrepreneurs have developed a range of plant-based meat and dairy analogues. Businesses such as Beyond Meat, Impossible Foods, Ripple, and JUST (formerly Hampton Creek)—to name the most well-known—seek to replicate and even supersede the mouth-feel, bite, texture, creaminess, and taste of animal products.



Plant-based milk options at a Whole Foods Market in Brooklyn, NY

These and other companies are both reacting to and driving interest among Millennials and Generation Z,[65] a significant percentage of whom consider themselves "flexitarians."[66] Eighty percent of Millennials eat meat alternatives, according to 2017 report from Mintel, a market research company.[67] Lux Research reckons that, by 2054, non–animal based sources of processed protein will account for a third of total protein consumption.[68] In June 2019 A. T. Kearney, a global management consulting firm, prognosticated that by 2040, plant-based and cellular animal products would occupy respectively 25 and 40 percent of the global meat market.[69]

A more developed and also rapidly expanding sector is plant-based dairy products. Purchases of non-dairy milks in the U.S. grew by 61 percent between 2013 and 2018,[70] and by nine percent in 2018 alone.[71] As of June 2018, sales stood at $1.6 billion and non-dairy milks constituted 13 percent of the U.S. milk market,[72] with (at the time of writing) soy, hemp, coconut, flax, oat, rice, pea, quinoa, and several different nut milks available at groceries. Total sales of non-dairy cheeses in the U.S. were at $124 million by mid-2018 (up 43 percent on the previous year), and global sales are forecast to be approaching $4 billion by 2024.[73] Reflecting a broader shift in that market, total sales of dairy milk fell in 2018 to $13.6 billion,[74] a drop of $1.1 billion from the year before and symptomatic of a ten-year decline.[75]

The expansion of interest in plant-based alternatives has not gone unnoticed by food conglomerates, which have snapped up plant-based start-ups and through their broader distribution channels enhanced the products' visibility and sales. In the last decade or so in the non-dairy division alone, General Mills has purchased Kite Hill, a non-dairy cheese company; French multinational Danone bought WhiteWave, developers of Silk, a non-dairy milk; Valio, a Finnish dairy producer acquired Oddlygood, a Swedish oat-milk company. MorningStar Farms, a producer of the "Veggie Cuisine" range of products, is now part of Saputo, a Canadian food giant; and a Japanese company Otsuka owns Daiya, creators of a line of vegan cheeses.[76]

These acquisitions continued into 2018. As the Good Food Institute noted: Maple Leaf Foods bought Field Roast Grain Meat Company; GreenSpace Brands acquired Galaxy Nutritional Foods; JAWEA and Good Karma Foods were purchased by Affinity Beverage Group and Dean Foods, respectively. This buying spree has been accompanied by

considerable investment in recent years. As of the end of 2018, over $17 billion had been plowed into the plant-based industry, with $673 million pledged in 2018 alone—a 40 percent increase over the year before.[77]

* * *

Accompanying the expanding market for these plant-based meat and dairy products is the development of cellular agriculture. The possibility that one could develop animal-derived food without raising and slaughtering the animal is a consequence of recent advances in cellular biology, although Winston Churchill famously prophesied in 1931 that, "we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium."[78] The challenges and opportunities of growing those "parts" and finding the "suitable medium" have recently garnered considerable scientific and investor interest.

Robert Hooke first viewed cells under a microscope in 1665,[79] and how they divide and propagate has been known since 1835. Stem cells (the cells from which all bodily tissue comes) were derived from embryos in 1981, and human embryonic stem cells have been developed in a lab since 1998.[80] Animal tissue was first cultivated in 1971, when a guinea pig's heart muscle was grown.[81] NASA in the U.S. and the Dutch government conducted their research in the early 2000s on developing cultured turkey, fish, and pigs' cells respectively.[82,83,84]

In 2003, two Australian artists, Ionat Zurr and Oron Catts, kept frog tissue alive in an installation for several weeks, with the frog present, before serving the tissue (and not the frog) in the form of miniature steaks.[85] This last experiment suggests that cellular biology is as much a vehicle for the re-conceptualization and re-imagination of our relationship to the "natural" and the non-human world as it is (in the case of NASA) for finding practical means of serving animal protein in an alien environment. Zurr and Catts' experiment illustrates the diversity of meanings that animal life, flesh, and our relationship with both bring to the discussion of cellular meat.

These advances in cellular biology have been made possible by other scientific breakthroughs—such as the

Plant-based meat options at a Food Bazaar Supermarket in Brooklyn, NY

Plant-based dairy options at a Whole Foods Market in Brooklyn, NY

mapping of the human genome,[86] a dramatic fall in the cost of sequencing genomes,[87] and synthesizing ("writing") DNA itself.[88] In 2013, biochemist Mark Post of Maastricht University in the Netherlands introduced a proof-of-concept cell-based beef patty.[89] Four years later, Uma Valeti's Memphis Meats unveiled a cell-based chicken nugget,[90] and Josh Tetrick's JUST aims to roll out other cell-based meat products shortly. (His promise to deliver these by the end of 2018 was unfulfilled.)[91] Four Israeli companies are also engaged in cellular agriculture—including Aleph Farms, which in December 2018 revealed it had created a cell-based beefsteak.[92] San Francisco–based Clara Foods plans to launch its cellular egg white by the end of 2019.[93]

In addition to plant- and cell-based meat and dairy products, research is continuing into the production of mycocelial and acellular versions of the byproducts of animal agriculture, such as Perfect Day's utilization of whey and casein. Acellular agriculture involves using cells or microbes, such as yeast or bacteria, to reproduce fats and proteins, a form of manufacturing that is around forty years old. Insulin, which used to require the slaughter of pigs, is now mainly developed with yeast; rennet, which used to be gathered from calves' stomachs, now involves using genetically engineered bacteria, fungi, or yeasts.[94] Papain, a meat tenderizer formerly extracted from papaya, is now produced enzymatically,[95] as is vanillin.[96] Similar opportunities are opening up to generate non–animal derived gelatin,[97] collagen,[98] silk,[99] leather,[100] and even rhinoceros horn.[101] Some of these are already in the marketplace. In November 2018, Perfect Day announced it would join with global food giant ADM to scale up its acellular fermentation of dairy proteins.[102]

As of this writing, interest in and investment goals for plant-based and cellular animal products among entrepreneurs are mainly driven by altruism and guided by a long-term strategy. According to Tobias Citron of Radicle Lab, a "data visualization" service for scientists and engineers, the founders of most of the nineteen companies involved in cellular agriculture (as of Spring 2018) are disturbed about the environmental effects of farmed animal agriculture, want to stop animal suffering, and are worried about how to feed the estimated 11 billion people that may be alive by 2100.[103,104] Many of them, according to Radicle Lab, agree with the scientific consensus that animal agriculture is a major cause of GHG emissions and that the continuing spread of a meat- and dairy-intensive diet around the world exacerbates already dire predictions about food security, biodiversity, and Earth's carrying capacity as the effects of climate change take hold.[105]

In their current stages of development, the rhetoric of the plant-based and cellular industries is bifurcated. It is simultaneously one of change (new technologies, new

engineering, new products, and new tastes) and continuity (familiar items, no disruption of values, no need to change behavior). A similar delicate balance is maintained between systemic transformation (ending animal agriculture; mitigating climate change; making meat production "clean," local, and democratic) and systemic integration (similar regulatory structures; "working alongside" traditional animal-protein providers; the same mass-market production and distribution model; and absorption into the current vertically integrated agribusiness structure).

As the buying and investing spree suggests, these markets and industries are expanding very fast. In 2018, the U.S. market for plant-based foods grew by 24 percent.[106] Impossible Foods had no products available in October 2017; by February 2019, its food was in five thousand restaurants,[107] following the introduction of "sliders" into the U.S. White Castle fast-food chain,[108] with Red Robin's 570 burger-and-brew stores adopting the Impossible Burger in April 2019.[109] Impossible plans to unveil various food items for the retail market in 2019,[110] and Beyond Meat launched a hugely successful IPO on the NASDAQ on May 1, 2019.[111] (Impossible is thinking of an IPO later in 2019).[112] Finless Foods, working on cellular Bluefin tuna, is aiming to deliver its product—at price parity with the threatened piscine version ($380 per pound)—by the end of 2019.[113] Traditional meat companies—such as Nestlé (the Incredible Burger),[114] McDonald's[115] (McVegan Burger), and Burger King's Impossible Whopper[116]—are developing or extending their line of plant-based food items, either alone or in tandem with other producers. In May 2019, JBS, the world's largest meat producer, announced it would produce a plant-based burger for sale in Brazil.[117] The following month, Tyson declared that it would begin developing its own pea-based meat products.[118] At the same time, Perdue launched "Chicken Plus," nuggets and patties that blend cauliflower, chickpeas, and "plant protein" to reach "flexitarian families."[119]

Interest in cellular agriculture has also grown exponentially. In 2016, only four companies operated globally; as of the end of 2018, there are, according to the Good Food Institute, twenty-seven cell-based meat and seafood businesses, eleven of which started in 2018 alone.[120] Tyson,[121] Cargill,[122] and PHW, Germany's largest chicken producer,[123] have become investors, as have Bill Gates and Sir Richard Branson,[124] and VC companies like Khosla Ventures.[125] PHW has put money into the Israeli startup Supermeat. Tyson has hinted that the future of food might be meatless,[126] and Branson believes that in thirty years we won't kill animals for food.[127]

Although no cellular meat or dairy products are available in retail outlets or to eat at restaurants, costs associated with their manufacture (still in the lab) have plummeted, although they are still far from parity, both in terms of cost of production or (except for Finless Foods' tuna) potential retail price.

THE MARKET CHALLENGES FOR PLANT-BASED MEAT AND DAIRY

The market challenges for the plant-based meat and dairy industry are different than those for cellular animal products, although there are continuities and contiguities. The challenges can be separated into three main areas: knowledge of plant properties, meeting the demands of plant production, and understanding how plant proteins interact.

KNOWING YOUR PLANTS

Most of the world's population currently receives most of its protein from plant-based sources. A 2010 report from the United Nations Food & Agriculture Organization (FAO) found that globally 57 percent of protein supply came from plants, with 18 percent from meat, 10 percent from dairy products, six percent from fish and shellfish, and nine percent from other animal products.[128] Humankind is aware of around 30,000 edible plant species on the planet, and yet we grow only around 150 of them. Of these, we employ a mere 30 to provide 90 percent of our diet.[129]

In fact, three-quarters of the food we eat comes from only twelve plant and five animal sources;[130] wheat, corn (maize), and rice form half the protein[131] and almost 60 percent of the plant-based calories for the majority of the world's diets.[132] These three are often subject to genomic innovation and breeding.[133] At the moment, the major sources for plant-based meats are soy and wheat. This is partly a consequence of their widespread availability, given industrial agriculture's concentration on growing corn for ethanol[134] or soy,[135] wheat,[136] and corn for livestock feed in large monocultures.[137]

The relative dearth of contemporary scientific knowledge surrounding the many other plants that could be used for food (or constituent elements of it) is matched, according to Justin Siegel, an assistant professor of molecular medicine at University of California-Davis, by how little we understand about the health benefits or otherwise of any foods—especially in comparison to the drugs in our medicine cabinet. He noted at the 2018 Good Food Institute Conference in San Francisco that the U.S. National Institutes of Health spent $30 *billion* on diseases that affected "old white men" (his words) whereas the U.S. Department of Agriculture's budget for understanding the health of food was a mere $300 *million*.[138]

Not only is the plant kingdom clearly ripe for further research let alone utilization for food, but the genomes of these plants could be altered to develop novel flavors and textures.[139] Research on plants at universities is at the moment linked to their utility for our current agricultural system, which is geared toward yield and nutrition as opposed to taste or texture.[140] Therefore, one challenge is to research and then reimagine the range and varieties of plants that could be used for plant-based meats and milks.

Companies are already showing increased interest in a wider variety of plant sources, as well as legumes, fungi, grains, and seeds, for their products.[141] Roquette and ADM are investing in a study on peas for use in plant-based meat and dairy,[142] and ADM is opening a legume-processing plant in North Dakota to produce pea protein.[143] Celeste Holz-Schietinger, director of research at Impossible Foods, is excited about the textural possibilities of the protein RuBisCo, which is found in leaves,[144] making it the most abundant protein source on the planet.

Students of Peggy Lemaux, a cooperative extension specialist in the department of plant and microbial biology at UC Berkeley, are investigating so-called ancient grains—like sorghum and millet—for their properties.[145] David Benzaquen, CEO of Ocean Hugger Foods, which offers plant-based versions of Asian tuna made from tomatoes (see image on next page), is a champion of duckweed (lemna).[146] Lupin,[147] flaxseed, hemp,[148] as well as various nuts, are also being used or seen as possibilities for expanding the varieties of non–animal based meat and dairy products.

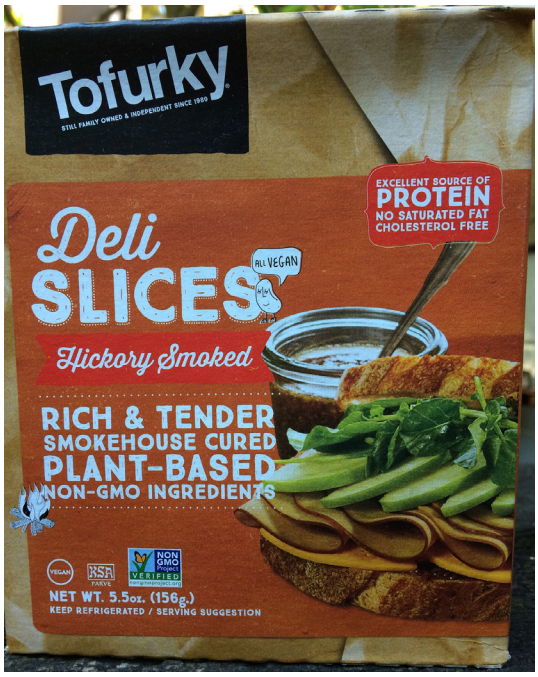
Ahimi from Ocean Hugger Foods

PRODUCING THE PLANTS

The second challenge is a matter of meeting supply and changing growing patterns. Since different proteins create different textures, and since different global markets require different levels of "meatiness" in their proteins, balancing the processability of a product with its flavor and texture cannot be one-size-fits-all.[149]

For example, according to Brian Plattner, director of food and industrial products at Wenger Manufacturing, soybeans are mainly grown for their oil content, although they might ultimately be more valuable for their processability, which is not yet a priority. Because of consumer apprehensions about celiac or gluten allergies, processors such as Wenger are exploring other legumes, flax, and potatoes for texturization. In Plattner's company, flax and potato are used for binding; and wheat, soy, and pea proteins are employed for extrusion, which is the method that squeezes mixed ingredients through tubes to mold them into shapes.[150]

Theoretically, successful experimentation with and utilization of greater varieties of plants for a wider variety of purposes should incentivize further research and encourage farmers to plant and harvest more different types and strains of grains, legumes, pulses, and nuts to supply the plant-protein market. Canada, which accounts for 30 percent of the world's pea harvests, increased its production of dried peas by 51 percent in 2017, to 4.8 million tonnes, with yellow pea varieties accounting for 4.2 million tonnes.[151] Some farmers in the U.S. upper Midwest are growing more pulses,[152] which have the added benefit of fixing nitrogen in the soil and reducing problems with diseases and pests. Furthermore, these plants can be intercropped, and their planting times can be staggered.



Substituting one crop for another is not, however, a panacea. According to Scott May, founder of MISTA, an innovation incubator at Givaudin, a flavors and fragrances developer,[153] many plant-based products employ only 20 percent of the plant for food, with 80 percent wasted: pea protein, for instance, is utilized for its carbohydrate properties, and the fiber is removed.[154] So, increasing the utility of more of the plant for other purposes within food creation would be a useful added value, given that soy's versatility gives it many advantages in current production systems.[155]

Whether Big Ag is prepared to make the switch from mass monocultures to capture the possibilities of a much more varied plant stock—and how quickly—is an important question, especially given the current realities facing farmers. These consist of (as of June 2019): government appropriations to offset the losses caused by the Trump administration's trade war with China;[156] the difficulties of making money when growing commodity crops for export;[157] the rising expense of land, labor shortages, personal indebtedness that affects many small farmers and contractors,[158] and extreme weather events. (Opportunities to help farmers are discussed in greater detail in the "Recommendations" section on p. 38.)

Diversifying and engaging more farmers in this shift to plant-based proteins for human consumption are needed commercially as well. As Barb Stuckey, president and CIO of Mattson, a food and beverage innovator, observes, plant-based producers need to offer a smooth supply chain from manufacture to retail, since empty shelves mean lost revenue for supermarkets and producers, and discourage those retail outlets from re-ordering.[159] Companies are already struggling to meet demand. Beyond Meat was forced to delay launching its products in the U.K. in 2018 because it could not keep up, despite trebling its capacity.[160] Tofurky, which has recently seen 25 percent growth year over year, has also been challenged in production; and Oatly, manufacturers of an oat-based milk, found

its product exceeded all sales expectations, leading to some stores not being able to receive supplies.[161] On April 30, 2019, CNN ran a story that the country was running out of Impossible Burgers, following the announcement of Impossible's deal to sell its burgers in 7,300 Burger King locations around the U.S.[162]

MAKING PLANTS TASTE GOOD

Chemical engineering and computer technology can now quantify the molecular structures of why something may taste good or bad, and allow combinations of chemicals to mimic flavors and smells found in other substances.[179] The result is a greater understanding of the complexity of the human response to consistency, texture, and juiciness, mouth-feel, bite, and flavor. Food science also now has clearer ideas of how and whether ingredients chosen for certain purposes release their desired properties at the right time and in the right order during the cooking process.

In this case, increasing computational sophistication and scientific knowledge about food have served to reveal just how complex and multi-dimensional are our sensory and neurological experiences of eating food. One challenge within plant-based cuisine is that in the course of manufacture and cooking, chemicals and proteins may interact to inhibit the release of desired flavors and smells or do so in a manner that is picked up by our nose and palate as an "off-note"—

TO BE *VEGAN* OR NOT TO BE *VEGAN*

When it comes to consumer acceptance of plant-based meats and dairy, considerable angst[163] exists over the use of the "v" word. Some surveys have shown negative consumer attitudes toward the term and those who label themselves as such.[164] Those working in marketing, such as Barb Stuckey of Mattson, fear the ***vegan*** label drives away "flexitarian" consumers by making them assume the product is only for vegans, and that because it is labeled ***vegan***, the product must taste less than delicious.[165]

Guaranteeing access to the non-vegan market is not a trivial matter (70 percent of Beyond Burger's consumers aren't vegetarian or vegan),[166] especially given the food industry is grappling with a proliferation of actual or conceptual labels for products with fewer or no animal ingredients, or differing animal welfare standards.[167] For some, ***veganism*** is a byword for faddishness and dilettantism.[168] Some doctors have criticized the term ***vegan*** as not necessarily descriptive of a healthy diet (Oreo cookies, soda, and French fries, after all, contain no animal products). Certain "vegan" physicians prefer to describe their diet as "whole-food, plant-based" (WFPB).[169] This is also not a matter of semantics. Unfortunately, as vegan nutritionist Ginny Messina has observed, some vegan diets may be a cover for an eating disorder, if the diet is unnecessarily restrictive of essential nutrients.[170,171]

By contrast, some vegans have questioned the use of WFPB because it doesn't necessarily exclude animal products.[172] They have observed that veganism is as much a commitment to a set of values as it is a dietary habit or lifestyle choice. They point out that veganism has become fashionable,[173,174] and offers a conveniently clear message to consumers about ingredients. Certainly, this last observation lies behind the decision by Sergio Eleuterio, general manager of Springboard Brands at the Kraft Heinz Company, to emphasize the long-standing commitment of Kraft's venerable Boca Burgers to plant-based eating, by placing the word ***vegan*** prominently on the packaging.[175]

As if to confirm the confusion around the impact of the "v" word, a 2019 Faunalytics survey of meat-eaters discovered that ***vegan*** was considered more attractive a descriptor than ***plant-based*** among most consumers, although the notably un-descriptive term ***feel-good*** outperformed both, and ***direct protein*** appealed most to young men. The survey concluded that different audiences would require different approaches and potentially different terms (a nightmare for product manufacturers), but that ***vegan*** might not be as toxic in the marketplace as some had thought.[176,177]

Whether or not to use the word ***vegan*** reflects divisions and different perspectives between and within the plant-based and cellular meat spheres. As for whether or not cellular meat or dairy can be considered vegan, or whether it matters at all: since neither can yet be made without an animal being harmed or killed at some point in the process, this argument is, for the moment, moot. As for their health profile: even without the animal-based medium in which they are currently grown (see "Terms of Reference" on p. 18), these products are likely to contain cholesterol and some form of saturated fat, and may indeed have to be treated with antibiotics to prevent bacterial infection in their production.[178] It's possible that once cellular agriculture becomes a reality, the definition of ***vegan*** as "free of animal derivatives" may shift to "animal-free"—reflecting the fact that the meat and dairy product no longer depends on the death or suffering of the animal from which it was derived. ●

such as "grassiness" or mealiness.[180] Celeste Holz-Schietinger of Impossible Foods notes that many different compounds operative within animal flesh are not intrinsic to meat: it's the combination of these compounds at the correct temperature that creates the experience of "meat."[181] "Off-notes" can emerge from particular plants when cooked or processed at various temperatures, and from when they're combined. For instance, some proteins lead to an unpleasant taste or aroma that we might define as earthy, beany, green, cardboard-y, bitter, astringent, or chalky.[182] (See image below.)

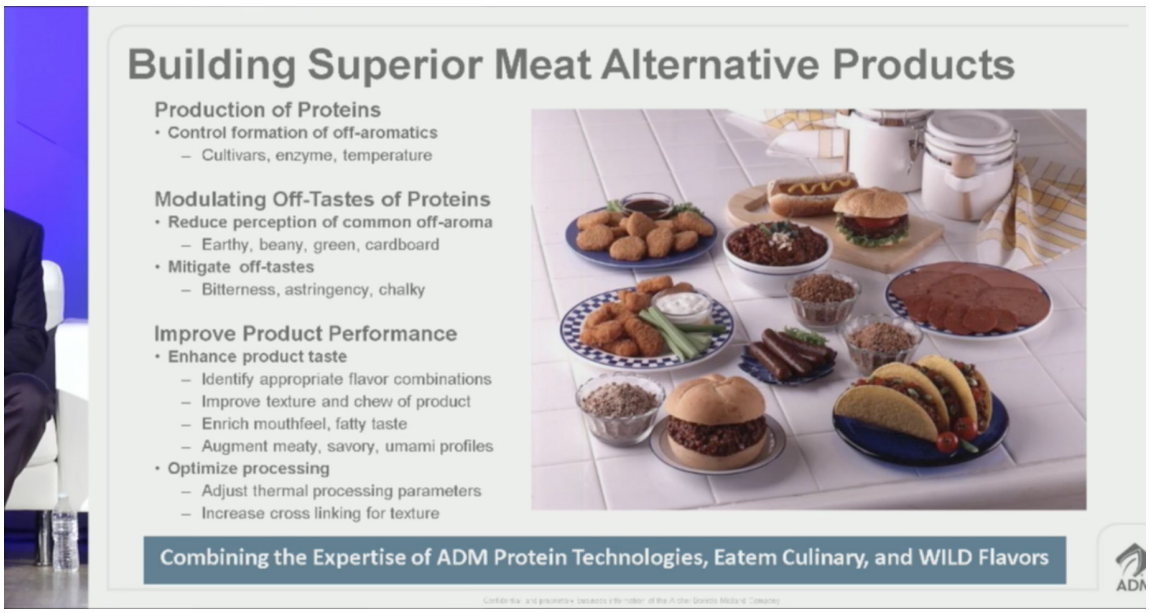
Conventional breeding for the removal of "off-notes" or addition of desirable properties can take years. Editing the plant's genome, however, as plant and microbial biologist Peggy Lemaux has observed, is a much faster and more efficient means of shaping a particular crop, especially as the genome sequences for commonly used crops are already known.[183] Indeed, given what remains to be discovered about plants, maintaining crop genetic diversity may be vital to locating possible plant sources for many sorts of tastes, textures, and flavors—as well as providing more varied sources for the food products themselves.

Such is the sensitivity of human organs of taste and smell that we can discern "off-notes" where scientific readings determine no difference. Moreover, we are only beginning to learn how our brain processes the information it receives from food receptors in the mouth, and that receptor sensitivity isn't necessarily matched by our ability to describe accurately just how the item is "off."[184]

These vagaries form one reason why artificial intelligence (AI) and predictive analytics (such as that being implemented by Scott May at MISTA, the innovation incubator) or psychophysics (a particular interest of Lav Varshney, assistant professor of electrical and computer engineering at the University of Illinois) are being employed to quantify sensory responses to flavors and taste perceptions in a manner that more accurately reflect customers' physiological reactions.[185] Whether it's possible to separate our predisposition to consider a food "needing" to taste a certain way because of its social identity from any neurochemical disgust or revulsion we may have at how a food looks, or its supposed source, is a matter of contention. For Varshney, the potato (see "Pomme de Terre, Anyone?" on p. 15) provides an object lesson on the limitations of data in the context of perceptual notions of the suitability or otherwise of a certain food within a social structure.[186]

CONSUMER ACCEPTANCE

Surveys have suggested that most purchasers of plant-based meat and dairy products are those who wish to eat less meat rather than no meat at all.[190] Judging by the growth in the marketplace, it would appear that consumers are neither confused that the products aren't animal-based nor particularly worried about how closely aligned these products are to the "real" thing.[191] (For efforts by animal agriculture to redefine meat and dairy products, see "Regulatory Challenges" and "What Is Meat and Dairy?" in the cellular agriculture portion of this paper.)



Photograph of a Slide from the Presentation of Mark Matlock, Senior Vice-President of Food Research at ADM, at the 2018 Good Food Institute Conference, San Francisco

POMME DE TERRE, ANYONE?

The potato, introduced into Europe from South America in the 1500s, was long considered a staple source of food in France . . . for pigs. French cuisine resisted it until scientist Antoine-Augustin Parmentier (1737–1813),[187] captured in the Seven Years War and forced to eat potatoes in prison, promoted it as a healthful addition to the French diet in his post-release 1789 volume on the potato, sweet potato, and Jerusalem artichoke.[188]

Despite Parmentier's best efforts to cultivate the potato's fashionability among the rich and famous, the French public would not be persuaded. Finally, in 1794, *La Cuisinière Républicaine*, a cookbook written by one Madame Merigot, illustrated many ways to prepare the vegetable. The tuber's popularity, associated with the virtues of republicanism, finally overturned French reluctance to embrace the potato.

This story illustrates the challenges facing manufacturers. A food's edibility depends on categories of appropriateness,[189] social acceptability, and demonstrated utility—at a remove if not wholly divorced from price, taste, or availability; supposed exclusivity or class affiliation; or, for that matter, a nation's perception of its food culture.

Indeed, the thing itself may, in essence, be irrelevant. Potatoes weren't novel, they were known not to be harmful, and many people ate them—except the French. Lav Varshney argues that Madame Merigot's cookbook took the three elements of consumer adoption (pleasantness, novelty, and familiarity) and created a narrative path for the French public to overcome their resistance to adoption. How and whether plant-based and/or cellular meat and dairy products need to do the same remains an open question (see "Consumer Acceptance"). ●

Although the growth in plant-based meat and dairy products may reflect a greater degree of consumer interest in and comfort with plant and dairy analogues of various kinds, those who eat animal products are often uninformed and contrarian in their attitudes, to say the least. In a 2017 systematic review of consumer perception and behavior on sustainable protein consumption, the authors concluded that consumers didn't understand the effects of meat consumption and production on the environment. When they were told about it, most were unwilling to change their meat habits and didn't want to replace conventional meat either with substitutes, cellular meat, or insects.[192]

As Haley Swartz, research program coordinator for the Johns Hopkins University's Berman Institute of Bioethics, suggests, mirroring other observers in this space, environmental messages may not resonate with consumers focused on taste, price, and convenience or preoccupied with perceived threats to their freedom of choice or the familial, social, and other associations they make with meat.[193]

This resistance might partly be due to the failure to disaggregate the food item. In considering consumer acceptance of a plant-based "substitute," it is tempting to think of the patty, sausage, or mince; wheel, spread, or slice; or drink or fermented dairy product as more-or-less self-contained components of a meal. Yet, as food marketers have reminded us, the food landscape has been diversifying for decades. We now consume food in many different forms, on different occasions, and for different reasons: from snacks to family dinners, impulse purchases to institutional cuisine.

In considering how plant-based products might enter the marketplace, therefore, Barb Stuckey of Mattson suggests that manufacturers move away from thinking of the center of the plate as the locus of change and consider other means of delivering a meal: prepared foods and snacks, such as soup, pizza, or sandwiches.[194] For Alison Rabschnuk, leader of corporate engagement at the Good Food Institute, shelf-stable products and the refrigerated section of the grocery store offer great market potential, as does supplying food-service companies rather than retail outlets, institutional food providers rather than restaurants, and ingredients rather than products.[195]

This last category (ingredients rather than products) presents an interesting opportunity to animal-meat suppliers, which has not gone unnoticed by some in the industry. According to meat scientist Benji Mikel, speaking at the 2018 New Harvest Conference at MIT, once an animal dies the flesh begins to dry, grow hard, decay, and lose color. To compensate for these biological processes, the meat industry marinates the flesh in water and sodium phosphate and adds modified food starch, soy protein isolate, carrageenan, gums,

seasonings, and flavorings to make meat resemble what consumers *expect* it to look like, and to help it last longer and taste better.[196] So much, one might add, for the "naturalness" or even "whole-food" quality of meat!

As Mikel points out, it's possible that plant-based ingredients might provide additional components for meat products and thus reduce the amount of meat in each meat product, as is the aim of the Better Meat Company, co, which according to its website (https://www.bettermeat.co/) is "a business-to-business company that helps institutional food sellers boost their meat products by using less meat and more plants." Such ingredients might, Mikel has observed, extend meat's shelf life, and provide added tastes, textures, and colors that would enable some meat-production companies to remain in business and even expand into new markets, which is *not* the stated aim of the Better Meat Company.

As Mikel has suggested, and as Lauren Sammel, a food scientist at Johnsonville, a sausage-making company, noted at the 2018 Good Food Institute Conference, there are many "consumer-facing" problems with current meat production that cellular biology and plant-based meat production could, theoretically, address, or vice versa. These are quality defects, shelf life and oxidation, color and color stability, fat supply, the physical state of the muscle, the consistency of the raw material, the functional ingredients, and labor shortages.[197]

Interestingly, some farmers within current animal agriculture operations are warning their fellow ranchers and feedstuff providers to recognize the changes in the food landscape and not ignore them. Chuck Jolley, president of the Meat Industry Hall of Fame, writing in *Feedstuffs* magazine, compares cellular meat to the technology of the personal computer and the iPhone. Echoing Nick Fiddes' thoughts about meat's symbolic weight, as well as the claims of meat as essential, natural, and "real," Jolley advises those in conventional animal agriculture to resist the temptation to use data or science to combat the rise of plant-based and cellular meat products:

> Faux burgers are here to stay. It's [*sic*] a product that is doing very well at finding its niche in the market and it will prove to be significant. Dismiss it at your own peril. Instead, get busy reminding millions why the real thing is tastier and better for you. One more thing: Don't fight it with facts. Food is an emotional thing.[198]

In a similar vein to Jolley's critique, some "natural" diet and public health advocates have argued against what they see as a further and unnecessary technologization of plant foods. At the 2018 Good Food Institute Conference, Dr. Dean Ornish, president and founder of the nonprofit Preventive Medicine Research Institute, objected to Impossible Foods employing genetically modified soyleghemoglobin to deliver *heme* to its burger.[199] Ornish stated that although he understood that the overall health outcomes for consumers eating plant-based burgers might be better than if they ate the animal-based versions, he (and others) noted studies that show that *heme* may increase the risk of cancer and Type-II diabetes,[200] and may also be an allergen.[201]

At a sustainable foods conference in January 2018, Impossible was criticized for rushing its product to market before a full safety test on the product was carried out.[202] In July of that year, the FDA, after raising initial concerns about *heme*,[203] indicated to Impossible that it considered *heme* GRAS ("generally recognized as safe") and thus was not required to undergo thorough testing.[204] Ironically, *heme*, an essential protein found mainly in meat, delivers iron,[205] and it is this which gives the Impossible Burger its slightly metallic taste, and thus makes it familiar to meat eaters. Furthermore, whereas the yeast that delivers the protein is genetically modified, in a manner similar to the acellular production of insulin and rennet, the burger itself is not[206]—or at least wasn't until Impossible decided in May 2019 to use GM soy in its production.

The safety, genetic modification, and desirability or otherwise of non–farmed animal meat and dairy products

come into greater focus in the cellular agriculture section of this paper (below). However, because plant-based meat and dairy products are all processed—with potentially added salt, sugar, and various chemicals—they are by definition at a remove from WFPB diets recommended by certain doctors and nutritionists. Although, they may be considered useful, as Ornish notes, for those in "transition," it is not a given that plant-based burgers and milks will encourage people either to consume less farmed animal meat or dairy overall, or to shift to a whole-foods, plant-based diet to reduce their risk of non-communicable diseases. Indeed, although processed plant-based meat and dairy products may contain more fiber, more protein, and less fat than their animal-based counterparts,[207] health profiles of some plant-based meats and dairy may be less nutritious than the analogues they mimic—a function not merely of their taste profile but their identity in the marketplace as "fast" or "comfort" food.[208]

A further consumer challenge is that these products enter a fast-food landscape defined by monocultures. One reason why corn, wheat, and soy are relatively inexpensive to produce is because of the direct and indirect subsidies that encourage their growth, and the relatively few subsidies provided to fruit and vegetable farmers.[209] Soy, wheat, and corn, which (unlike many fruits and vegetables) can be harvested by machines and therefore don't require the additional expense of manual labor, are also used in part for processed foods such as high fructose corn syrup or feed for animals.

These, respectively, have been shown to contribute to obesity and Type-II diabetes, and (when delivered in meat and dairy products) cardiovascular disease and colon cancer.[210] In turn, these non-communicable diseases add considerably to the costs to public health, which are not reflected in the price-points of the products that people buy.[211,212]

This paper has already noted that most of the world gets its protein from plant-based sources, and that most of those plant-based sources are relatively unprocessed. As you will read later, the plant-based and putative cellular products don't necessarily address the fears of those who believe the agricultural system is overly dependent on a genetic or molecular technology that poses too many risks to the environment, the human biome, and food sovereignty. In fact, the concentration on burgers, dogs, and other forms of fast food might further cement the idea—inherent in this very paper's *raison d'être*—that "vegan food" is, by definition, processed food that acts analogously as a substitute for an animal-based default.

Here, too, we see the strange dialectic between meat-eaters and some vegans when it comes to what "vegan food" is or is not. When former Trump White House staffer Sebastian Gorka told the Conservative Political Action Conference (CPAC) in Washington, DC, in March 2019, that Democrats "want to take away your hamburgers,"[213] he was aiming to define efforts to combat climate change by reducing the consumption of beef as an anti-patriotic destruction of liberty by the nanny state.

Yet, as Carol Adams reveals in *Burger*, the composition, shape, delivery method (on a bun), and even regional origin of this supposedly quintessential and untouchable American food were all up for grabs when the patty was developed at the turn of the twentieth century. These burgers were, from the outset, subject to the manipulations of marketing, condiments, and luck, before they—like the potato with the French—received the imprimatur of the people to make a burger the quintessentially republican (and, to Gorka, Republican) meal.[214]

So, *both* plant-based burger companies and those on the "right" who wish to stop them, are staking their claims to iconic foods that seem at once already defined and yet, as Adams illustrates, their constituent parts are as inherently and multivalently malleable as, we might say, America itself. It's a further irony that, in his evocation, Gorka echoes whole foods advocates in arguing for food sovereignty as an essential, particular identity against liberal, technologized multiculturalism.

These anxieties and competing goals are more concentrated in the cellular agriculture space. However, since several of the companies producing plant-based substitutes are developing (or could develop) cellular versions, the plant-based space is not immune to the criticisms leveled at cellular agriculture.

TERMS OF REFERENCE: CLEAN, CELLULAR, CRAFT?

What to call animal cells propagated in a medium is a point of contention, both inside and outside the industry. This paper uses ***cellular meat*** or ***cellular dairy*** to describe the results of this process, and ***farmed animal*** or ***conventional animal meat*** or ***dairy*** for the products of present-day animal agricultural practices. The term ***cellular agriculture*** can refer both to animal cells in a medium, or proteins of animal origin "brewed" using a medium such as yeast, which this paper calls ***acellular agriculture***. Technically, of course, all animal products are cellular and, at the moment, the medium for cellular meat and dairy consists mainly of fetal bovine serum (FBS), the source for which currently involves the death of an animal. So, no cellular meat products as of writing are vegan, under the loosest definition of the term.

Some, for instance the Good Food Institute, prefer the word ***clean***[215]—a nod to the assumption that the manufacture of cellular animal meat and dairy will be less environmentally polluting and bloody. The term carries the meaning that, unlike conventional animal agriculture, neither the process nor product will be exposed to gut pathogens (such as E. coli, salmonella, and campylobacter) and will require fewer antibiotics or growth hormones. Furthermore, its proponents argue that its creation is likely to be more transparent, since cellular meat and dairy won't be subject to the "ag-gag" laws that make it illegal in some U.S. states to film, or take photographs or audio recordings, inside CAFOs or slaughterhouses.[216]

Ann Veneman with Ezra Klein of *Vox* at the 2018 Good Food Institute Conference, San Francisco

Understandably, some in conventional animal agriculture, such as farmed animal veterinarian Cody Creelman[217] and former U.S. Secretary of Agriculture Ann Veneman[218] (see image), have bridled at the suggestion that animal agriculture and its products aren't hygienic. Some in the cellular agriculture sphere, such as Mark Post of Mosa Meat[219] and Uma Valeti of Memphis Meats,[220] argue that the term ***clean*** unnecessarily labels the product with an emotion that may prove galvanizing internally but might not be appropriate for neutralizing opposition outside the industry.

Unlike terms such as ***lab-grown***, ***in vitro***, ***bio***, ***synthetic***, or ***Frankenmeat***, ***cellular*** conjures fewer images of scientists or their chimeras running amok. Consumer assumptions about the amount or role of technology (genetic, chemical, industrial, or electronic) in the current food system are often inconsistent or inaccurate,[221] especially given how loosely or misleadingly terms such as ***natural***, ***certified humane***, and ***organic*** are applied to products.[222] This misplaced notion of the natural is particularly relevant given the well-documented genetic distortion of farmed animals' bodies; their confinement inside factory farms; and the cocktail of hormones and antibiotics they are fed before they are slaughtered.[223] ***Cellular*** does retain a futuristic quality that may be attractive to early adopters and within the industry, although it can strike others as too clinical and technological and at a far remove from the notion of food as a warm and nourishing symbol of home.[224]

Perceptions of the cellular process as lab-based are only accurate in so far as the industry is in its early, developmental-technology stages.[225] Industry analyst Jack Bobo has suggested employing the term ***craft***[226] in order to align the products and their putative ultimate manufacturing process with artisanal, regional, and supposedly less impersonal or mechanized processes, such as brewing and cheese making. The term ***cultured*** might be similarly applied. However, it comes with its own issues: a fermenting process does not accurately reflect the process ***yet*** for all products, and surveys have suggested that consumers associate ***cultured*** with a product that has been processed or de-naturalized [***sic***].[227] Both ***cultured*** and ***craft*** could send a signal to the market that products under these labels are niche and not for the ordinary omnivore: these may lend them cachet and appeal even as they might restrict their widespread adoption.

It is already being argued in the cellular meat space that, beyond the nomenclatures the FDA and USDA (see "Regulatory Challenges") may assign to these products, branding and marketing may be more significant for consumer acceptability than terms that define the product's provenance and means of manufacture.[228] Until such processes are considered safe, normative, and widespread, however, terms such as ***cellular*** or ***cell-based*** have the advantages of being accurate and relatively neutral. ●

At the time of writing, no cellular meat or dairy products are in the marketplace—either in retail, restaurants, or in the food service industry. Neither Memphis Meat's chicken strips nor JUST's chicken nuggets have yet to hit the shelves or restaurants, and you can taste New Age Meats sausages, as far as is known, only in the lab.[229,230,231]

As far as is known is a necessary caveat in reflecting on this industry at this time. The technological challenges remain significant—not least because the basic and developmental science is occurring at the same time as private money and commercial interests are applying pressure to move from open-source, collaborative research toward patent- or trademark-protected technologies. Commercial scaling for production will likely mean further technological modifications that may require different engineering skills beyond the lab. Questions over how these products will be regulated and what they can be called; how much pushback or cooperation the industry can expect from conventional animal agriculture; and suspicions over the safety or what might be termed the "propriety" of cellular agriculture are occurring simultaneously. These exist independently of any consumer resistance that may arise once these products reach the market.

Although the cellular agriculture space is aware of these contradictory impulses, and is attempting to accommodate them all, the *Umwelt*—to use semiotician Jakob von Uexküll's word to describe the environment experienced by an organism[232]—is an occasionally whiplash-inducing mix of scientific caution and giddy futurist imaginings; stern admonitions for corporate responsibility and sales, marketing, and investment pitches; and moral fervor and a naked mercenary appeal to acquire a slice of the multi-billion-dollar global food market. Although a necessary task, separating what is true from what is probable, possible, or fantastical can be difficult for an outside observer, let alone an interested party.

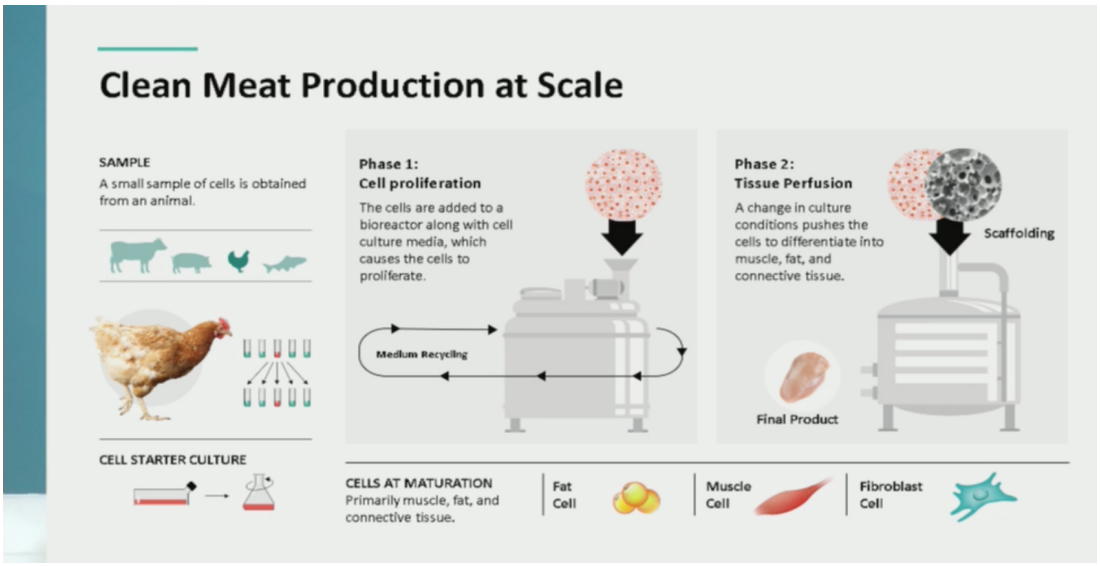
TECHNOLOGICAL CHALLENGES

The technological challenges for cellular meat and dairy remain formidable, says Kate Krueger, research director at New Harvest. Cellular agriculture, she notes, has more hurdles to surmount than other areas of scientific investigation because of a lack of standardized approach from either government or university funding to conduct this research.

Then there is the basal knowledge from which cellular biologists can work. Even though cellular biology has been known for centuries, Krueger observes, very little study has been undertaken on the cells of animals used for food.[233] Until very recently, for instance, cellular and molecular biology has largely centered on potential medical uses (such as growing skin for grafts or replacement organs), and scientists working in medicine may not be interested personally, intellectually, or financially in moving into a food space—even though they are much-needed and in short supply. The website Clean Meat lists current job openings in a number of cellular companies,[234] and they invariably involve biologists, bioprocessors, various sorts of engineers, and food scientists.

Beyond these meta-challenges, continues Krueger, are the specifics of the processes themselves: tweaking cells so they proliferate and differentiate (become muscle) faster and at scale; constructing a more efficient bioreactor for three-dimensional muscle growth; isolating, for instance, muscle cells from pigs to work on cellular pork (the task of New Age Meats);[235] researching structures for the meat to grow on and within; and making the whole process cost-effective. Indeed, the painstaking and expensive work of growing cells is itself ripe for disruption. Biocellion, a virtual experiment simulator, is endeavoring to reduce the cost of developing cellular meat through computer-aided design to create cheaper and more efficient experiments.[236]

As for the research itself, the challenges can be disaggregated into media, scaffolding, and the bioreactor.



Clean Meat Production at Scale. Photograph of Slide from a Presentation by Elizabeth Specht, GFI's Senior Scientist, at the Good Food Institute Conference, San Francisco, October 2018

A Happy Medium?

According to Kate Krueger, in order for animal cells to develop, you need salts and sugars, vitamins and minerals, protein, fats, cholesterol, hormones, and specialized proteins. The medium used to grow animal-cell culture for now consists of a combination of these and fetal bovine serum (FBS). FBS itself is made up of hormones, albumins, globulins, attachment and regulatory proteins (such as growth factors), and various other proteins. FBS is expensive to use, not fully defined, there are variations within batches because it's animal-derived, and it is difficult to source at scale.[237] To grow the single burger produced by Mark Post in 2013, for instance, required hundreds of individual cell-growing dishes, and cost $300,000.

Although it is possible to conduct a biopsy on an animal to remove a cell-line (whether an embryonic stem cell or fully differentiated muscle cells) without harming that animal, scientists appear to agree that finding a medium that doesn't involve the death of an animal is essential if cellular agriculture is to make sense as an alternative to conventional animal agriculture. Whereas some sera, such as Ultroser, exist as a substitute for FBS,[238] these, says Krueger, are also medical grade, proprietary, cell-specific, and expensive.[239]

Some companies, like Memphis Meats,[240] Mosa Meat, and JUST,[241] are claiming they have found or have developed a serum that either uses much less FBS or is synthetic or plant-based. However, much of the information surrounding the exact composition of these sera is, perhaps understandably given its potential market value, a closely guarded secret, and no serum has emerged either as a proof-of-concept or for sale that could be categorized as "vegan" in terms of its production.

So, the race to find a cheap, clean, and renewable source of non–animal derived serum is on, since the cost of sourcing and accessing enough of the current media and growth factors are the principle reason why the price of cellular meat is prohibitively high. These costs are likely to decrease once appropriate media and growth factors have been identified and can be generated at scale to meet the production of animal flesh rather than lab-based applications.[242] How fast and how much they will decrease are open questions.

In spite of these difficulties, it's clear that the range of potential media is growing. Some have suggested fungal extracts and even Gatorade as candidates![243] Another possibility is using yeast (Finless Foods' apparent formulation).[244] Triton Algae Innovations[245] is attempting to make animal proteins from *Chlamydomonas reinhardtii* ("Chlamy"), a single-cell green alga that tastes like sweet parsley. Chlamy, which is ubiquitous throughout the world, has yet to be scaled and is presently available only as a dietary supplement (it contains 847 percent of the recommended daily amount of Omega-3 fatty acids). Chlamy, claims Xun Wang, the president and CEO of Triton, may also be a good basal feedstock for cellular meat.[246]

Still another option, pioneered by futurist engineer Yuki Hanyu of Integriculture is to use cellular biology to bypass the serum and simply grow the animal organ—such as the liver—that produces the serum in the first place.[247] His company aims to bring cellular foie gras to market by 2021.[248]

Once more, caution is required in imagining the ideal feedstock. The reproduction of cells involves many different processes: myogenesis (the development of skeletal muscle cells), vasculogenesis (the production of endothelial cells),

and adipogenesis, which marbles meat with fat. (See illustration on p. 22.) Finally, comes the extrusion or stereolithography (a form of 3-D printing), or a combination of the two.[249] These procedures may not only require their own media formulation but may need to be altered for different meat outcomes; muscle cells at various stages may require different temperatures and levels of stimulation to ensure they are properly "exercised" and don't atrophy and die.

Furthermore, write Kadim *et al*:

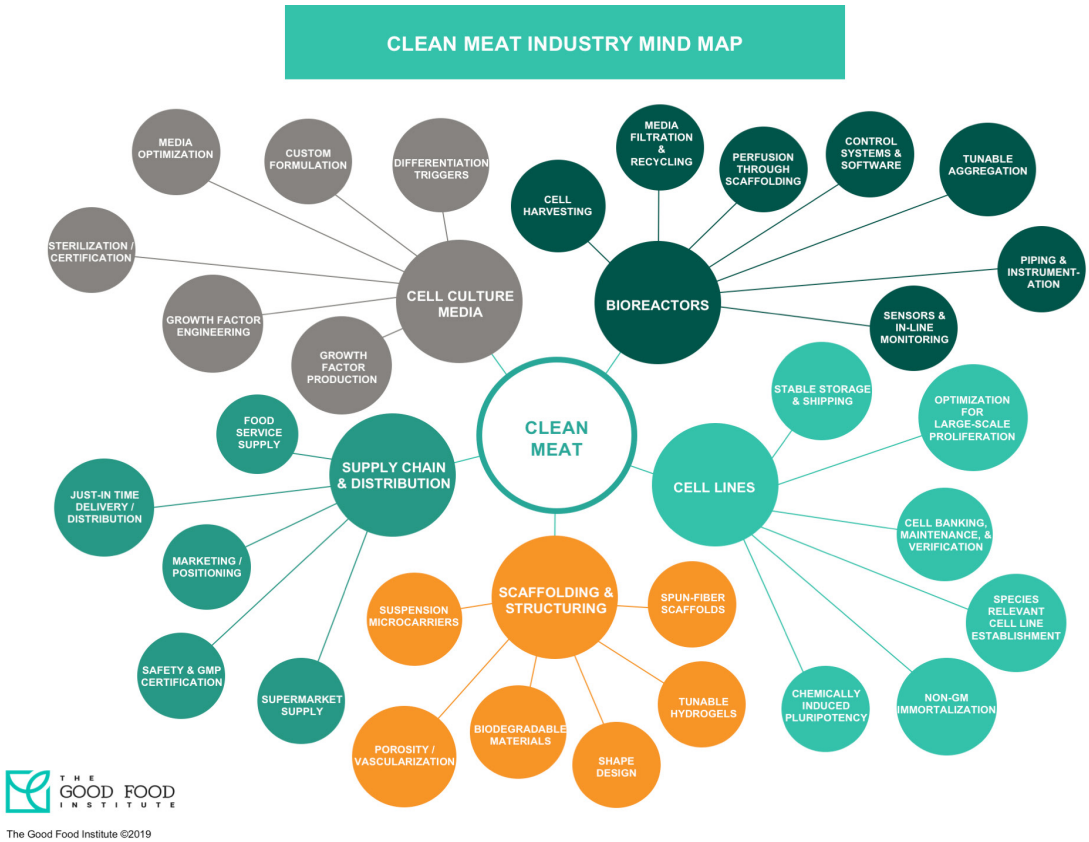
> The removal of waste products including carbon dioxide and lactate will also be necessary. . . . In the conversion of conventional muscle to meat the metabolic processes include anaerobic glucolysis, lactic acid accumulation, a decrease in pH, protein denaturation and enzymatic proteolysis. . . . These changes influence the texture, taste and appearance of meat, so it is likely that it will be necessary to ensure that comparable processes occur in cultured meat after harvest.[250]

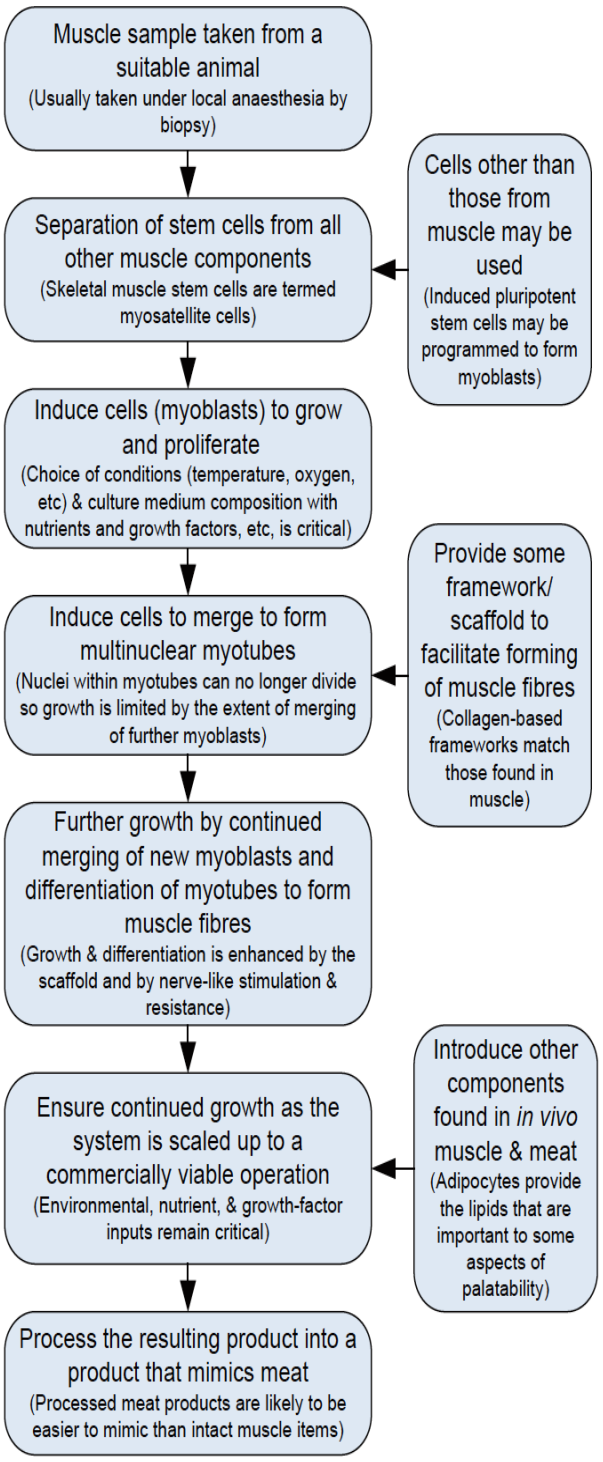
It is, therefore, safe to say that operations at scale will almost certainly be different from operations in the lab, in ways that may be unforeseeable. Recycling media to avoid or lower the amount of waste produced and reduce cost may increase the risk of contamination, so sterilizing bioreactors might be necessary, even with a "clean" product such as cellular meat. Different media may "taint" the meat with unwelcome flavors and aromas. Ironically, it's possible that vitamin B_{12} and iron may need to be added to the media to allow cellular meat to retain the properties common to farmed animal meat, and that are essential in a human diet.[251]

All these technical challenges—both known and unknown—may require phasing in the use of cellular agricultural products more slowly, and in stages. Among others, New Harvest fellow Jessica Krieger at Kent State University has suggested that, initially, animal cells might be additives for plant-based products before pure animal-cell products are created, with the final development being full-animal products.[252]

If You Build It, Will They Proliferate?

The second technological issue is the nature of the structure upon and within which those propagated cells begin to form muscle tissue: a structure usually called *scaffolding*. The Good Food Institute's "mindmap"[253] for cellular agriculture (below) identifies several components for scaffolding. It must be porous enough to allow vascularization (the "veins" that would let the serum perfuse the muscle tissue, as blood does in the body). It needs a design and a biodegradability





A flow diagram illustrating in general terms some of the steps in the production of a cultured meat product. From Kadim, Isam T. *et al.* "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* (2015) 14(2): 222–233.

such that meat is formed with the desirable consistency and without elements of the scaffolding negatively affecting that taste or texture. The scaffolding could contain suspension microcarriers, like polymer beads, that would allow the individual muscle fibers to develop; and hydrogels, perhaps from algae, mycelium, or cellulose, that would let muscle cells self-organize into tight fibers, and within which they could be stimulated to grow.[254]

Polymer beads in suspension might be suitable for generating ground-meat products,[255] but whole cuts will require a more robust scaffold. Mycelium (the vegetative part of fungus) might be optimal in this space. Ecovative Design is using mycelium to manufacture biodegradable packaging; however, it hopes to use mycelium as scaffolding for cellular leather, bone, and meat, as well as (through Bolt Threads) a leather-like fabric.[256] Three New Harvest fellows are currently researching Asian pears, carrots, rose petals, asparagus, and mushrooms as potential scaffolding.[257]

Plants offer an attractive option for scaffolding. Engineers in the U.K. are using grass to grow animal cells.[258] Glenn Gaudette, a tissue engineer and professor of biomedical engineering at Worcester Polytechnic Institute, has demonstrated how spinach leaves, with their DNA removed, provide a transparent vascular system that, much like the human one, can supply nutrients through porous veins to the muscle cells that form around it. With calcium inserted into the system one can stimulate an electrochemical reaction that pumps those nutrients through the veins of the leaf.[259]

Gaudette's background, expertise, and interest in collaboration illustrate the debt to, potential crossover from, and integration that cellular meat can share with new therapeutic models of cellular biology (beyond artificial valves or pigs' hearts). Grass and spinach leaves are obviously abundant, adaptable, variable, and health-supporting, and may well be cheaper than scaffolding from synthetic materials.[260]

Scaling It Up

Third, there are questions over the nature of the design of the "bioreactor" in which the cells will be grown at scale. Some progress has been made in moving from tiered culture flasks to first- and second-stage bioreactors. But these remain on a small scale. Moreover, warns Kate Krueger of New Harvest,[261] eventual bioreactors may look very different from the "fermentation" tanks that cellular agriculture visionaries are touting.

Jessica Krieger is developing (along with other New Harvest engineers) a bioreactor with a system that pumps nutrients and artificial blood into the developing cells and removes waste, thus "exercising" the muscle and helping it grow. The hope is to increase the amount of tissue and the

speed at which it is developed.[262] Finally, leaving the laboratories and animal-science departments in which these labs are currently situated, and moving toward a self-contained, engineered system at scale present challenges both known and not-yet-addressed, and unknown and therefore not-yet-addressable.

Brian Spears of New Age Meats is a chemical engineer employing an integrated, interdisciplinary approach to data to develop automated cell-line structures and mini bioreactors. He is skeptical about the timeframes suggested by some in the industry,[263] as well as cautious about the challenges of scaling-up. He echoes Adam Flynn's reservations (see "The Naysayer" on p. 24) about the difference between lab and commercial production:

> Many of [the cellular meat companies] are still taking an academic approach, saying, "We'll perfect this in the lab and then we scale," rather than approaching this as an industrial automation project. Cells don't behave the same way in the 2D environment vs. a 3D environment, so you have to address the late stage questions earlier.[264]

BRINGING THE MEAT TO MARKET

Commercial challenges can be found at every stage of the manufacturing process.

For all the hoopla surrounding cellular agriculture, by the latter half of 2018, according to Justin Kolbeck, CEO of Wild Type, a cellular salmon company, fewer than 150 people were developing cell-based meat. Most were employed as scientists, with vast areas of the business awaiting scientific exploration let alone commercial exploitation.[265] Isha Datar, CEO of New Harvest, echoed this challenge in a podcast aired in May 27, 2018. Creating tissue culture *in vitro* was only a decade old, she said; engineers whose experiences were with human and animal tissues for scientific purposes weren't working with cells that mattered for cultured meat. Food science labs didn't have a lot of experience with tissue-culture capabilities—except on medical applications on a small scale, rather than delicious, inexpensive, and sustainable cells in great quantity for food.[266]

These realities in turn suggest that the technological challenges might be harder to overcome, given pressure from investors to move scientists from collaborating and sharing research to patenting products and processes, and then commercializing ingredients, design, and products. Such pressures will by default complicate current calls for transparency, the publication of open-source research, and third-party corroborative analysis.

Furthermore, it's likely that within the next few years, the necessity of accessing proprietary technologies and patenting or trademarking will lead to some companies requiring more capitalization, merging, being purchased by pre-existing protein suppliers, or failing altogether because of over-specialization or the lack of it. Other companies may choose to concentrate on supplying businesses with constituent parts and processes of the assembly chain (including additional cellular components for farmed animal meat products, or plant-based additives for cellular meat products).[267]

Refining the ability of yeast, bacteria, and enzymes to create biomaterials and animal byproducts (acellular agriculture) may represent a surer and quicker way to market, and thus be a timelier return on investment. However, these biomaterials might ultimately have less market potential, although not necessarily be less profitable, than developing a cellular fish or meat product.[268] Other companies may move away from retail and direct-to-consumer markets into institutional sales.

Indeed, although large protein providers such as Tyson and Cargill at the moment remain only investors in cellular meat companies, a consequence according to David Benzaquen (at least in part) of risk aversion among current shareholders,[269] it seems probable that once the technological issues have been solved, these multinationals will either purchase the technology, hire its developers, or replicate the technology within the company.

This consolidation might occur at the same time as another round of major investment responds to actual products and processes at market readiness, even if at high prices or with limited availability. (Indeed, the exclusivity and premium status afforded by the products may make them attractive to some consumers.)[270] The attractions for any business are obvious: Tobias Citron of Radicle Lab has estimated the total addressable market for the full replacement of animal products might be $US1.6 *trillion*; even the market that is immediately in reach represents a $US44-billion opportunity.[271]

Tyson, the largest processor and marketer of meat in the United States, has already indicated its competitive advantages in this space. Given the challenges facing any company to expand manufacturing capacities, lock in feed supply, meet exponentially increasing demand, and deliver a consistent product over a wide geographic area, cellular agriculture may require the scale that a corporate agribusiness like Tyson provides to meet market and consumer expectations. In turn, such economies of scale may be required to lower costs of manufacturing[272] so products achieve parity with those of conventionally farmed animal meat and dairy.

THE NAYSAYER

For Adam Flynn,[273] the founder of ForeLight, which is engaged in creating "naturally derived replacements for synthetic ingredients used in the food & beverage, animal feed, health and cosmetic industries," employing blue-green algae and other photosynthetic organisms, the entire mindset of the current cellular agriculture industry is a problem.

Based on his own knowledge of the failures of the algal biofuel industry to disrupt the fossil fuels industry,[274] Flynn told the 2018 New Harvest Conference at MIT that he was troubled that cellular agriculture, like biofuels, was making huge claims about solving problems orders of magnitude beyond its current technological or business-scale capabilities. For Flynn, cellular agriculture had many applications for its emerging technologies that were more immediately in reach and profitable than building a T-bone steak.

For Flynn, the cellular agriculture community was too supportive and not critical enough of itself—either in ensuring that bad ideas aren't funded or that development is thought through clearly.

It would, he considered, be more prudent, responsible, and strategic to develop technical solutions, expertise, and capacity, as well as earning revenue, at each stage of the process. For instance, it would be sounder to develop collagen for spinal-disk replacement, where the product could sell for hundreds of dollars a piece, than to marble meat (a marginal addition at best). Likewise, it would be wiser to attempt to take the ground beef out of beef—where the added monetary return on the product would likely be greater than (in an implicit dig at JUST)[275] removing the eggs from mayonnaise.

Even at this relatively early stage of development, it was clear to Flynn that cellular agriculture would always be a business-to-business and not a business-to-consumer industry.

A further problem observed by Flynn, echoing Brian Spears of New Age Meats, was that due to cellular agriculture's origins within the biology labs of animal sciences departments, engineers who might be able to offer the kind of systemic thinking and scalable solutions essential to commercialization were not being brought into the process early enough. Doing so, would likely correct a conceptual bias that orients itself to the development of the cellular structure of the animal it would otherwise become rather than the bioreactor it is destined to be grown in.

Even beyond these systemic difficulties, Flynn believed that the amount of private capital available to cellular start-ups at the moment (just under a billion dollars at the time of writing) was woefully inadequate. He said that the industry required $US12 billion, as well as the technical skills and all-round capacities of major corporations or governments, if it was to meet the challenges of delivery and performance at scale.

For Flynn, the cellular agriculture community was too supportive and not critical enough of itself—either in ensuring that bad ideas weren't funded or that development was thought through clearly. He feared that the premature launch of a product that was either unsafe or a huge monetary loss for investors could hold back market acceptance or development for a decade or longer. His unease was shared. Ricardo San Martin, research director of the Alternative Meat Program at the Sutardja Center for Entrepreneurship and Technology at UC Berkeley, told the audience at the Good Food Institute's 2018 Conference in San Francisco about his concerns over maintaining the supply chain, unanticipated health issues caused by a product, and the product having a high carbon footprint. To ensure that the process worked as a whole, San Martin observed, required more transparency and third-party corroborative analysis.[276]

Even at this relatively early stage of development, it was clear to Flynn that cellular agriculture would always be a business-to-business and not a business-to-consumer industry: it was the only way the industry could benefit from the economies of scale already embedded in the agriculture and food delivery systems. As such, he said, cellular agriculture was already crying out for streamlining and consolidation—with the remaining organizations either forming their own trade association or joining existing ones. ●

Regulatory Challenges

Although the cellular meat industry in the United States recognizes the difficulties faced in bringing products to market, it acknowledges the prime need for a sound regulatory structure to allay potential fears regarding this new technology.

At the moment, U.S. governmental regulation focuses on what ingredients and processes could be "generally recognized as safe" (GRAS), what are novel or unique, and what processes or substances might cause contamination. After some jurisdictional squabbling,[277] the Department of Agriculture (USDA) and Food and Drug Administration (FDA) in October 2018 agreed to act as joint regulators for cellular meat and dairy products: the latter tasked with regulating food and ingredients and determining the safety of ingredients, including those in meat, poultry, and biotechnology; the former responsible for meat and poultry and their products.[278]

The decision to regulate jointly presents potential obstacles as well as benefits. In the case of the former, joint regulation might lead to more bureaucratic wrangling and political interference. In the case of the latter, it might open a clearer pathway from where cellular meat currently is (as a biological-scientific process within the purview of the FDA) to where it wants to be (as a food item associated with other protein sources, and thus within the purview of the USDA). On the face of it, therefore, there would appear to be little regulatory variability that couldn't be encompassed by the current U.S. governmental system.

Big Ag may find it needs plant-based and cellular meat companies more than it thinks: either in growing the media that cellular agriculture will require or using food science to expand the range, sustainability, and shelf life of their products.

Either way, the cellular agriculture industry appears to recognize, according to Deepti Kulkani, partner in the food, drug, and medical device regulatory practice at the law firm Sidley Austin, that all parts of the cellular meat–production process (ingredients, media, scaffolding, and bioreactor) would need to be inspectable and traceable—including ensuring that ingredients that may undergo change during manufacturing—even those that are GRAS—are appropriately labeled and the facility is clean. The agencies would need to be assured that facilities have controls in place to prevent unique hazards and toxicity, and establish levels of purity—known as HACCP (Hazard Analysis and Critical Control Points). The industry is aware of this, with those, such as Kulkani and Eric Schulze, vice-president of product and regulation at Memphis Meats, who were themselves regulators, urging cellular agriculture companies, even those in their earliest stages, to welcome regulatory oversight and document thoroughly every component of their business.[279]

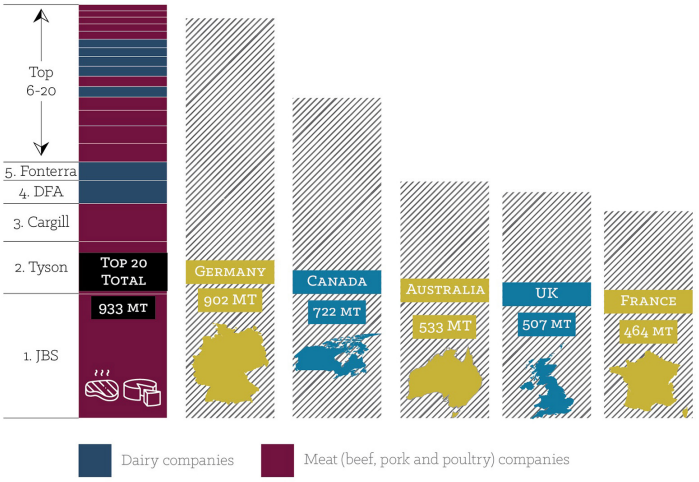
One of the purviews of this regulatory structure is likely to be the standardization of current and future cellular technologies. Regulation and standardization will need genuine third-party certifications and the checks and balances provided by rigorous academic and civil society groups examining the entire chain from development to product rollout. These, in turn, will require transparency, thorough safety assessments, and clear standards and definitions. They will also demand less hype and more realistic timeframes to obviate false expectations.

A further regulatory question is whether the plant-based and cellular agriculture industry might wish state or federal governments to go beyond their limited purview of what cellular meat and dairy will be called and determinations about its safety. Perhaps not surprisingly, given their nascent and potentially difficult relationships with governmental agencies and conventional animal agriculture, most entrepreneurs in the plant-based and cellular meat space prefer not to engage with food policy, except when it infringes on their rights to call their products "meat" or "dairy."

For instance, when the author of this paper asked Celeste Holz-Schietinger of Impossible Foods and David Benzaquen of Plant Based Solutions whether they thought companies might wish to pressure government to remove subsidies from conventional animal agriculture, Holz-Schietinger stated that Impossible Foods' strategy was customer-based, and Benzaquen argued that the Good Food Institute and the Plant-Based Food Association were doing the necessary work of making sure that food is not labeled disadvantageously for plant-based and cellular products. Benzaquen argued that business could generate change much faster than policy.[280]

As meat scientists Benji Mikel and Lauren Sammel have suggested at the New Harvest and Good Food Institute conferences respectively, Big Ag may find it needs plant-based and cellular meat companies more than it thinks: either in growing the media that cellular agriculture will require or using food science to expand the range, sustainability, and shelf life of their products.[281] With the investments made by Tyson, Cargill, and ADM in the plant-based and cellular agriculture sectors, neither conventional nor cellular agricultural industries may see strategic reasons to disturb a food system geared to growing the crops that might literally constitute the product they're trying to manufacture and sell.

Another area of potential policy conflict or synergy may be political or social pressure on financial institutions to move their investments from conventional animal agriculture because of corporate social responsibility (CSR) mandates from shareholders and higher insurance costs. The latter might come from future crop[282] and livestock loss[283] due to heat stress caused by climate change, and public health challenges as a result of antimicrobial resistance because of the global overuse of antibiotics in industry rearing practices.[284] This is the approach of FAIRR: an organization that with eighty institutional investors with assets of $12 trillion is pushing asset managers in large financial institutions to switch investment from large-scale intensive animal agriculture.[285]



Sources: GRAIN & IATP. See Appendix, Methodology Note, Section B.
"Greenhouse gas emissions," OECD. Accessed 17 June 2018. https://stats.oecd.org/Index.aspx?DataSetCode=AIR_GHG.

The top 20 meat and dairy companies combined emit more greenhouse gases than either Germany, Canada, Australia, the UK or France.[288]

Tyson, Cargill, and others may accelerate their investment in and diversification of protein sources to reduce their financial liabilities as well as demonstrate that the industry is contributing to meeting the climate-change goals of the Paris Agreement,[286]—especially given the enormous GHG emissions multinationals such as Tyson, Cargill, and Brazilian behemoth JBS produce (see illustration, right).[287] Whether such a move would prolong conventional animal agriculture or hasten its demise is an open question.

Consumer Challenges

The notion that we stand on the verge of a revolution in food science permeates both the plant-based and cellular agriculture spaces. In general, there is a faith that technology will solve apparently insuperable problems. However, even within plant-based and cellular industries defined by moving "beyond" and making the "impossible" possible, strategies for broadening consumer interest remain unclear—especially as foods that seem novel and technologically advanced may be exciting and forward-thinking to some, but worrisome or even dangerous to others.

Both the Good Food Institute and New Harvest conferences have featured speakers who emphasize how essential it is for cellular agriculture companies to prepare consumers for new food items well in advance of their introduction into the marketplace. Whether it is Ron Stotish of Aquabounty,[301] the company behind the genetically modified AquAdvantage salmon,[302] or Katharine Kreis of PATH Innovation,[303] who spoke at the 2018 New Harvest Conference about Golden Rice, a genetically modified form of the staple with enhanced beta-carotene, the watchword is *caution*.

Stotish and Kreis pointed out that in spite of the salmon and rice being approved by U.S. regulatory bodies, the salmon had not (as of 2018) been released into the U.S. market and the Golden Rice rollout remains stalled.

The AquAdvantage salmon, the first FDA-approved genetically modified food animal,[304] was given the green light in 2015, after sixteen years in development. Although available for sale in Canada since 2017, the salmon isn't grown in the United States. Environmental NGOs, such as Food & Water Watch[305] and Friends of the Earth,[306] have raised the alarm regarding public health about eating what Friends of the Earth calls "synthetic salmon," and the effect of "Frankenfish" on wild ecosystems.

In the case of Golden Rice, groups such as GRAIN, India-based Navdanya, and Greenpeace have claimed its introduction would promote monocultures, limit farmers' choices, threaten biodiversity and conventional rice breeds, and jeopardize food sovereignty.[307,308,309]

For Stotish, speaking at the 2018 New Harvest Conference, the lessons for cellular agriculture companies were threefold: to be optimistic, engage early and often with those who might oppose them, and to communicate what they were doing and why. It was vital, he said, to conduct the best science one could but not assume it would insulate the company from attack. He urged conference attendees to resist assuming the regulatory process was free of politics (it most emphatically wasn't), but instead to develop coalitions with like-minded organizations. He added that innovators should be prepared for delays, media attacks, and setbacks.

At the moment, contradictory impulses and uncertainty mark consumers' attitudes toward cellular food

WHAT IS MEAT AND DAIRY?

Another purview of the USDA and FDA will be the naming of the cellular manufacturing process and its products (see "Terms of Reference" on p. 18). This decision will likely be affected to some extent by the current wrangling over the words ***meat*** and ***milk***. Although plant-based meat products still represent less than one percent of the current protein market, their visibility and recent growth—as well as the significant inroads that non-dairy milks have made into the broader milk market—have caused some legislators and animal-based agricultural organizations to seek to narrow the definition of what can be called ***meat*** or ***milk***.

In 2018, the state of Missouri, where Beyond Meat is expanding its operations,[289] passed legislation[290] determining ***meat*** as a product only "from harvested production livestock or poultry." The Dairy Pride Act, co-sponsored by U.S. senators from Minnesota and Idaho, would enforce labeling of butter and milk as only coming from a "hooved mammal."[291] The European Union has moved to legislate[292] against allowing cellular meat to call itself ***meat***, and the U.S. Cattlemen's Association has petitioned the government to request that ***beef*** and ***meat*** labels not be attached to products "not derived directly from animals raised and slaughtered."[293] A number of groups are now challenging the Missouri law as unconstitutional.[294,295]

The farmed animal industry and the legislators couch their complaint as consumers being misled into thinking they will either be tasting "real" meat or milk or butter, as opposed to a plant-based substitute or a non–animal sourced beverage or spread. In the case of cellular products, the concern is that consumers will be unable to discern whether the meat or dairy comes from a slaughtered animal or not. Tendentious though either argument may be, and protectionist of conventional animal agriculture though such legislative efforts may appear, both actions nonetheless point to interesting hermeneutic questions that may, in turn, present conceptual openings or, in turn, barriers to the widespread adoption of plant-based and cellular meat and dairy products.

For instance, a specified clarification of what constitutes ***beef*** or ***meat*** etc. may alert consumers to the very origins and processes that are themselves disguised in words like ***livestock***, ***foie gras***, ***veal***, ***offal***, or, for that matter, ***harvesting***, ***rendering***, and ***maceration***. Furthermore, given that the standard industry definition of animal-based milk is "lacteal secretions," the dairy industry might not feel sanguine about having to employ that definition on its packaging.[296]

Furthermore, instead of asking non-dairy milk to call itself a "beverage," for example, clarification might as readily be achieved by non–farmed animal meat and dairy producers making the distinction on their packages that their products do not involve death, dismemberment, forced feeding, an animal's organs, or the removal of calves from their mothers. Such transparency might also be aided by an honest assessment of what the labels ***humanely raised***, ***free-range***, or ***cage-free*** mean—either in theory or in practice.[297] At any of these points, of course, the push for "transparency" or an appropriately informed consumer might draw even more attention to an animal-based agriculture that, in lobbying for "ag-gag" laws, is making it harder for people to know what goes on in CAFOs.[298]

Indeed, highlighting assumptions over what exactly constitutes meat or milk offers an opportunity to reflect on the fluid, even arbitrary meanings surrounding both terms: ***meat***, after all, once referred to food in general. One might further inquire why it is appropriate to use ***meat*** to describe the flesh of cows, pigs, sheep, goats, poultry, rabbit, and deer, but not cats, rats, or elephants. Why should drinkable ***milk*** for humans come from cows, goats, and sheep, but not from rats, possums, or, for that matter, humans after weaning?

Whether this conversation occurs or not, it seems likely that the financial investment of agribusiness in the cellular space and the continued expansion of the non-dairy beverage market will ultimately limit the farmed animal industry's resistance to using terms like ***meat*** and ***milk*** only for farmed animal products, especially since further "clarifying" legislation might run afoul of terminology for shea or peanut butter, nut cutlets, milk of magnesia, or artichoke hearts."[299] Regulatory efforts may push more companies in the cellular and plant-based space to brand their products as neither the old veggie burger nor a meat/dairy analogue, but something new: like Beyond Meat, Impossible Foods, and Ripple. Indeed, as Chris Bryant, director of social science at the Cellular Agriculture Society and a scholar of public perceptions of cellular meat at the University of Bath, observes, the goal may be to make all such products—whether plant, cellular, and animal—***meat***, or return the category to the general term of ***food***.[300] ●

products—as well as a deep investment in the status quo. When participants in one study were asked to choose between theoretical meat-based, plant-based, and cell-based meat burgers, two-thirds opted for the first even when they were informed the burgers would taste exactly the same.[310] As Barb Stuckey of Mattson notes, consumers are extremely confused about what "clean meat" is, and who it is for—with most assuming that "clean meat" is for, presumably no longer sad and gastronomically deprived, vegans.[311] However, these attitudes might be changing. In a November 2018 survey conducted on behalf of the Good Food Institute by Faunalytics, a research organization that focuses on animal issues, more than two-thirds of respondents said they were open to tasting a cellular meat product, half were willing to eat it instead of a current meat product, and slightly fewer than half indicated they would buy it.[312]

Wild Earth's Dog Treats (made with Koji, a fungus)

Beyond the consumer surveys, however, are broader concerns about whether cellular meat and dairy products will gain purchase among customers. First, it is reasonable to ask why cellular meat and dairy products might even be necessary if biochemistry is revolutionizing the taste profiles of plant-based foods—especially given the many technological, regulatory, and consumer-response complexities outlined above—and if plant-based equivalents are proving so successful. Indeed, Pat Brown, CEO of Impossible Foods, has called cellular meat "one of the stupidest ideas ever expressed,"[313] a statement that indicates that businesses in competition may share common goals but little else with one another.

One response to this observation might be that the technology that supports the former also supports the latter, and that cellular products would enable those with allergies to certain nuts, legumes, or grains to continue to eat meat without an animal having to die to support that diet. Cellular meat could also supply pet food for so-called obligate carnivores and potentially remove a considerable source of revenue for the conventional meat industry, given that the pet food industry is responsible for a quarter of all the meat produced worldwide.[314] Indeed, it might be the case that cellular products could prove the best market for companion animals, since they won't have to look or taste like conventional animal meat to keep their clients content.[315] In addition, these products would resolve some of the moral conflict that vegans may experience in feeding companion animals.[316] One company looking to develop food for companion animals in the plant-based and cellular meat spaces is Wild Earth (see image, left).

This paper has already touched on the possibility that cellular meat might extend the shelf life of animal products and provide more hybridized items to bring to market. It is also possible that cellular meat and dairy products might enable consumers to eat *more* farmed animal meat and dairy.[317] Obviously, this decision remains hypothetical, and consumers who claim otherwise may be virtue-signaling in a space ripe for it. However, the various and sometimes contradictory responses to surveys suggest that assumptions about consumption patterns and various "substitution" analyses might be simplistic regarding the upcoming relationship between plant-based, cellular, and farmed animal meat and dairy.[318]

Yet another riposte might be that those who are protein deficient, or who live in areas of the world where climate change is threatening pastoral or small-scale farming, may welcome access to cellular meat and dairy as a means of gaining food security without intensifying or industrializing their animal agriculture industries. (See "The Case against Cellular Meat" below for a counter-argument.) That said, reliable supply chains and the affordability of products would remain formidable obstacles to widespread adoption.

For Kate Krueger of New Harvest, speaking at the Ivy League Future of Food Conference in Philadelphia in 2018,[319] one interesting element of cellular agriculture is not in the replication of current animal products but in their improvement: manipulating cells to increase un- and polyunsaturated fatty acids and lowering amounts of saturated fats in meat; adding fiber to any meat product; and even perhaps delivering *heme*'s beneficial iron without its carcinogenic properties,[320] which might or might not settle Dean Ornish's unease, as expressed in the 2018 Good Food Institute Conference, about the Impossible Burger. Such "improvements," however, might *still* not allay worries about the ultimate safety of cellular meat and dairy products that seek to replace ones that, for all their many problems, are nonetheless known quantities with known issues.

Several of the criticisms leveled at Ron Stotish's Aquadvantage Salmon and Golden Rice are being leveled at the new plant-based and putative cellular products, some of them by the same groups.

The first complaint is about safety and transparency—particularly of foodstuffs developed through GM or CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) technology. In *From Lab to Fork: Critical Questions on Laboratory-Created Animal Product Alternatives* (see image) Dana Perls, senior food and agriculture campaigner of Friends of the Earth, asks how and what chemicals are or will be used to develop cellular meat products. Will, for instance, the eventual cell culture medium for the food source contain drugs or antibiotics in order to keep it free of contamination? Will all ingredients and processes be listed—including GMOs—on the products' labels, and what risks might there be of environmental contamination should engineered organisms be released by accident?[321]

To these anxieties about safety, one might add those articulated by Stephens *et al.* regarding how stringently the industry would prevent contamination caused by cells dying in the production process or how tightly it would monitor fraudulent attempts to pass farmed animal meat off as cellular meat and vice versa.[322] Further, given that it is possible to produce exotic or extinct animal flesh, or even human body parts, from stem cells, what is to prevent people from growing "Dodo Nuggets" or "Celebrity Cubes"—from human cells.[323]

A second criticism, articulated in *From Lab to Fork*, is whether the claims made by cellular and plant-based meat and dairy companies that their products are energy-efficient, environmentally sustainable, and climate-friendly reflect full accountings of their lifecycle and footprint. For instance, a 2015 study[324] found that cellular meat production "could involve some trade-offs, with significant energy use leading to cultured meat having greater global warming potential than pork or poultry, but lower than beef, while retaining significant gains in land use."[325] Another study questioned whether cellular meat's benefits in methane reduction (caused by lowering the number of cattle that produce the gas, which is highly GHG-intensive but lasts relatively few years in the atmosphere) would be more than offset by the generation of CO_2 (which lasts longer in the atmosphere) in its production. John Lynch and Raymond Pierrehumbert, the authors of the study, observe that "cultured meat is not *prima facie* climatically superior to cattle; its relative impact instead depends on the availability of decarbonized energy generation and the specific production systems that are realized."[326]

A third objection takes a broader perspective. Long-time food sovereignty activist Vandana Shiva[327] has poured scorn on the ongoing and decades-long efforts of Western companies such as Monsanto to patent biological processes[328] and to stop farmers sharing seeds.[329] At the launch in February 2019 of *Eating Tomorrow: Agribusiness, Family Farmers, and the Battle for the Future of Food*, a book by Timothy Wise of the Small Planet Institute on small farmers around the world resisting the depredations of global agribusiness,[330] Shiva railed against the EAT-Lancet Commission on Food, Planet, Health[331] for, as she stated, aligning itself with multinational corporations and philanthrocapitalists such as the Bill Gates Foundation. The Commission, she said, placed too much faith in "fake" meat and dairy solving the global climate crisis, while ignoring the "glaring chronic disease epidemic related to pesticides and toxics in food, imposed by chemically intensive industrial agriculture and food systems."[332]

For the ETC Group, a non-profit headquartered in Canada that monitors emerging technologies, what it terms "petri-proteins" are firmly embedded within a Western globalized model of large-scale monocultures, chemical agriculture, and multinational agribusiness.[333] They would, biologist Tom Wakeford[334] of ETC has argued, present an existential threat to smallholder farmers in the global South, whose locally raised animal products could be displaced by a disruptive technology that provided cheap imports of plant-based or cellular meat. Cellular agriculture, therefore,

would, like Golden Rice, be a potential further eroder of food sovereignty,[335,336] and make it even harder for small farmers to retain their autonomy against a vertically integrated model of contract farming.[337]

Journalist Joe Fassler, writing in *The New Food Economy*, parallels that worry when it comes to the potential disappearance of food animals. He argues that any patents on protein production stemming from cellular meat production (or, as he calls it, "the alt-protein factory") threaten ordinary people's access to what he calls the "public good" of animals. He writes:

> The alt-protein factory of the future may have glass walls, and may contain nothing within it that incites human squeamishness at the idea of killing animals for meat. But it would also herald the rise of a new class of corporate food titan, a world where the protein we rely on to survive is not just food but intellectual property, the domain of corporations with millions in R & D money.[338]

As if to underscore the concerns of those such as Shiva, Pat Brown, CEO of Impossible Foods, announced on May 16, 2019 that his company would start using GM soy from the U.S. in its Impossible Burger.[339] In the statement, Brown was emphatic and pugnacious, criticizing those who "reflexively oppose[d] any and all use of genetic engineering," and waving off "[n]oise from anti–genetic engineering fundamentalists." In boldface type, he offered a different set of environmental metrics:

> **Compared to beef from a cow, producing the Impossible Burger uses 87% less water, emits 89% fewer greenhouse gases into the atmosphere, contributes 92% less water pollution, and uses 96% less land, enabling healthy ecosystems to be restored for nature and biodiversity.**
>
> And crucially for critics of GM agriculture and those interested in food and environmental safety: **About 80% less herbicide** is required to produce the Impossible Burger than an average American cow-derived burger, because of the large amount of crops required to feed a cow to produce beef.

Some environmentalists[340] have contested Brown's claims about the health, safety, and environmental benefits of GM soy. They note that GM soy is sprayed with Monsanto's herbicide Roundup, whose main ingredient, glyphosate, in addition to being implicated in wildlife loss and reduced biodiversity,[341] is the subject of three successful court cases where individuals sued for not being informed about the chemical's carcinogenic properties.[342] Indeed, in May 2019, it was announced that the Impossible Burger tested positive for glyphosate at eleven times the level of its competitor, the Beyond Burger.[343] Of course, the presence of GM soy in U.S. products is not unique to Impossible's burger. The Glyphosate Fact Sheet, published by the U.S. Right to Know,[344] acknowledges that in the United States some 90 percent of corn and 94 percent of soybeans have been "engineered to tolerate herbicides."

THE PARADOXES OF THE DEBATE

Brown's press release/article weighs the claims of one set of environmental values (those held by those who consider the manipulation of nature in the form of genetic material to be potentially toxic, and bad for the environment, wildlife, and humans) against his own environmental values (in which he argues that the raising of animals and the growing of feed used to supply them is bad for the environment, wildlife, and humans). It would be fair to say that each holds the others' views to be unreasonable, ideologically driven, and unscientific. So, how might we reconcile these competing sets of environmental values—assuming we might want to?

One way would be for all concerned to push for less GM soy and more non-GM soy to be grown in the U.S., and for other sources than soy to be used for plant-based meat products. The new Impossible Burger itself switched from wheat to soy as the base for the patty. Another option would be for consumers to "decide for themselves" to reject the Impossible Burger in favor of a plant-based diet that doesn't involve soy or GM soy—much as the Aquadvantage salmon was considered an unnecessary addition to the many varieties of fish available to U.S. consumers.

Still another choice would be to reject this method of food production in favor of regenerative and agro-ecological agriculture, or, as Dana Perls of Friends of the Earth describes them, "well-managed, high-welfare pasture-based systems." These, she argues, "result in cleaner water, promote healthier soils that can sequester more carbon, release fewer toxins and improve biodiversity and pollinator habitat compared with industrial animal agriculture."[345,346] Under such agricultural systems, animal products would be consumed, presumably as whole cuts of meat and unprocessed milk, and presumably in smaller quantities. Such products, to echo the rhetorical flourishes of Shiva, Wakeford, and Fassler, would be "real" and not "fake"; field-grown and not "petri-tarian"; and the protein would come from real slaughtered animals and not "alt" protein from their cell-lines.

These alternative systems to both current industrial animal agriculture *and* the efforts to move away from animal

farming altogether are not without their own controversies or strongly held ideological positions.[347,348] For regenerative agriculturalist Allan Savory, the solution to the climate and environmental crisis is not to end beef production but to massively expand and extend it. He argues that better ruminant-grazing practices could balance ruminant GHG emissions by sequestering carbon in the soil.[349] In Savory's formula, the land is heavily grazed and densely stocked, but for much shorter periods of time than common practice among pastoralists. The manure within this area is trampled into the soil, while plants are "shocked" into growing deep roots. Savory claims that were this strategy to be employed on grasslands around the world, 500 billion tonnes of carbon dioxide equivalent would be removed from the atmosphere over forty years and sequestered in five billion hectares of land. Such a reduction would, in effect reverse global warming.

Critics have remarked that these practices would at best only work in a limited number of locations. They observe that claims as to their viability, carbon-reduction levels, and universal applicability have been exaggerated, or the data unforthcoming.[350] They point out that even were all ruminants to be grass-fed at every stage of the process (without supplementation from grains in the finishing process or other inputs, and not using arable land that could be used for food directly delivered to humans), the per capita availability of animal protein would not be enough to meet the expected global demand for meat and dairy products.[351]

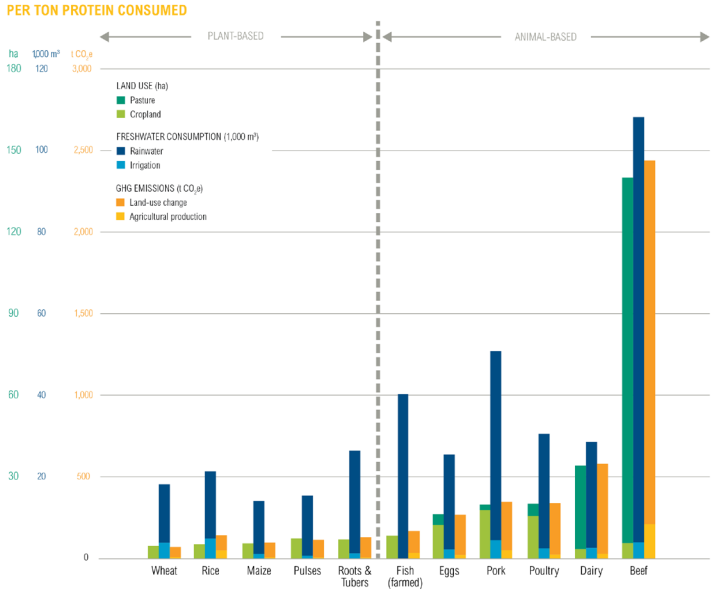
There are other problems with a regenerative agricultural approach, which will be addressed below. However, it's worth noting the larger contexts within which these conflicts take place—ones that can form the basis of future mutual engagement. One fixable problem in the current system is not one of too little food or protein sources to feed the world, but that many of us in the industrialized world may be eating too much of it to start off with.[352] In addition, too much of the plant-based and animal-based protein we grow or raise is either lost before it reaches market or wasted once it reaches the consumer. According to the FAO, roughly 1.3 billion tons of food is annually lost in the fields, or through poor storage or refrigeration in transportation, waste at retail,[353] or by being fed to animals instead of directly to human beings.[354] The World Resources Institute calculates that halving food loss would reduce by 22 percent the food gap between production now and consumption in 2050, when the human population will be likely almost two billion larger.[355]

Secondly, we could be eating the wrong kind of animal-based protein. Some advocates point to the possibility of farming insects to provide protein at scale with a significantly lower carbon footprint.[356] In a study comparing theoretical efficiencies provided by at-scale insect farming, cellular meat production, and current agricultural methods, scientists found that insects were more efficient calorie and protein converters than larger animals, especially when they could be fed by-products and waste, but less efficient than plant-based meats (assuming the latter were made of soy). The study estimated, however, that more land would need to be used to scale up soy production to meet plant-based needs and that cultured meat would save much more energy over beef production. The study also found that chicken-meat production would be more than 30 percent more efficient than cellular meat production. This scenario, of course, cannot take into account *how* the cellular meat is produced (what energy source is used, or what the medium consists of); nor does it reflect the many different plant proteins (other than soy) that may be available in the future.[357]

Insects have been consumed by many cultures throughout history, in spite of the unease with which many in the global North may greet the idea. Insects can be grown in profusion, with little worry over extinction, and in multitudinous varieties.[358] Some advocates propose feeding them to farmed animals and/or aquaculture fish,[359] which may cut down on using other fish or soy or other crops to do this, but might ultimately not lead to significant reductions in greenhouse gas emissions or water use. Others are suggesting that insects may provide good alternatives for cat and dog food to reduce the amount of farmed animal–meat used for this purpose.[360]

It should be added that those motivated by the reduction of animal suffering are worried that insect farming might dramatically increase individual suffering at a time when science is showing that animals previously thought of as

Animal-Based Foods Are More Resource-Intensive than Plant-Based Foods



wri.org/shiftingdiets

WORLD RESOURCES INSTITUTE

lacking sentience, such as fish and insects, possess it.[361] One solution to this conundrum might be the cellular production of insect cell-lines, which could be grown with little or even no serum, but may require enough energy to make it inefficient to produce at scale.[362]

It's worth pointing out just how far away the *current* industrialized animal farming system is to achieving almost all of the goals expressed by either agro-ecological systems or plant-based and cellular agriculture. The current approach to reducing GHGs in animal agriculture is to adjust the composition and acidity-levels of farmed animal feed to lower methane emissions; to move the animals off pasture into factory farms to better control their food consumption, water use, temperature, and waste emissions; repurpose waste as a biofuel; or use more "efficient" breeds of animals.[363] Instead of providing corn, soy, or wheat as feedstock, some are advocating turning food waste, insects, seaweed, or algae into an animal feedstock, or supplementing feed with a woody biomass.[364]

To advocates of industrialized animal agriculture, the widespread use of technology—whether electronic, chemical, or genomic—has allowed farms to become much more productive and efficient.[365] However, those efficiencies can involve using more, larger animals who consume more energy and produce more GHG emissions in total. Nor do such efficiencies make up for the inherent waste in the decision to plant feedstock and raise animals—rather than growing food directly for human consumption.[366] Nor do they necessarily remove the perverse incentives that lead to producing too much milk or corn, for instance, and then finding ways to generate demand for it.[367,368] Nor do they lessen animal cruelty, nutrient run-off, GMO usage, or the public health costs of non-communicable diseases.

In fact, according to a study in the journal *Science*, more than 80 percent of all farmland on the planet is given over to livestock, even though it only produces 18 percent of food calories and 37 percent of protein.[369] Using plant-sourced foods to provide the same nutrition as beef, says a 2016 U.S. study, would require only 10 percent of the land and generate four percent of the GHGs.[370] Another study found that whole-foods vegetarian and vegan diets use considerably less water and land, and produce fewer GHGs than conventional beef production. Plant-based beef burgers (which require more processing) lessen those gains, but they are still more beneficial in water consumption and GHG emissions than the current industrialized production system.[371]

Of course, cellular agriculture is still not at a production stage that would reveal just how much water, energy, or feedstock would be required—a point essentially conceded by Lynch and Pierrehumbert at the outset of their report.[372] Would the energy calculations change dramatically, for instance, if the bioreactors were fueled solely by renewable energy? Indeed, given how much water is spent, land-use change required, and GHGs emitted through beef production[373] (see graph on this page), would no longer eating cows and drinking cow's milk be enough to make it unnecessary to change the rest of the agricultural system?[374]

THE (LESS) MEAT OF THE MATTER

As the above paragraphs illustrate, the challenges of comparing different agricultural systems—insect; cellular; agro-ecological or regenerative; plant-based; chemical-industrial—are complicated by the degrees of emphasis placed by advocates and policy makers on ensuring personal and public health, meeting the desires of a global population to eat more animal products, protecting the environment and stopping climate change, and ending factory farming and animal exploitation.

That said, however you balance the competing demands of the various protein delivery systems, most authorities on the environment and climate change crises recognize the need to produce and eat less meat, especially among those of us who have access to a wide variety of alternatives. Meat reduction, however, is not the current trajectory of the planet's human population; in fact, more of us are eating more meat than ever

before.[375] By mid-century, according to the United Nations, poultry consumption is projected to double, and beef and pork consumption will rise by 69 and 42 percent respectively over 2012 levels.[376] Simultaneously, climate change is likely to make both arable and pastoral land more vulnerable to drought or flooding,[377] reducing feedstock acreage and threatening (farmed) animals with heat stress and lower productivity.[378] Rural populations, unable to make a living through farming, will move to cities or leave countries, further threatening food production and putting more pressure on ecosystems, since urban dwellers tend to eat more animal products.[379]

Therefore, even if many more farmers were to raise animals using "well-managed, high-welfare pasture-based systems," as Dana Perls of Friends of the Earth advocates, it seems very unlikely that regenerative agriculture would be enough to meet the demands of a planet hungry for meat and dairy products. Indeed, simply as a matter of carbon sequestration, as Garnett and Godde *et al.* report of current grazing populations in *Grazed and Confused?*, "[t]he sequestration potential from grazing management is between 295–800 $MtCO_2$-eq/year: this offsets only 20–60 percent of annual average emissions from the grazing ruminant sector, and makes a negligible dent on overall livestock emissions."[380]

As most in these varied spaces recognize—including the Intergovernmental Panel on Climate Change (IPCC)[381]—business as usual is unsupportable. Agriculture as a whole contributes about a quarter of all anthropogenic GHG emissions;[382] however, of those emissions, two-thirds come from animal-based agriculture, and of all land used for agriculture, three-quarters is set aside for the production of animal-based foods—the animals themselves and the crops grown to feed them.[383] Animal agriculture utilizes nearly one-third of the total water footprint for agriculture,[384] and is responsible for widespread deforestation, particularly but not solely in Central and Latin America.[385] According to the FAO, the production of animal feed "constitutes 36 percent, 36 percent and 28 percent of the total emissions for cattle, small ruminants, and buffalo, respectively."[386]

Whatever the scientific merits of the case for and against cellular agriculture's utilization of molecular biology and genetic modification, or Impossible's decision to use GM soy, or the countervailing promises of agro-ecology's commitment to an older science of animal breeding, seed propagation, intercropping, and natural pest management, it's clear that the debate about what is or is not an acceptable way of raising or eating animal products cannot be limited to science *qua* science. "Science" and "technology" themselves are not ahistorical, fixed entities; and it might be impossible to avoid ideological battles over the limits of Nature and the nature of limits—or, for that matter, about the appropriate place of the domesticated animal in the environment.

In the end, unpleasant and uncomfortable compromises are likely to be necessary as we struggle to cope with diminishing resources in a world marked by simultaneous over-abundance and scarcity. That world will require many more people who can afford it to eat fewer animal products so those who don't get enough protein of any kind can eat some. Or, there will need to be many more vegans by choice and not necessity. Urban, industrialized, and cellular agricultures are likely to be essential because climate change is already affecting pastoralists and farmers of all kinds all over the world.[387] The services required to maintain such farms amid globalization, the failure of governmental extension services, land degradation, human population growth, and urbanization are so significant that reducing our dependency on livestock would seem the minimum requirement.[388]

The standoff between some environmentalists and plant-based and cellular agriculturalists is, to this author, another iteration of the longstanding debates over what is or is not "unnatural." Its echoes and fears exist in words like "fake" and "petri-tarian"—as if the animal whose meat we eat or milk or eggs we take is not herself a product of scientific investigation in labs and genetic manipulation, or is not regularly artificially inseminated, mutilated, fistulated, hooked up to milking machines, trucked to slaughter, or subject to a host of other mechanized, technologized, and automated systems. But that, of course, is not the purpose of these nomenclatures. They exist, like Brown's criticism of "fundamentalism," to point to a rigid adherence to an overarching ideology that is non-normative. The ideology is messing with the proper order of nature; it is junk science masquerading as a practical solution.

The curious paradox of the rhetorical stances of both groups is how they mirror one another. Neither side can honestly claim their products are totally "clean," since cellular meat is likely to require additives and other substances to avoid necrosis of the cell and extend the products' shelf-life—just like meat scientist Benji Mikel tells us that meat does today. Indeed, the notion of "cleanness" itself harkens back to the ideas of purity and goodness that govern what we consider to be "natural" food. Microbes can be *both* devastating and necessary in food production. The delivery of *heme* iron can be *both* an untested carcinogen and/or potential allergen whose presence in food reflects scientific and corporate irresponsibility, and it can be an essential component for human health in the global South and thus the reason to continue or expand small- and medium-scale pastoralism there.[389]

THE SEARCH FOR COMMON GROUND

So, how might it be possible to find common ground amid the rancor of these niche concerns? After all, cellular meat and dairy has yet to be produced at scale; plant-based meat products remain a fraction of the animal-based meat market; certified organic acreage in the U.S. makes up less than one percent of the more than 900 million acres of farmland around the nation;[390] and organic food is currently only 5.5 percent of the food sold in the U.S.[391] According to Jacy Reese, cuts of organic meat constituted only 1.5 percent of sales of fresh meat in the U.S. in 2016. Less than one percent of that fresh meat fell under the label "grass-fed."[392]

Supporters of regenerative agriculture and/or a whole-food plant-based diet, and those who believe that it is morally wrong to eat animal products, could find themselves aligned against the development of cellular agriculture, and to a lesser extent against contemporary plant-based meat and dairy.

Both may for valid reasons resist the further commodification of animal flesh for the profit of the technocratic global North that, they believe, fails to value the essential right of the farmed animal to exist outside a purely instrumental value determined by their ultimate demise or exploitation. After all, if the ruminant offers manure, carbon-sequestering potential, social status, haulage, or tillage, then why should the animal have to die to prove its worth or offer a biopsy to justify its existence?

Both may, also validly, question the motivations of Cargill, ADM, Tyson, Nestlé, and other corporations that have profited off industrial animal agriculture in investing in these start-ups. They may wonder why some long-time animal advocates have been so welcoming of these behemoths—without asking why they are continuing to invest in feedstock production and factory farming, and muting criticism of their ongoing systemic cruelty toward and slaughter of billions of animals.

They may question why ethics or even animal rights have so quickly been jettisoned as a tenable motivator of change, even by those who were themselves long-time social activists, who have assumed that technology takes place in a social vacuum and ignoring the values-driven knowledge base of the founders of the companies they champion or fund.[393] They might also be skeptical whether, in spite of the stated altruistic motivations of some of the investors, entrepreneurs, and institutions in cellular agriculture, later adopters of the technology, or the big private corporations that may take it over, will have anything other than their shareholders' interests at heart.[394]

That said, given that so many vegan processed products are *already* owned in part by multinational corporations, is this argument already moot?[395] Acellular agriculture is already well established, producing a range of items that, as was noted earlier in this paper, range from rennet to casein to insulin. These products are already in our bodies and foods we eat. Is it perhaps already understood in the emergent cellular and plant-based meat and dairy space that the trajectory of both involves corporate synergy and continued expansion of processed foods? Are these products attractive to corporate farmed animal producers and feed growers mainly because they expand the very thin margins of profitability to be found in current industrial feedstock and livestock farming?

This last rhetorical question may strike the reader as very cynical. As a counterpoint, it might be argued that were plant-based and cellular products to become additives in processed animal products they could complicate consumer notions of the "authentic" meat-based product and potentially draw attention to how industrial farmed animal–meat production is *currently* dependent on a range of "unnatural" processes and non–animal based ingredients.

This would assume, of course, that consumers *want* or *need* to know what's in their food or how it's made, despite calls for transparency, hygiene, and "natural" ingredients. Recalling Upton Sinclair's difficulties in convincing people to care, perhaps instead of wanting transparency, provenance, and engagement with their local farmers, the vast majority of consumers would prefer *not* to know or think about where their food comes from, what's in it, or who grows it—trusting that the government or corporations will keep their products "safe."

A further reality check must be added here. As the ongoing crisis affecting American farmers demonstrates,[396] the current life for traditional contract farmers, both large and small, is hard—and getting harder. Increased debt, further consolidation, more frequent extreme weather events, the rising price of land in rural areas, labor shortages: all these point to a reality that, around the world, animal-based farming may no longer be a viable industry *unless* it is highly consolidated. The implications should concern everyone involved in food production. Throughout the American Midwest, and elsewhere, rural areas are losing population, talent, and skills to the cities, with subsequent diminishment of a tax base, along with impoverishment and blight.[397]

All these are occurring *now*, before plant-based meat and dairy products and cellular agriculture's technologies make a considerable impact on the market. Nor is cellular technology the only disruptive technology. The use of robotics and automation (such as 3-D printing)[398] could take some of the low-cost labor out of food creation.[399] They could localize food production and its deliverability.[400] The emergence of cellular medicine may generate individual diet regimens to provide targeted health outcomes. Computers and block chain technology are already allowing farmers to monitor spoilage and retailers to trace products.

It is a further function of the explosion in possibilities opened up by cellular and genomic technologies that not only can an organism be altered but the ecosystem in which that organism operates might also change. According to Caleb Harper, director of the Open Agriculture Initiative at MIT's Media Lab, speaking at the 2018 New Harvest Conference, computers now make it possible for farmers to estimate a yield and the biochemical composition of any organism within any given environment. This technology allows for a maximally efficient or desirable outcome for the organism within that biome. In other words, farmers can calculate which plants within which part of a field will grow under which optimal conditions, rather than a single monoculture in a uniform biological space.

Furthermore, farmers can now grow food under conditions that optimize flavor, develop bacterial resistance, and provide valuable health outcomes through adjusting chemicals and growing periods, without changing the plant's genetic structure.[401] These processes, says Harper, whose Open Phenome Project offers "an open-source digital library with open data sets that cross link phenotypic response in plants (*taste, nutrition, etc.*) to environmental variables, biologic variables, genetic variables and resources required in cultivation (*inputs*)," have the potential to maximize yield and variety, with a minimum of wasted inputs and unused land, in a myriad of settings, both indoor and outdoor.[402] So technology, science, and genomics might in fact *help* small farmers and agro-ecologists utilize their land more efficiently, and solve some of their most pressing needs—if they were to be affordable, open-source, or widely available.

What will be required if these clashing notions of appropriate technology are to come together are imagination and, perhaps, some courage. As Lav Varshney noted in his talk at the 2018 Good Food Institute Conference, we are defined by our current conceptual space that determines the assumptions of the appropriate use of technology, only for that technology to redefine that conceptual space.

When radio was first invented, he said by way of an example, it was known as "wireless telegraphy," since the operational space within which the technology was developed was point-to-point communication. The significant change of that particular technology came when it shifted to a broadcasting medium, or "radio": a point-to-everywhere communication. Plant-based and cellular meats, he continued, might be in their "wireless telegraphy" phase, and that it, like "radio," had the potential of becoming something totally different and transformative in a manner as yet unknown to us.[403]

As the effects of climate change become more severe and systemic, the meaning of "natural" and "sustainable" will likely be radically revised. What is and is not food or farming—or who a farmer "is" and where she farms will also change, and perhaps in ways that seem, literally, inconceivable to us today. Under such circumstances, why should the definition of "farmed animal" not also be transformed?

A VISION OF THE IMPOSSIBLE?

In 2003, the imaginative implications of the transformative possibilities of cellular agriculture were hinted at by the artists Ionat Zurr and Oron Catts, who prepared their miniature frog steaks as "disembodied cuisine." As Cor van der Wiele and Clemens Driessen observe, the many options provided by new production methods and recombination of cellular meat in the future,

> afford the possibility to play, first imaginary, potentially also real, with form, color, additions and taste, as well as with various production processes, moral profiles, marketing profiles and consumer practices. It seems to us a loss of opportunity to restrict the contribution of ethics to an evaluation of arguments for and against (underdeveloped forms of) cultured meat.[404]

At this juncture in the development of plant-based food products and cellular agriculture, the possibilities still remain open for a fully reimagined food landscape, even as companies rush to bring products to market, scale up, and integrate completely into the current production and delivery system. As van der Weele and Driessen observe,[405] the promise or peril of cellular meat has destabilized binaries of veganism and carnivorism, sustainability and cruelty, natural and unnatural, and has opened up many conceptual spaces for rethinking how we relate to food and animals in the Anthropocene. Cellular meat could reshape the marketplace as well.

In contrast to the fears voiced by environmentalists such as Vandana Shiva and Tom Wakeford that cellular meat's inevitable corporatization will destroy local farmers' livelihoods and practices, Yuki Hanyu, a chemist and nanotechnologist who runs the Shojinmeat Project[406] and Integriculture Inc.[407] in Japan, has a different vision. Hanyu's interest extends beyond the science and commercialization of cellular meat (the task of Integriculture) to the psychocultural landscape where cellular meat is part of our everyday experience (Shojinmeat's orientation). Shojinmeat aims to democratize cellular agriculture by encouraging DIY biofabrication enthusiasts, students, researchers, artists, and writers to provide familiar contexts for people within which to imagine cellular meat, such as setting up comic-cons and creating fantasy fiction featuring cellular meat.

For Hanyu, the opportunities for cellular meat lie not in industry consolidation but in personalized and regionalized production. He envisages a time when every home has its own kitchen-top bioreactor, local farmers and hobbyists can develop their own cellular meat recipes (perhaps including algae or combinations of cells from different animals), and consumers can videolink to the field in which the cow whose proliferated cells they are now chewing on is grazing.

Prefiguring Hanyu, in 2006, cell biologist Vladimir Mironov similarly imagined a coffee maker–sized bioreactor,[408] an idea that Mark Post considers impractical, given the scale of production required to make the economics viable. However, like van der Weele and Driessen's "pig in our backyard" (in which people would be able to source their own biopsies of muscle cells on a regular basis from an animal in the neighborhood), Hanyu and Mironov's active imaginations are in some ways an acknowledgment that a purely cellular future without the presence of farmed animals at all is, both morally and aesthetically, a less than satisfactory response to a world without animal slaughter. Van der Weele and Driessen characterized the atmosphere of their workshop on the "pig in our backyard" as "a combination of joy, inspiration and amazement."[409]

Why, therefore, wouldn't it be possible to reimagine pastoralist communities around the world employing Yuki Hanyu's vision—or the animals whose biopsies make cellular meat possible? Why wouldn't these same thousands of ruminants offer an opportunity to sequester carbon for carbon credits via regenerative agriculture and provide cell-lines for meat, leather, and milk in Kenya and Paraguay and Mongolia, and more than pay their way? Animal families could be kept together as part of an extended community of fellow beings providing one another with sustenance for the full lifespan of both human and non-human animal.

Presented through this lens, as Van der Weele and Driessen note, "we can have it all: meat, the end of animal suffering, the company of animals and simple technology close to our homes."[410] In this way, Van der Weele, Driessen, and Hanyu's visions present one means by which we can provide "positive duties" to farmed animals, as articulated by Will Donaldson and Sue Kymlicka in their book *Zoopolis*.[411] These positive duties—in addition to the negative ones of not harming animals physically or emotionally—take the form of allowing these beings to live within their biological environments and among their conspecifics, and in so doing restore a measure of justice for the past wrongs we humans have inflicted on them by stifling their basic needs, breaking up their families, subjecting them to torturous confinement, and taking their lives by the billions.

Of course, many billions fewer of such animals would be alive. Perhaps they would exist in sanctuaries, among other farmed animals; perhaps they would be leased out to other

farmers to provide manure. Clearly, such visions for the future of cellular meat would have to fit into some set of legal parameters that would guarantee safety and transparency, not least regarding the treatment of the animals we use and the meat we eat. Nonetheless, it does not seem to this author to be inconceivable.

Hanyu feels strongly that beyond the technological possibilities, and the need for businesses to commercialize the processes and products that emerge from those possibilities, it is citizens and not industrialists who should set the direction of how they imagine these products might be used and the amount of control they wish to exert over them. How to go about doing that is the central challenge that faces all communities confronted by corporate power in the years ahead. To that extent, Hanyu's vision admirably parallels the need for agency, connection to the animal, regionalism, and democratization that locavorism, slow food, and other social food and farming movements champion.

As Yogi Berra once noted, "It's tough to make predictions, especially about the future." The future of protein and its delivery might, in fact, look nothing like cellular meat. In 2017, a group of Finnish researchers reportedly used electricity and carbon dioxide to produce a batch of single-cell proteins, a protein that "can be produced anywhere renewable energy, such as solar energy, is available," in a technology that "releases food production from restrictions related to the environment."[412] Researchers in the U.K. are doing much the same from car exhausts.[413] Perhaps we will be eating this, or some iteration of Soylent.[414] On the other hand, the future of protein might also be surprisingly non-technological: it might be a combination of fungus and insects; or the chewy, versatile, and unglamorous jackfruit—ubiquitous throughout Southern Asia—might come to dominate the market.[415] And there may remain, as ever, tofu, seitan, and tempeh.

THE FUTURE FROM DAVOS?

Still another future is hinted at (or parodied) by the writer Zoe Levitt in a piece for a journal composed for the 2017 Davos conference.[416]

Leavitt imagines the U.S. in 2031, ten years after the breakthrough in cellular meat production (using an algae-based serum). Cellular meat production is now 50 percent of the U.S. meat market, spurred by falling prices for its production and an outbreak of pig flu in 2024 that saw fast-food chains switch to cellular meat. This meat comes in a variety of flavors and with additions, such as "Meattastic Vitamin B booster burger, Iron Maiden iron-enhanced beef for women and dozens more targeting everyone from diabetics to those worried about bad breath."

Opposition to the growth of cellular meat has solidified among "third-generation farmers and anti-genetically modified organism naturalists to animal rights advocates, who believe cultured meat doesn't go far enough." But, she observes, many farmers (already propped up by government subsidies and the victims of automation and robotics) have gone bust as the industry has consolidated and "big meat producers launched new, smaller 'craft' brands, aiming to bring a sense of nostalgia and authenticity to traditional meat."

She imagines the energy savings from cellular agriculture as limited, but "this is more than offset by the massive reductions in agricultural water usage." Some rewilding has taken place, greenhouse gas emissions are lower, and, Levitt notes wryly, the pharmaceutical industry has also shrunk considerably. ●

RECOMMENDATIONS

Given the nascent stage of cellular agriculture and the ever-growing interest in plant-based meat and dairy alternatives, the following recommendations are, like the industries themselves, at once bold and cautious. Plant-based and cellular agriculture *could* challenge the entire premises of current agricultural practices as well as what constitutes meat and dairy. At the very least, they could reorient themselves to address criticisms, both current and those that might be raised soon, through specific policies.

DIVERSIFYING LOCATION, VOICES, PEOPLE, AND OUTLOOK

Take It on the Road: To date, all conferences that have focused on cellular meat in the United States have taken place on the West and East Coast in locations—Berkeley; San Francisco; Cambridge, Mass.; New York City—associated with technology hubs, so-called liberal elites, and consumers who consider themselves at the forefront of new trends and tastes. Given the challenges faced by farmers and rural communities within the current system of agriculture, let alone what they may face in the future, it would make sense to host more conferences in places that would welcome investment, e.g., in Columbia, Mo., where Beyond Meat is expanding its manufacturing capacities. Here, individuals who wouldn't otherwise be exposed to this information might learn about opportunities for a future where diversified feedstock meets rising demand for plant-based foods and/or providing the medium or scaffold for cellular agriculture.

Listen to More Voices: Such a move would also center cellular and plant-based meat and dairy products as solutions for farmers and perhaps allay concerns among environmentalists about what kind of technology might be integrated into their practices. Either way, it would benefit the conferences to include more farmers (and not just cattle-ranchers) among speakers, attendees, and exhibitors—especially on the possibilities of growing a wider variety of plants either for the cellular media or plant-based meat and dairy. Bringing in farmers might reduce potential criticism that cellular and plant-based agriculture is only interested in courting the processors of Big Ag at the expense of the growers. And it would open a pathway of ideas *from* growers, workers, small companies, and everyday consumers to and from developers, unfiltered by surveys. Such a dialogue could make cellular or plant-based meat the new "potato."

Several speakers at the various conferences this author attended observed that food is not a nifty "app" or a dot.com start-up to be launched into the marketplace and fixed in countless patches or iterations. Due care and diligence were, therefore, essential. This was an implicit rejection of a "tech-bro" Silicon Valley culture that has been criticized for its cavalier attitude to institutions, personal privacy and data, and exploitation of the vulnerable. It has also been criticized for its lack of racial diversity. Therefore, it would be valuable to diversify a space that lacks African-American or Latinx representation, and that has not, to this moment, spoken much about equity, social engagement, food justice, or food security.

Make a Genuine Commitment to Diversity: To hear from and communicate with such voices would likewise yield insights into how social and conceptual barriers to the adoption of new technology could be lowered *and* ensure the food system reflects the diversity of producers as well as consumers. As Eric Schulze of Memphis Meats notes, given the global potential of this industry and the global and manifold cultural expressions of meat and dairy cuisine, it would make sense to diversify the industry from the outset to match the scope of the effort required, as well as the available market.[417] To instantiate equity, social capital, and community engagement as these industries begin to move to developing and expanding their product lines would make sense in multiple ways—especially if there is a genuine wish to shift the potentially catastrophic trajectories of farmed animal–product consumption. Providing space for voices outside the world of consumer products would ensure that the socially transformative dimensions of these industries are not forgotten or stifled at birth.

ADDRESSING THE HEALTH ISSUE

From strictly an environmental, public health, and animal-welfare perspective, the shift from farmed animal to plant-based and cellular meat and dairy agriculture offers considerable benefits: a potential reduction in GHG emissions, lower risk of zoonotic disease and consumption of contaminated meat, and an end to the manifold cruelties of industrial animal agriculture, as well as the slaughter of tens of billions of individual animals.

Nonetheless, the health profiles of processed foods remain a concern. The Impossible Burger 2.0, launched in 2019, reduced the amount of salt and saturated fat in its burger, even as it switched from wheat to soy in the patty—and the use of GM soy.[418] This author considers Impossible's decision, and its CEO's arrogance, not only a public relations mistake but ultimately shortsighted. Why couldn't Impossible Foods drive the market for *non*-GM soy, or another plant protein, rather

NüMilk Machine, Whole Foods, Brooklyn, NY

than fit into the current paradigm? Why not state that Impossible will use GM to support U.S. farmers, but see it as a transitional stage to a non-GM process and healthier, more diverse systems of agriculture? As it is, plant-based and cellular meat companies should engage more forthrightly about how much (if at all) they are improving public health—particularly in terms of the costs to health-care systems of non-communicable diseases, antibiotic overuse and inefficacy, and the health profiles of their various meat and dairy products.

MAKING ORGANIZATIONS MORE TRANSPARENT

Protect against Fraud and Stop Overclaiming: It is possible, perhaps even probable, that cellular agriculture is hosting a Theranos "unicorn"[419] among its start-ups: where the promise of a technology that changes everything (and doesn't exist) is delivered by a young, charismatic founder who has considerable corporate investment and star backers, and whether deliberately or not misleads everyone to the detriment of those trying to do similar work in that space. A culture that encourages anyone to start their own business; that fails to police the hype; and that dampens due diligence, corporate responsibility, and realistic timeframes and actual deliverables to reward charismatic leaders or media-friendly funding pitches is one that opens itself up to potential fraud and recklessness.

Ensure Third-party Corroboration: As various speakers have pointed out at the conferences the author has attended, the food space involves public trust, the protection of health, and government oversight that make it vital to tread cautiously. The violation of any of these would have many more severe consequences for the industry going forward. This caution, therefore, demands that the buzzwords of transparency, accountability, and collaboration need to be actualized and codified. A third-party corroborative institution would be a valuable addition to this space—beyond the business incubators, scientific clearinghouses, and conveners. This organization would do more than lobby for government not to change the names of their products or stall the regulatory process. It would monitor governance, timetables, and claims of companies.

Don't Ignore Ethics, the Public Good, or Animal Rights: It would also be valuable to include voices in the space that address ethics and a vision of the future that isn't about marketing, regulation, product development, consumer acceptance, and rounds of investment. How, for instance, might the world of cellular biology and cellular meat work in concert to provide "food as medicine"? What might be the ethics of our responsibilities to the thousands of animals that would still be used as the sources of the cell-lines? Would the cellular meat companies bear an obligation to these animals to ensure not only their welfare, but of those others who remain alive but whose utility might be in that they remind us of the exploitation, suffering, and death of billions of others? Would consumers or the CEOs allot a portion of the profits they make to fund farmed animal sanctuaries, or help farmers transition to non–animal based agriculture, or to rewild land no longer needed for feedstock to sequester carbon, or where wind and/or solar could be "farmed"?

If You're Really Game-Changers, Change the Game: If the response to the above questions is "How is this my business?", "Why should I be responsible for farmers' transition?", "What do *we* owe to the animals?", or "The market's invisible hand will be enough," then what makes this space any more socially transformative than any other corporate reboot of a commodified food culture processing animal products? What's to stop its businesses meeting their VC investors' demands at the earliest opportunity with a novelty product that sustains and diversifies current farmed animal products rather than pushing for a radical overhaul of how animal protein is grown and delivered? There need to be commitments from founders to a triple bottom-line or to educate shareholders to seek a greater return on investment than found on quarterly income sheets. And if monitoring these is not the business of the Good Food Institute, New Harvest, or other bodies, then whose responsibility is it?

Think about the World After Cellular Meat Becomes a Reality: If, as planned by some in the space, a cellular meat

experience or product is delivered to consumers within the next four or five years,[420] it may be that the regulatory protocols are in place; the production, manufacturing, and delivery mechanisms are primed to perform their functions at scale; and the people are ready to embrace these new technologies. But it seems worth taking the risk, like Yuki Hanyu, of stretching our imaginations to ask "And then what?" Perhaps it's in responding to that follow-up question that cellular and plant-based animal products may offer the most compelling and suggestive answers. Beyond the Vegan America Project itself, how might other individuals, universities, and other institutions begin this conversation—in a way that honors risk and imagination and ethical frameworks for humans and animals? Perhaps faculties engaged in animal studies, the environmental humanities, and social sciences might convene with businesspeople, futurists, and natural scientists to open up new conceptual possibilities and examine or define areas for caution and care?

Foster a Genuinely "Open-source" Culture: Finally, given the scope of the opportunities to refashion animal farming in a way that genuinely ends so much animal suffering and *at least theoretically* offers many climate, environmental, and public health advantages, it would be a singular contribution of these industries to make as much of their processes as transparent, open-source, and patent-limited as possible. If moral (and even contractual) pressure is applied in these early stages, then it might be possible to avoid cartels and corporate behemoths stifling innovation, holding up development, and further impoverishing local or small-scale food providers. If that seems unlikely, then it's up to the organizations in this space to hold them accountable; and if they can't, then they will invite more, and more stringent, criticism—and it will be justifiable.

RECOGNIZING THE IMPORTANCE OF POLICY

There Is No Such Thing as a Policy Vacuum. Fill It: In his book *The End of Animal Farming: How Scientists, Entrepreneurs, and Activists Are Building an Animal-Free Food System*, ethicist Jacy Reese of the Sentience Institute argues that one reason why years of vegan advocacy has failed to expand significantly the number of those who do not eat animal products is that "people are far more willing to support institutional change than they are to change their individual consumption."[421] Reese's observation suggests that veg*sm's tying of dietary habits to virtuous behavior convinces no one and instead signals to those who still eat animals that they are bad people, which creates backlash and resentment rather than change. As Tobias Leenaert puts it, vegans want people not only to stop eating animals, but to do it for the right reasons.[422]

As was noted at the beginning, the response to veganism's moralism from some in the cellular and plant-based meat spaces has been not only to avoid ethical issues but to emphasize the rights of consumers in a market to be free to choose the products they want—and to make cellular and plant-based products tasty, affordable, and ubiquitous: as good as, or even better than, their animal-based counterparts. The question remains, however, whether framing cellular and plant-based meat in the language of choice rather than ethics may delay the adoption of products and processes that are beneficial to the environment and public health over products that are detrimental. Continuing to pour salt, sugar, palm oil, and high fructose corn syrup into processed foods and products is also a choice; subsidies to industry or lack of regulation make that choice a less costly one for business and a more costly one for society, nonhuman animals, and the planet. Silence on the current governmental policies that support Big Ag for fear of "politicizing" the space would seem only to risk reinforcing business as usual.

Seek Government Investment: As Adam Flynn (see "The Naysayer" on p. 24) suggests, private capital may not be enough to move cellular agriculture beyond its niche position. It would, therefore, be wise to press governments to bring their scientific research, funding capabilities, and institutional weight so as to galvanize the development of cellular agriculture and conduct research into other plant sources. Lincoln's signing of the Morrill Land Grants Act in 1862 enabled extension services and agricultural knowledge to be spread throughout the United States.[423] Something similar could be applied here not only to kick-start a new frontier of agriculture but to create an agriculture that moves away from a chemically dependent, commodity crop–based system in favor of something more diverse, regional, creative, and locally sustainable. Why shouldn't the plant-based and cellular industries lead that charge?

Emphasize Varied Engagement: Varied policy engagement is essential—if only to situate plant- and cell-based meat companies in a conversation with environmentalists, rural development specialists, and public health advocates, and to show how the plant- and cell-based meat and dairy industries understand how *currently* the supposed choices we consumers make in the marketplace may not be genuine choices at all. Why should the default for *protein* be animal? Why *should* richness, status, and masculinity be defined by meat? For that matter, why should the word *farmer* conjure up a middle-aged white man in rural America herding cattle, and not a young black woman owning a vertical farm in Balti-

more? To cede the political *and* conceptual space to current agricultural policies; to disengage the ethical dimension of eating responsibly; and to ignore animal cruelty for the sake of not discomforting business partners is itself a policy and an ethical position—whether we want to admit it or not.

DEVELOPING A NEW SYSTEM OF MEANINGS

Recognize that Food Is Never Just Taste, Price, Convenience: In his talk on the panel "From Field to Fork: The Science and Nutrition Behind Plant-based Meat" at the 2018 Good Food Institute Conference, Ricardo San Martin of UC Berkeley was in no doubt that the scientific issues surrounding the development of alternative proteins would be solved. For him, however, the main issue that needed to be grappled with in the years to come was not looking at an animal product as an object (to which you might affix taste, price, and convenience), but as a "system of meanings."[424] These, to return to Nick Fiddes' observations at the start of this paper, constitute a set of ideas, feelings, and relationships that center a human being in a family, culture and region, and generate stories that we tell about these facets of our humanity to ourselves, our children, and society at large and over time.

Reimagine, (Re)create What It Means to Consume: One suggestion that stems from San Martin's insight would be to invite into the plant-based and cellular spaces at this nascent stage more cultural anthropologists and artists who could frame a discourse around the animal product that goes beyond science, market, and business, and perhaps to construct subtle responses to that "system of meanings." Of course, these are always subject to change: witness the French and the potato. However, the speed and scope of global warming, the assault on biodiversity and ecosystems, the ongoing exploitation of billions of farmed animals, and technological transformation make the urgency of discovering new systems of meaning even more pressing.

Don't Be Afraid to Be Wrong: Every person on this planet who will be alive in the year 2050 is likely to encounter, either directly or indirectly, unimaginable change—both miraculous and cataclysmic. Dislocations, both physical and conceptual, will demand not only flexibility and resilience but also the willingness to discard old identities that may have served our societies and our roles within them in the past but may no longer be viable or even possible. Neither the blithe assurances of market disrupters and techno-utopians, nor the comforting visions of Eden restored (as expressed by agro-ecologists and whole-food, plant-based vegans), will likely be able to carry the multiple breakdowns in meaning that communities of the future may experience in the face of massive ecological, economic, and social disruption.

In such circumstances, and given the possibilities opened up at this moment for completely reimagining our relationship with the farmed animal, it is worth opening up dialogue, accepting insights, and increasing the dimensions of the space within which plant-based and cellular meat and dairy products operate—in short, to generate more systems of meaning—before (in every sense of the phrase) it is too late. ❖

NOTES

1 For these organizations: Ivy League Future of Food Conference <http://www.ivyffc.com>, Food Tank Food Waste <https://foodtank.com/news/category/food-waste/>, and Cultured Meat and Future Food Podcast <http://cleanmeatpodcast.com>.

2 The extent of biodiversity loss is reflected in the May 2019 IBPES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) report, which stated that up to a million species faced potential extinction. See IPBES. Media Release: Biodiversity and Nature's Contributions Continue Dangerous Decline, Scientists Warn, n.d. <https://www.ipbes.net/news/media-release-biodiversity-nature's-contributions-continue-%C2%A0dangerous-decline-scientists-warn>.

3 Vegan America Project. About Us, n.d. <https://veganamericaproject.com/about-us/>.

4 Lewin, Jo. "The Health Benefits of Tofu." *BBC Good Food*, n.d. <https://www.bbcgoodfood.com/howto/guide/ingredient-focus-tofu>.

5 Tempeh.info, n.d. <https://www.tempeh.info/tempeh-history.php>.

6 Shurtleff, William, *et al. History of Soybeans and Soyfoods in China and Taiwan, and in Chinese Cookbooks, Restaurants, and Chinese Work with Soyfoods Outside China (1024 BCE to 2014)* (Lafayette, CA: SoyInfo Center, 2014), 9 <http://www.soyinfocenter.com/pdf/176/Chin.pdf>.

7 Shurtleff, William, and Akiko Aoyagi. Dr. John Harvey Kellogg and Battle Creek Foods: Work with Soy, SoyInfoCenter.com, 2004 <http://www.soyinfocenter.com/HSS/john_kellogg_and_battle_creek_foods.php>.

8 Prichep, Deena. "The Rise of Mock Meat: How Its Story Reflects America's Ever-Changing Values." *NPR The Salt*, September 2, 2017 <https://www.npr.org/sections/thesalt/2017/09/02/547899191/the-rise-of-mock-meat-how-its-story-reflects-americas-ever-changing-values>.

9 Shurtleff, William, and Akiko Aoyagi. Chronology of Soymilk Worldwide 1500 A.D. to 1949, SoyInfoCenter.com, 2001<http://www.soyinfocenter.com/chronologies_of_soyfoods-soymilk.php> and History Dollop. Almond Milk the Medieval Way, November 9, 2016 <https://historydollop.com/2016/11/09/almond-milk-the-medieval-way/>.

10 ADM. Meat Analogs, n.d. <https://www.adm.com/products-services/food/proteins/applications/meat-analogs>.

11 You can still buy Sosmix in the U.K. today. Alternative Stores, n.d. <https://www.alternativestores.com/index.php?route=product/product&product_id=2402>.

12 Smith, K. Annabelle. "The History of the Veggie Burger." *Smithsonian*, March 19, 2014 <https://www.smithsonianmag.com/arts-culture/history-veggie-burger-180950163/>.

13 Plamil Foods. About, n.d. <https://www.plamilfoods.co.uk/about>.

14 Tofurky. Seth Tibbott, On Founding Tofurky, n.d. <https://tofurky.com/articles/seth-tibott-on-founding-tofurky/>.

15 Quorn. Mycoprotein: Discover a Delicious Nutritious Protein Source with Quorn, n.d. <https://www.quorn.us/mycoprotein>.

16 Lappé, Frances Moore. *Diet for a Small Planet* (New York: Ballantine, 1971).

17 The terms *veg*ns* and *veg*sm* are shorthand for "vegetarians and vegans," or "vegetarianism and veganism." For the purposes of this paper, these terms will apply mainly to vegans and veganism.

18 For an example of vegan asceticism, see Nick, Mitch. What I Learned from 100 Days without Meat, Dairy, Caffeine, and Alcohol. Medium, March 12, 2017 <https://medium.com/@mitchnick/what-i-learned-from-100-days-without-meat-dairy-caffeine-and-alcohol-c154f5242e22>.

19 During the nineteenth century, vegetarian foods were deliberately bland for fear of over-stimulating the nervous system. See Prichep, Deena. "The Rise of Mock Meat," note 8.

20 For example, Cannold, Lesli. "Are Vegetarianism and Vegans about Not Harming Animals or Feeling Morally Superior?" *Guardian*, May 2, 2016 <https://www.theguardian.com/commentisfree/2016/may/02/isvegetarianism-and-veganism-about-not-harming-animals-or-feeling-morally-superior>.

21 *Food & Wine*. "28 Festive Christmas Roasts," n.d. <https://www.foodandwine.com/slideshows/christmas-roasts>.

22 Adams, Carol J. *The Sexual Politics of Meat: A Feminist-Vegetarian Critical Theory* 20th Anniversary Edition (New York: Bloomsbury, 2010).

23 McWilliams, James. "Gluttony and Global Warming: We're Eating Ourselves to a Warmer Planet." *Pacific Standard*, December 15, 2014 <https://psmag.com/environment/gluttony-global-warming-eating-warmer-planet-96495>.

24 Fiddes, Nick. *Meat: A Natural Symbol* (Routledge: London, 1992), 107–109.

25 For a classic work on many aspects of food culture and philosophy, see *Cooking, Eating, Thinking: Transformative Philosophies of Food*, edited by Deane W. Curtin and Lisa M. Heldke (Indianapolis: Indiana University Press, 1992).

26 The outlines of these ancient arguments can be discerned in a contemporary article on policy: Klassen, Susanna, and Sean Patrick Kearney. The "Irony" of Gendered Meat Consumption. Medium, March 7, 2019 <https://medium.com/the-nature-of-food/the-irony-of-gendered-meat-consumption-15371fe0cfcd>.

27 For a summary, see "Dietary Law" in *Encyclopedia Britannica*, n.d. <https://www.britannica.com/topic/dietary-law>. For more on gender and meat, see the work of Carol J. Adams, particularly *The Sexual Politics of Meat: A Feminist-Vegetarian Critical Theory* 20th Anniversary Edition (Bloomsbury: New York, 2010).

28 Fiddes, Nick. *Meat: A Natural Symbol* (Routledge: London, 1992), 30.

29 Fiddes, Nick. *Meat: A Natural Symbol* (Routledge: London, 1992), 33.

30 Fiddes, Nick. *Meat: A Natural Symbol* (Routledge: London, 1992), 43.

31 Fiddes, Nick. *Meat: A Natural Symbol* (Routledge: London, 1992), 1.

32 For more on religion and vegetarianism, and the various cults from Pythagoreans, Essenes, and Gnostics, through to the South and East Asian religious traditions, see Berry, Rynn. *Food for the Gods: Vegetarianism and the World's Religions* (New York: Pythagorean, 1998); Rosen, Steve. *Diet for Transcendence: Vegetarianism and the World Religions* (Badger, CA: Torchlight, 1997); Spencer, Colin. *Vegetarianism: A History* (New York: Four Walls Eight Windows, 2002); Akers, Keith: *The Lost Religion of Jesus: Simple Living and Nonviolence in Early Christianity* (New York: Lantern, 2000), and Avey, Tori. "From Pythagorean to Pescatarian—The Evolution of Vegetarianism, The History Kitchen." *PBS* January 28, 2014 <http://www.pbs.org/food/the-history-kitchen/evolution-vegetarianism/>.

33 For symbolic, cultural, and social meanings of cooking, eating, and preparing the flesh, see Lévi-Strauss, Claude. *The Raw and the Cooked* (Chicago: University of Chicago Press 1983 [1964]; Douglas, Mary. *Natural Symbols: Explorations in Cosmology* (London: Routledge, 2013 [1970]), and *Cooking, Eating, Thinking: Transformative Philosophies of Food* edited by Lisa Heldke and Deane Curtin (Indianapolis: Indiana University Press, 1992).

34 For an overview of the health arguments made over the last several centuries, see Stuart, Tristram. *The Bloodless Revolution: A Cultural History of Vegetarianism: From 1600 to Modern Times* (New York: Norton, 2008).

35 Leenaert, Tobias. "Don't You Dare Call Yourself a Vegan." Vegan Strategist, February 1, 2016 <http://veganstrategist.org/2016/02/01/dont-you-dare-call-yourself-a-vegan/> and "The First Rule of a Vegan Club: Do Not Make It a Club." Animal and Mind, July 7, 2018 <https://animalandmind.com/2018/07/20/the-first-rule-of-vegan-club-do-not-make-it-a-club/>.

36 For a contemporary analysis of how modern slaughterhouses are designed to divide up labor, sightlines, and animals as they become meat, see Pachirat, Timothy. *Every Twelve Seconds: Industrialized Slaughter and the Politics of Sight* (New Haven, CT: Yale University Press, 2011).

37 Slotnik, Daniel E. "Upton Sinclair, Whose Muckraking Changed the Meat Industry." *New York Times*, June 30, 2016 <https://www.nytimes.com/interactive/projects/cp/obituaries/archives/upton-sinclair-meat-industry>.

38 For more on the industrialization of animal agriculture around the world, see Brighter Green's policy papers on India, Ethiopia, Brazil, and China <http://brightergreen.org/publications/>.

39 For conditions in factory farms, see, for instance, Baur, Gene. *Farm Sanctuary: Changing Hearts and Minds about Animals and Food* (New York: Touchstone, 2006); and Runkle, Nathan, and Gene Stone. *Mercy for Animals: One Man's Quest to Inspire Compassion and Improve the Lives of Farm Animals* (Avery: New York, 2017). Many organizations—such as Farm Sanctuary, Mercy For Animals, and Compassion Over Killing—have produced graphic videos of what goes on in factory farms.

40 Many recent books catalogue the cruelties of contemporary animal agriculture. For a fully illustrated and graphic examination, see Imhoff, Daniel (ed). *CAFO: The Tragedy of Industrial Farming* (Healdsburg, CA: Watershed Media, 2010) <http://www.cafothebook.org>. For conditions for workers in slaughterhouses, see Eisnitz, Gail: *Slaughterhouse: The Shocking Story of Greed, Neglect, and Inhumane Treatment*

Inside the U.S. Meat Industry, revised edition (Amherst, NY: Prometheus, 2006); and Pachirat, Timothy. *Every Twelve Seconds: Industrialized Slaughter and the Politics of Sight* (New Haven, CT: Yale University Press, 2011).

41 Ritchie, Hannah, and Max Roser. "Meat and Seafood Production & Consumption." Our World in Data, August 2017 <https://ourworldindata.org/meat-and-seafood-production-consumption>.

42 For a comparison, see "Numbers in Perspective." Speaking of Research, March 2006 <https://speakingofresearch.files.wordpress.com/2008/03/animals-used-by-humans-in-numbers-in-us.jpg>.

43 These are the "28 Hour Law," which monitors animals on their way to slaughter, and the "Humane Slaughter Act." Many animals are exempted. See: Animal Legal Defense Fund. Laws that Protect Animals, n.d. <https://aldf.org/article/laws-that-protect-animals/>.

44 For an overview of federal and state guidelines on food animal protection and the law, see Wolfson, David J., and Mariann Sullivan, "Foxes in the Hen House: Animals, Agribusiness, and the Law—a Modern American Fable," in *Animal Rights: Current Debates and New Directions* edited by Cass Sunstein and Martha Nussbaum (Oxford: Oxford University Press, 2005).

45 Harrison, Ruth. *Animal Machines: The New Factory Farming* (London: Vincent Stuart, 1964); Singer, Peter. *Animal Liberation* (New York: HarperCollins, 1975); Mason, Jim, and Peter Singer. *Animal Factories* (New York: Crown, 1980); Victor Schonfeld and Myriam Alaux, directors: *The Animals Film* (1981).

46 Open Rescue International. About, n.d. "Open rescue is a form of nonviolent direct action in which activists enter animal farms and other facilities, document the conditions, and rescue animals. These rescues are open as the activists do not hide their identities from the public" <https://www.openrescues.com/about>.

47 For example: Hatkoff, Amy. *The Inner World of Farm Animals: Their Amazing Social, Emotional, and Intellectual Capacities* (New York: Stewart, Tabori and Chang, 2009), Masson, Jeffrey Moussaieff. *The Pig Who Sang to the Moon: The Emotional World of Farm Animals* (New York: Ballantine, 2004), and Baur, Gene. *Farm Sanctuary: Changing Hearts and Minds about Animals and Food* (New York: Touchstone, 2006).

48 A partial bibliography of works on animal ethics can be found at Lengauer, Edwin. Animal Ethics, n.d. Philpapers.org <https://philpapers.org/browse/animal-ethics>.

49 Judkis, Maura. "You Might Think There Are More Vegetarians Than Ever. You'd Be Wrong." *Washington Post*, August 3, 2018 <https://www.washingtonpost.com/news/food/wp/2018/08/03/you-might-think-there-are-more-vegetarians-than-ever-youd-be-wrong/?utm_term=.bb22dcc31b23>. The Vegetarian Resource Group has conducted polls on this question for many years. The organization's latest poll on the number of vegans and vegetarians was in 2016. See: <https://www.vrg.org/nutshell/Polls/2016_adults_veg.htm>.

50 Leichman, Abigail Klein. "Israel Has Most Vegans Per Capita and the Trend Is Growing." Israel 21C, March 26, 2017 <https://www.israel21c.org/israel-has-most-vegans-per-capita-and-the-trend-is-growing/>.

51 Bloomberg. "'Beef Will Always Be King.' Americans Are Set to Eat More Meat in 2018 Than Ever Before." *Fortune*, January 2, 2018 <http://fortune.com/2018/01/02/meat-consumption-america-2018/>.

52 "World Meat Production to Reach Record High in 2018, FAO." Global Agriculture, November 9, 2018 <https://www.globalagriculture.org/whats-new/news/en/33468.html>. See also Brighter Green's policy papers on the rise of meat consumption in China, Ethiopia, India, and Brazil <https://brightergreen.org/publications/>, and dairy production: Ava, Jessika. *Beyond the Pail: The Emergence of Industrialized Dairy Systems in Asia* (2014) <https://www.brightergreen.org/files/beyond_the_pail_brighter_green_final.pdf>.

53 Watson, Elaine. "'Henry Ford Did More for Horses than Animal Rights Activists Ever Did . . .'" *Food Navigator*, February 11, 2019 <https://www.foodnavigator-usa.com/Article/2019/02/11/Henry-Ford-did-more-for-horses-than-animal-rights-activists-ever-did-technology-has-enabled-us-to-align-our-ethics-with-our-behaviors.-Paul-Shapiro-talks-cell-based-meat>.

54 Illing, Sean. "Ethical Arguments Won't End Factory Farming. Technology Might." *Vox*, October 11, 2016 <https://www.vox.com/conversations/2016/10/11/13225532/bruce-friedrich-good-food-institute-meat-factory-farming-vegetarianism>.

55 For a distillation of this strategy see Leenaert, Tobias. *How to Create a Vegan World: A Pragmatic Approach* (New York: Lantern, 2017).

56 For the reasoning behind this strategy, see the Open Philanthropy Project. Animal Welfare Fund, n.d., which is committed to the principles and philosophy of Effective Altruism <https://app.effectivealtruism.org/funds/animal-welfare>.

57 Steinfeld, H. *et al. Livestock's Long Shadow: Environmental Issues and Options*. Rome: FAO, 2006 <http://www.fao.org/3/a-a0701e.pdf>.

58 The original 2006 FAO estimate of 18 percent was subsequently revised to 14.5 percent in a 2014 FAO report, *Tackling Climate Change through Livestock* <http://www.fao.org/3/a-i3437e.pdf>.

59 Greenpeace International. Greenpeace Calls for Decrease in Meat and Dairy Production and Consumption for a Healthier Planet, March 5, 2018 <https://www.greenpeace.org/international/press-release/15111/greenpeace-calls-for-decrease-in-meat-and-dairy-production-and-consumption-for-a-healthier-planet/>.

60 World Wildlife Fund. *Appetite for Destruction*, October 2017 <https://www.wwf.org.uk/sites/default/files/2017-10/WWF_AppetiteForDestruction_Summary_Report_SignOff.pdf>.

61 Center for Biological Diversity. Take Extinction off Your Plate, 2019. <https://www.takeextinctionoffyourplate.com>.

62 Shapiro, Paul. *Clean Meat: How Growing Meat without Animals Will Revolutionize Dinner and the World* (New York: Gallery Books, 2018), 30.

63 Leenaert, Tobias. *How to Create a Vegan World: A Pragmatic Approach* (New York: Lantern, 2017): 69.

64 Legally, Christie, *et al. Plant-based Mind Map: An Exploration of Options, Ideas, and Industry*. Good Food Institute, September 25, 2017 <https://www.gfi.org/files/PBMap.pdf>.

65 Robinson, Melia. "Generation Z Is Creating a $5 Billion Market for Fake Meat." *Business Insider*, November 1, 2017 <https://www.businessinsider.com/generation-z-is-eating-fake-meat-2017-10>.

66 Gallagher, Sarah. "Anuga Report: Flexitarians Driving Plant-based Innovations." *Specialty Food News*, October 9, 2017 <https://www.specialtyfood.com/news/article/plant-based-innovations-appeal-flexitarian-market/>.

67 Johnson, Patty. What Consumers Really Think about Meat

Alternatives. Mintel, October 1, 2018 <https://www.mintel.com/blog/consumer-market-news/what-consumers-really-think-about-meat-alternatives>.
68 Stice, Camilla. WhooPea: Plant Sources Are Changing the Protein Landscape. Lux Research, December 22, 2014 <https://members.luxresearchinc.com/research/report/16091>.
69 Gerhardt, Carsten, *et al.* How Will Cultured Meat and Meat Alternatives Disrupt the Agricultural and Food Industry? A.T. Kearney, n.d. <https://www.atkearney.com/retail/article/?/a/how-will-cultured-meat-and-meat-alternatives-disrupt-the-agricultural-and-food-industry>.
70 Mintel. Non-Dairy Milk Sales Grow 61 Percent Over the Last Five Years, January 4, 2018 <http://www.mintel.com/press-centre/food-and-drink/us-non-dairy-milk-sales-grow-61-over-the-last-five-years>.
71 Houck, Brenna. "America's Obsession with Oat Milk Is Hurting the Dairy Industry." *Eater*, March 26, 2019 <https://www.eater.com/2019/3/26/18282831/milk-sales-fall-2018-plant-based-alternatives>.
72 Watson, Elaine. "US Retail Sales of Plant-based Milk up 9%, Plant-based Meat up 24% YOY." *Food Navigator*, July 30, 2018 <https://www.foodnavigator-usa.com/Article/2018/07/30/US-retail-sales-of-plant-based-milk-up-9-plant-based-meat-up-24-YoY>.
73 Statista.com. Forecasted Market Value of Vegan Cheese Worldwide from 2015 to 2024 (In Million U.S. Dollars), n.d. <https://www.statista.com/statistics/799195/vegan-cheese-market-value-global/>.
74 Raphael, Rina. "Don't Cry, But Milk Sales Plummeted by $1.1 Billion Last Year." *Fast Company*, March 25, 2019 <https://www.fastcompany.com/90324853/dont-cry-but-milk-sales-plummeted-by-1-1-billion-last-year>.
75 Houck, Brenna. "America's Obsession with Oat Milk Is Hurting the Dairy Industry." *Eater*, March 26, 2019 <https://www.eater.com/2019/3/26/18282831/milk-sales-fall-2018-plant-based-alternatives>.
76 Tobias Leenaert mentions these purchases: "Seven Possible Responses of Meat and Dairy Companies to Vegan Growth." Vegan Strategist, October 26, 2018 <http://veganstrategist.org/2018/10/26/seven-possible-responses-of-meat-and-dairy-companies-to-vegan-growth/>.
77 Cameron, Brianna, and Shannon O'Neill. *State of the Industry Report: Plant-based Meat, Eggs, and Dairy*. Good Food Institute, 2019: 17, 10.
78 Churchill, Winston. "Fifty Years Hence." *Strand*, December 1931. The etiology of the quote can be found at Quote Investigator, January 22, 2017 <https://quoteinvestigator.com/2017/01/22/meat/>.
79 "History of Biology: Cell Theory and Cell Structure." Biology Reference, n.d. <http://www.biologyreference.com/Gr-Hi/History-of-Biology-Cell-Theory-and-Cell-Structure.html>.
80 National Institutes of Health. Stem Cells: Basics 1, 2016 <https://stemcells.nih.gov/info/basics/1.htm>.
81 Ross, Russell. "The Smooth Muscle Cell." *Journal of Cell Biology* (July 1971) 50(1) <http://jcb.rupress.org/content/50/1/172>.
82 Goodwin, J. N., and C. W. Shoulders. "The Future of Meat: A Qualitative Analysis of Cultured Meat Media Coverage." *Meat Science* (2013) 95: 445–450.
83 Cassiday, Laura. "Clean Meat." *AOCS: Your Global Fats and Oils Collection*, February 2018 <https://www.aocs.org/stay-informed/inform-magazine/featured-articles/clean-meat-february-2018>.
84 Kadim, Isam T., *et al.* "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* (2015) 14(2): 222–233.
85 For more on the artistic experiment, see van der Weele, Cor, and Clemens Driessen. "Emerging Profiles for Cultured Meat; Ethics through and as Design." *Animals* (2013) (3): 647–662 (649).
86 National Human Genome Research Institute. "Human Genome Project Timeline of Events," November 12, 2018 <https://www.genome.gov/human-genome-project/Timeline-of-Events>.
87 National Human Genome Research Institute. The Cost of Sequencing a Human Genome, July 6, 2016 <https://www.genome.gov/about-genomics/fact-sheets/Sequencing-Human-Genome-cost>.
88 As per Justin Siegel at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=CeJXe7yK170&t=1221s>, 15:08–15:45.
89 For an overview of the origins of Mark Post's burger, see Datar, Isha, and Daan Luining. "Mark Post's Cultured Beef." New Harvest, November 3, 2015 <https://www.new-harvest.org/mark_post_cultured_beef>.
90 Galarza, Daniela. "Lab-Grown Meat Finally Available in Chicken Nugget Form." *Eater*, March 15, 2017 <https://www.eater.com/2017/3/15/14933922/lab-grown-chicken-duck-memphis-meats>.
91 Watson, Elaine. "JUST Strikes Deal to Bring Cell-Cultured Wagyu Beef to Market." *Food Navigator*, December 11, 2018 <https://www.foodnavigator-usa.com/Article/2018/12/11/JUST-strikes-deal-in-Japan-to-bring-cell-cultured-Wagyu-beef-to-market>.
92 Lamb, Catherine. "Aleph Farms Puts a Steak in the Ground, Unveils New Cell-Based Cut of Meat." *The Spoon*, December 12, 2018 <https://thespoon.tech/aleph-farms-puts-a-steak-in-the-ground-unveils-new-cell-based-cut-of-meat/>.
93 Starostinetskaya, Anna. "Animal-Free Egg Whites to Debut in 2019." *Veg News*, August 15, 2018 <https://vegnews.com/2018/8/animal-free-egg-whites-to-debut-in-2019>.
94 For information on these and other acellular processes, see New Harvest. About Cellular Agriculture, n.d. <https://www.new-harvest.org/about#cellular_agriculture>.
95 Scott-Thomas, Caroline. "Biocatalysts Develops Microbial Alternative to Papain." *Food Navigator*, July 8, 2013 <https://www.foodnavigator.com/Article/2013/07/09/Biocatalysts-develops-microbial-alternative-to-papain>.
96 The Swiss company Evolva is making vanillin, see: Evolva. Vanillin, 2019 <https://www.evolva.com/vanillin/>.
97 Watson, Elaine. "Geltor Seeks to Disrupt Gelatin Market with Cellular Agriculture." *Food Navigator*, December 8, 2017 <https://www.foodnavigator-usa.com/Article/2017/12/08/Geltor-seeks-to-disrupt-gelatin-market-with-cellular-agriculture>.
98 Modern Meadow. Our Technology, 2019 <http://www.modernmeadow.com/our-technology/>.
99 Spiber. Spiber Biomaterial, n.d. <http://spiber.se>.
100 Modern Meadow. Our Technology, 2019 <http://www.modernmeadow.com/our-technology/>.
101 Pembient is biofabricating rhino horn using keratin and recombined rhino DNA. See Datar, Isha and Matthew Markus. "Pembient: Rhino Horns without Poaching." New Harvest, November 17, 2015 <https://www.new-harvest.org/pembient_rhino_horns>.
102 Bandoim, Lana. "Perfect Day Partners with ADM to Make

Milk without Cows." *Forbes*, November 16, 2018 <https://www.forbes.com/sites/lanabandoim/2018/11/16/perfect-day-partners-with-adm-to-make-milk-without-cows/#321c963d66ca>.
103 Citron, Tobias. Presentation at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA <https://www.youtube.com/watch?v=gxH4Ma-fm-8>, 6:40–8:10.
104 United Nations. World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100, June 21, 2017 <https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html>.
105 The founders of Beyond Meat and Impossible Foods have received honors from the United Nations for precisely this reason. See "Plant-based Meat Revolutionaries Win UN's Highest Environmental Honor." *UN Environment*, September 28, 2018 <https://www.unenvironment.org/news-and-stories/press-release/plant-based-meat-revolutionaries-win-uns-highest-environmental-honor>.
106 Watson, Elaine. "US Retail Sales of Plant-based Milk up 9%, Plant-based Meat up 24% YOY." *Food Navigator*, July 30, 2018 <https://www.foodnavigator-usa.com/Article/2018/07/30/US-retail-sales-of-plant-based-milk-up-9-plant-based-meat-up-24-YoY>.
107 Business Wire. "Impossible Foods' Flagship Product Is Now Available in About 5,000 Restaurants." November 8, 2018 <https://www.businesswire.com/news/home/20181108005123/en/Impossible-Foods'-Flagship-Product-5000-Restaurants>.
108 Whitten, Sarah. "White Castle's Plant-based Impossible Slider Gets Nationwide Release." *CNBC*, September 12, 2018 <https://www.cnbc.com/2018/09/12/white-castles-plant-based-impossible-slider-gets-nationwide-release.html>.
109 Von Alt, Sarah. Red Robin Announces Plan to Launch Impossible Burger at 570 Locations. Choose Veg, March 27, 2019 <https://chooseveg.com/blog/red-robin-to-launch-impossible-burger-at-570-locations/>.
110 Watson, Elaine. "Impossible Burger to Launch in Retail Stores in 2019." *Food Navigator*, November 8, 2018 <https://www.foodnavigator-usa.com/Article/2018/11/08/Impossible-Burger-to-launch-in-retail-stores-in-2019>.
111 Murphy, Mike. "Beyond Meat Soars 163% in Biggest Popping US IPO Since 2000." *Market Watch*, May 5, 2019 <https://www.marketwatch.com/story/beyond-meat-soars-163-in-biggest-popping-us-ipo-since-2000-2019-05-02>.
112 Rowland, Michael Pellman. "Vegan Company Reportedly Sets Sights on IPO." *Forbes*, October 21, 2018 <https://www.forbes.com/sites/michaelpellmanrowland/2018/10/21/beyond-meat-ipo/#3b43f5dc6b14>.
113 Watson, Elaine. "Cultured Fish Co Finless Foods Aims to Achieve Price Parity with Bluefin Tuna by the End of 2019." *Food Navigator*, December 21, 2017 <https://www.foodnavigator-usa.com/Article/2017/12/21/Finless-Foods-co-founder-talks-clean-meat-clean-fish-cultured-meat>.
114 Siegner, Cathy. "Nestlé Will Launch Plant-based Incredible Burger This Spring." *Food Dive*, January 2, 2019 <https://www.fooddive.com/news/nestle-will-launch-plant-based-incredible-burger-this-spring/545072/>.
115 Overgaard, Sidsel. "Even the Hamburgler Might Like McDonald's New McVegan Burger (We Did)." *NPR The Salt*, February 21, 2018 <https://www.npr.org/sections/thesalt/2018/02/21/587406992/even-the-hamburglar-might-like-mcdonalds-new-mcvegan-burger-we-did>.
116 Min, Sarah. "Burger King Testing Meatless Whoppers." *CBS News*, April 2, 2019 <https://www.cbsnews.com/news/burger-king-impossible-whopper-burger-king-launches-vegan-burger-on-april-fools-day/>.
117 Guadagnini, Gustavo. JBS Launching Plant-based Burger in Brazil. Good Food Institute, May 21, 2019 <https://www.gfi.org/jbs-launching-plant-based-burger-in-brazil>.
118 Min, Sarah. "Tyson, America's Largest Meat Producer, Sinks Its Teeth into Fake Meat." *CBS News*, June 13, 2019 <https://www.cbsnews.com/news/tyson-vegan-meat-americas-largest-meat-producer-is-tearing-into-fake-meat/>.
119 Perdue Farms. Perdue Foods Launches CHICKEN PLUS™ With Vegetable Nutrition New Chicken Nuggets, Tenders and Patties Meet Demand for Flexitarian Families, June 12, 2019 <https://www.perduefarms.com/news/press-releases/perdue-foods-launches-chicken-plus-with-vegetable-nutrition-new-chicken-nuggets-tenders-and-patties-meet-demand-for-flexitarian-families/>.
120 Cameron, Brianna, and Shannon O'Neill. *State of the Industry Report: Cell-based Meat*. Good Food Institute, 2019: 5.
121 Tyson Foods. Tyson Foods Invests in Cultured Meat with Stake in Memphis Meats, January 29, 2018 <https://www.tysonfoods.com/news/news-releases/2018/1/tyson-foods-invests-cultured-meat-stake-memphis-meats>.
122 Cargill. Protein Innovation: Cargill Invests in Cultured Meats, August 23, 2017 <https://www.cargill.com/story/protein-innovation-cargill-invests-in-cultured-meats>.
123 Michail, Niamh. "German Poultry Giant PHW Partners with SuperMeat to Bring Cultured Meat to Europe." *Food Navigator*, January 4, 2018 <https://www.foodnavigator.com/Article/2018/01/04/German-poultry-giant-PHW-partners-with-SuperMeat-to-bring-cultured-meat-to-Europe>.
124 Morgan, Rick. "Bill Gates and Richard Branson Bet on Lab-Grown Meat Startup." *CNBC*, March 23, 2018 <https://www.cnbc.com/2018/03/23/bill-gates-and-richard-branson-bet-on-lab-grown-meat-startup.html>.
125 Khosla Ventures Agriculture: Agriculture/Food, n.d. <https://www.khoslaventures.com/portfolio/agriculture-food>.
126 Scipioni, Jade. "Tyson Foods CEO: The Future of Food Might Be Meatless." *Fox Business*, March 7, 2017 <https://www.foxbusiness.com/features/tyson-foods-ceo-the-future-of-food-might-be-meatless>.
127 Branson, Richard. Clean Meat Is the Future of Meat. Virgin, February 13, 2018 <https://www.virgin.com/richard-branson/clean-meat-future-meat>.
128 Henchion, Maeve, *et al.* "Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium." *Foods* (July 2017) 6(7): 53 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5532560/>.
129 Shelef, Oren, *et al*. "The Value of Native Plants and Local Production in an Era of Global Agriculture." *Frontiers in Plant Science* (2017) 8: 2069. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5723411/>.
130 Beardsley, Eleanor. "For A Healthier Planet, Eat These 50 Foods, Campaign Urges." *NPR The Salt*, March 24, 2019 <https://www.npr.org/sections/thesalt/2019/03/24/706004242/for-a-healthier-planet-eat-these-50-foods-campaign-urges?>.
131 Barnett, Adrian. "The Nature of Crops: Why Do We Eat So Few of the Edible Plants." *New Scientist*, July 15, 2015 <https://www.newscientist.com/article/mg22730301-400-the-nature-of-crops-why-do-we-eat-so-few-of-the-edible-plants/>.
132 A figure cited from a World Wildlife Fund report, *Future 50 Foods*,

in Beardsley, Eleanor. "For A Healthier Planet, Eat These 50 Foods, Campaign Urges." *NPR The Salt*, March 24, 2019 <https://www.npr.org/sections/thesalt/2019/03/24/706004242/for-a-healthier-planet-eat-these-50-foods-campaign-urges?>. Not a single food item in the report comes from an animal.

133 As per Natalie DiNicola at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?time_continue=3&v=vdMzrfQsBZE>, 4:06–4:20.

134 U.S. Department of Energy. U.S. Corn for Fuel, Feed, and Other Use at the Alternative Fuels Data Center, n.d. <https://afdc.energy.gov/data/10339>.

135 USDA. USDA Coexistence Factsheets: Soybeans, February 2015 <https://www.usda.gov/sites/default/files/documents/coexistence-soybeans-factsheet.pdf>.

136 Feedipedia. Wheat, n.d. <https://www.feedipedia.org/node/223>.

137 As per David Welch at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kShStGMkkX0>, 3:50–4:10.

138 As per Justin Siegel at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=CeJXe7yK170&t=1221s>, 33:35–36:02.

139 As per Natalie DiNicola at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?time_continue=3&v=vdMzrfQsBZE>, 6:18–7:17.

140 As per Peggy Lemaux at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=X_vviu0391E>, 17:41–18:05.

141 Gelski, Jeff. "Plant Protein Options for Meat Alternatives." *Food Business News*, March 30, 2018 <https://www.foodbusinessnews.net/articles/11501-plant-protein-options-for-meat-alternatives>.

142 Michail, Niamh. "Roquette Looks to Plant Milk Category for Future Pea Potential." *Food Navigator*, January 4, 2019 <https://www.foodnavigator.com/Article/2019/01/04/Roquette-looks-to-plant-milk-category-for-future-pea-potential>.

143 Nickel, Rod, and P. J. Huffstutter. "Big Ag Turns to Peas to Meet Soaring Global Protein Demand." *Reuters*, May 18, 2018 <https://www.reuters.com/article/us-crops-protein/big-ag-turns-to-peas-to-meet-soaring-global-protein-demand-idUSKCN1IJ1B3>.

144 Van de Velde, Fred, and Arno Alting. "From Waste Product to Food Ingredient: The Extraction of Abundant Plant Protein RuBisCo." *New Food Magazine*, May 13, 2011 <https://www.newfoodmagazine.com/article/4461/from-waste-product-to-food-ingredient-the-extraction-of-abundant-plant-protein-rubisco/>. Celeste Holz-Schietinger mentioned RuBisCo at the 2018 Ivy League Future of Food Conference in Philadelphia, PA.

145 As per Peggy Lemaux at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?time_continue=1971&v=X_vviu0391E>, 33:10–33:20.

146 Menayang, Adi. "Duckweed: A Promising New Source of Plant-based Protein?" *Food Navigator*, September 1, 2016 <https://www.foodnavigator-usa.com/article/2016/09/01/new-study-looks-at-duckweed-protein-nutritional-value-to-humans>. David Benzaquen mentioned lemna at the 2018 Ivy League Future of Food Conference in Philadelphia, PA.

147 "There's a New Dairy Free Ingredient in Town: Lupin." *Plant Based News*, November, 17, 2017 <https://www.plantbasednews.org/post/new-plant-based-milk-made-lupin>.

148 Michail, Niamh. "Innova Sees Plant-based Promise in Lupin, Hemp, and Flax Seed." *Food Navigator*, July 13, 2018 <https://www.foodnavigator.com/Article/2018/07/13/Innova-sees-plant-based-promise-in-lupin-hemp-and-flax-seed>.

149 As per Brian Plattner of Wenger Manufacturing at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=X_vviu0391E&t=4s>, 29:00–30:15.

150 As per Brian Plattner of Wenger Manufacturing at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=X_vviu0391E&t=4s>, 31:07–32:20.

151 Gelski, Jeff. "Taking on Off-Flavor Issues in Plant Proteins." *Food Business News*, March 23, 2017 <https://www.foodbusinessnews.net/articles/9092-taking-on-off-flavor-issues-in-plant-proteins>.

152 Knutsen, Jonathan. "Dry Peas: A Crop Whose Time Has Come?" *AgWeek*, March 4, 2019 <https://www.agweek.com/business/agriculture/4578753-dry-peas-crop-whose-time-has-come>.

153 Givaudin. Givaudan Launches MISTA, November 29, 2018 <https://www.givaudan.com/media/media-releases/2018/givaudan-launches-mista>.

154 As per Scott May at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=CeJXe7yK170>, 50:40–51:00.

155 As per Monjur Hossen at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=CeJXe7yK170>, 49:20–50:30.

156 Swanson, Ana. "Trump Gives Farmers $16 Billion in Aid Amid Prolonged China Trade War." *New York Times*, May 23, 2019 <https://www.nytimes.com/2019/05/23/us/politics/farm-aid-package.html>.

157 Appelbaum, Binyamin. "Their Soybeans Piling Up, Farmers Hope Trade War Ends Before Beans Rot." *New York Times*, November 5, 2018 <https://www.nytimes.com/2018/11/05/business/soybeans-farmers-trade-war.html>.

158 Chrisman, Siena. "American Farmers Are in Crisis." *Eater*, September 14, 2018 <https://www.eater.com/2018/9/14/17855080/american-farmers-crisis-trade-war>.

159 As per Barb Stuckey at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc&t=11s>, 35:50–36:56.

160 Peters, Adele. "2019 Will Be the Year that Alt Meat Goes Mainstream." *Fast Company*, December 26, 2018 <https://www.fastcompany.com/90280647/2019-will-be-the-year-alt-meat-goes-mainstream>.

161 Chiorando, Maria. "Vegan Companies 'Struggling to Meet' Growing Demand." *Plant Based News*, November 20, 2018 <https://www.plantbasednews.org/post/vegan-companies-struggling-growing-demand>.

162 Valinsky, Jordan, and Danielle Wiener-Bronner. "America Is Running Out of Impossible Burgers." *CNN Business*, April, 30, 2019 <https://www.cnn.com/2019/04/30/business/impossible-meat-shortage/index.html>.

163 Fox, Katrina. "Should Your Business Use the Word Vegan in Its Branding or Marketing?" *Forbes*, January 23, 2018 <https://www.forbes.com/sites/katrinafox/2018/01/23/should-your-business-use-the-word-vegan-in-its-branding-or-marketing/>.

164 Watson, Elaine. "'Plant-based' Plays Way Better Than 'Vegan' with Most Consumers, Says Mattson." *Food Navigator*, April 19, 2018 <https://www.foodnavigator-usa.com/Article/2018/04/19/Plant-based-plays-way-better-than-vegan-with-most-consumers-says-Mattson> and Bernot, Kate. "No Food Word Is Less Appealing than 'Vegan.'" *The Takeout*,

March 25, 2018 <https://thetakeout.com/survey-no-food-word-is-less-appealing-than-vegan-1826326553>.

165 See the discussion on the label "vegan" at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc>, 20:45–23:00.

166 Watson, Elaine. "An Estimated 70% of Beyond Burger Fans Are Meat-Eaters Not Vegans/Vegetarians, Says Beyond Meat." *Food Navigator*, January 12, 2018 <https://www.foodnavigator-usa.com/Article/2018/01/12/An-estimated-70-of-Beyond-Burger-fans-are-meat-eaters-not-vegans-vegetarians-says-Beyond-Meat>.

167 For instance, see: Nestlé Professional. Vegetarian, Flexitarian, Vegan. Plant-Oriented Diets Are Growing, October 1, 2016 <https://www.nestleprofessional.us/nutrition/vegetarian-flexitarian-vegan-plant-oriented-diets-are-growing>.

168 See Siddhu-Robb, Gita. "Are We All Going Vegan Because We Care about Ethics Or Simply Because It's Trendy?" *Glamour UK*, November 1, 2018 <https://www.glamourmagazine.co.uk/gallery/why-you-should-go-vegan>.

169 Center for Nutrition Studies. What Is a Whole Food Plant-based Diet? August 8, 2018 <https://nutritionstudies.org/what-is-a-whole-food-plant-based-diet/>.

170 Messina, Ginny. "Vegan Diets and Orthorexia: How Should Activists Respond?" The Vegan RD, December 16, 2015 <https://www.theveganrd.com/2015/12/vegan-diets-and-orthorexia-how-should-activists-respond/>. See also Brown, Jessica. "The Dark Side of Veganism: How the Diet Can Be a Cover for Disordered Eating." *Independent*, September 17, 2018 <https://www.independent.co.uk/news/long_reads/veganism-orthorexia-dieting-anorexia-food-bloggers-diet-vegans-a8537211.html>.

171 Moody, Liz. 8 Real People Share Why They Stopped Being Vegan. Mind Body Green, May 7, 2018 <https://www.mindbodygreen.com/articles/why-i-stopped-being-vegan>.

172 Mahoney, Paul. Is "Vegan" a Better Term than "Plant-based" for an Animal-Free Diet? Terrastendo, December 28, 2017 <https://terrastendo.net/2017/12/28/is-vegan-a-better-term-than-plant-based-for-an-animal-free-diet/>.

173 Hancox, Dan. "The Unstoppable Rise of Veganism: How a Fringe Movement Went Mainstream." *Guardian*, April 1, 2018 <https://www.theguardian.com/lifeandstyle/2018/apr/01/vegans-are-coming-millennials-health-climate-change-animal-welfare>.

174 Chiorando, Maria. "44% of Generation Z Say Being Vegan Is 'Cooler Than Smoking'." *Plant Based News*, October 1, 2018 <https://www.plantbasednews.org/post/44-of-generation-z-vegan-cooler-smoking>.

175 For Instacart. Boca Original Vegan Veggie Patties, n.d. <https://www.instacart.com/shopping/products/254181-oscar-mayer-boca-original-vegan-veggie-patties-30-oz>. Eleuterio discussed his decision at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=RoFbmYyTRFA>, 17:25–20:40.

176 Faunalytics. Plant-Based Product Labeling: Veg*n Vs. Other Options, June 3, 2019 <https://www.youtube.com/watch?v=HQ3SWGAAzLk>.

177 Shapiro, Paul. "Is 'Vegan' a Four-Letter Word on Product Packaging?" *Food Navigator*, April 4, 2019 <https://www.foodnavigator-usa.com/Article/2019/04/10/GUEST-ARTICLE-Is-vegan-a-four-letter-word-on-product-packaging>.

178 For a skeptical view on clean meat's health claims, see McGowan, Kat. The "Clean Meat" Industry Has a Dirty Little Secret. Medium, November 15, 2018 <https://medium.com/neodotlife/the-clean-meat-industry-has-a-dirty-little-secret-421d510b8136>.

179 Once such company is Ginkgo Bioworks, which is profiled by Johnny Drain. Organism Designers at Ginkgo Bioworks Are Designing Tasty Food Flavors. This Is Mold, September 21, 2017 <https://thisismold.com/process/manufacture/ginkgo-bioworks-christina-agapakis#.XHbcIa3MxHU>.

180 Gelski, Jeff. "Taking on Off-Flavor Issues in Plant Proteins." *Food Business News*, March 23, 2017 <https://www.foodbusinessnews.net/articles/9092-taking-on-off-flavor-issues-in-plant-proteins>.

181 Holz-Schietinger made this point at the 2018 Ivy League Future of Food Conference in Philadelphia, PA.

182 As per Mark Matlock, Senior Vice President Food Research, at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?time_continue=7&v=vdMzrfQsBZE>, 7:45–10:15.

183 As per Peggy Lemaux at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=X_vviu0391E&t=259s>, 34:04–35:31.

184 As per Celeste Holz-Schietinger at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?time_continue=2494&v=X_vviu0391E>, 43:03–43:31.

185 As per Scott May and Lav Varshney at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=CeJXe7yK170&t=69s> at 22:05–22:30 and 24:00–24:45 respectively. Varshney is profiled on the Good Food Institute's website: Allen, Mary. How AI Can Help Fix the Food System. Good Food Institute, July 5, 2018 <https://www.gfi.org/how-ai-can-help-fix-the-food-system>.

186 As per Lav Varshney at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=CeJXe7yK170&t=69s>, 8:25–9:15.

187 Kanuckel, Amanda. Parmentier Made Potatoes Popular. Farmers Almanac, n.d. <https://www.farmersalmanac.com/parmentier-made-potatoes-popular-28537> and the interview with Lav Varshney on the Good Food Institute website: Allen, Mary. How AI Can Help Fix the Food System. Good Food Institute, July 5, 2018<https://www.gfi.org/how-ai-can-help-fix-the-food-system>.

188 To see copies of these books, visit the Radcliffe Library blog: Radcliffe Institute for Advanced Study, Harvard University. Celebrating Bastille Day: 18th-Century French Culinary Books at the Schlesinger (with Recipes!), July 13, 2012 <https://www.radcliffe.harvard.edu/schlesinger-library/blog/celebrating-bastille-day-18th-century-french-culinary-books-schlesinger>.

189 For an example of the malleability of appropriateness regarding which animals one should or should not eat, see Bratanova, B., *et al.* The Effect of Categorization as Food on the Perceived Moral Standing of Animals. *Appetite* (August 2011) 57: 193–196.

190 Gallagher, Sarah. "Anuga Report: Flexitarians Driving Plant-based Innovations." *Specialty Food*, October 9, 2017 <https://www.specialtyfood.com/news/article/plant-based-innovations-appeal-flexitarian-market/>.

191 Splitter, Jenny. "2019 Could Be a Turning Point for Plant-based and Cultured Meats." *Forbes*, December 18, 2018 <https://www.forbes.com/sites/jennysplitter/2018/12/18/plant-based-cultured-meats-turning-point/#39c810da20a7>.

192 Hartmann, Christina, and Michael Siegrist. "Consumer Perception and Behaviour Regarding Sustainable Protein Consumption: A Systematic Review." *Trends in Food*

Science & Technology (March 2017) 61: 11–25 <https://www.sciencedirect.com/science/article/abs/pii/S0924224416302904>.
193 Swartz, Haley. The Role of Plant-based, Meatless Meats in Sustainable Diets. FCRN Blog, July 27, 2017 <https://www.fcrn.org.uk/fcrn-blogs/hswartz5/role-plant-based-meatless-meats-sustainable-diets>.
194 As per Barb Stuckey at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc>, 26:00–27:11.
195 As per Alison Rabschnuk at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=RoFbmYyTRFA&t=881s>, 25:00–25:10; 31:30–32:55.
196 Benji Mikel made these observations at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA.
197 As per Lauren Sammel at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?time_continue=3&v=9hqtWfVXpvU>, 7:21–14:05.
198 Jolley, Chuck. Getting Real about Unreal Meat. Feedstuffs, June 4, 2019 <https://www.feedstuffs.com/commentary/getting-real-about-unreal-meat>.
199 As per Dean Ornish at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=X_vviu0391E&t=297s>, 20:12–21:07.
200 Ward, Mary, *et al.* "Heme Iron from Meat and Risk of Adenocarcinoma of the Esophagus and Stomach." *European Journal of Cancer Prevention* (March 2012) 21(2): 134–138. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3261306/>.
201 Quora Contributor. "How the 'Impossible Burger' Revealed Some Disturbing FDA Practices." *Forbes*, August 31, 2017 <https://www.forbes.com/sites/quora/2017/08/31/how-the-impossible-burger-revealed-some-disturbing-fda-practices/>.
202 Roseboro, Ken. Impossible Burger Rep Grilled at Sustainable Food Summit. Non-GMO Report, March 6, 2018 <https://non-gmoreport.com/articles/impossible-burger-rep-grilled-sustainable-foods-summit/>.
203 Strom, Stephanie. "Impossible Burger's 'Secret Sauce' Highlights Challenges of Food Tech." *New York Times*, August 8, 2017 <https://www.nytimes.com/2017/08/08/business/impossible-burger-food-meat.html>.
204 Gelski, Jeff. FDA: Soy Leghemoglobin Heme Safe for Consumption. Meat + Poultry, July 24, 2018 <https://www.meatpoultry.com/articles/19863-fda-soy-leghemoglobinheme-safe-for-consumption>.
205 Hooda, Jagmohan, Ajit Shah, and Li Zhang. "Heme, an Essential Nutrient from Dietary Proteins, Critically Impacts Diverse Physiological and Pathological Processes." *Nutrients* (March 2014) 6(3): 1080–1102.
206 For more, see Jacobs, Grant. The "Impossible Burger" Is Not Genetically Modified. SciBlogs, July 6, 2018 <https://sciblogs.co.nz/code-for-life/2018/07/06/the-impossible-burger-is-not-genetically-engineered/>.
207 Atkin, Emily. "The Promise and Problem of Fake Meat." *New Republic*, June 7, 2019 <https://newrepublic.com/article/153998/promise-problem-fake-meat-beyond-burger-impossible-foods>.
208 For a discussion of the health profiles, see Wilson, Bee. "The Trouble with Fake Meat." *Guardian*, January 27, 2019 <https://www.theguardian.com/food/2019/jan/27/the-trouble-with-fake-meat-beetroot-burgers-food-substitutes>.
209 Sotirovska, Dorotea, and Elizabeth Philip. "Why Eating Healthy Is So Expensive in America." *Vox* Video, March 22, 2018 <https://www.vox.com/videos/2018/3/22/17152460/healthy-eating-expensive>.
210 Center for Science in the Public Interest. Why Good Nutrition Is Important, n.d. <https://cspinet.org/eating-healthy/why-good-nutrition-important>.
211 Centers for Disease Control and Prevention. Adult Obesity Causes & Consequences, August 29, 2017 <https://www.cdc.gov/obesity/adult/causes.html>.
212 Centers for Disease Control and Prevention. Diabetes: Deaths and Cost, February 20, 2018 <https://www.cdc.gov/diabetes/data/statistics-report/deaths-cost.html>.
213 Farzan, Antonia Noori. "The Latest Right-wing Attack on Democrats: 'They Want to Take Away Your Hamburgers'." *Washington Post*, March 1, 2019 <https://www.washingtonpost.com/nation/2019/03/01/latest-right-wing-attack-democrats-they-want-take-away-your-hamburgers/?utm_term=.f98c686f9014>.
214 Adams, Carol J. *Burger* (Origins Series) (New York: Continuum, 2017), 14–18.
215 Friedrich, Bruce. Cultured Meat vs. "Clean Meat": The "Clean Energy" of Food. Good Food Institute, September 6, 2016 <https://www.gfi.org/clean-meat-the-clean-energy-of-food>.
216 ASPCA. What Is Ag-Gag Legislation? n.d. <https://www.aspca.org/animal-protection/public-policy/what-ag-gag-legislation>.
217 Cody Creelman expressed such a reservation in the panel conversation following his presentation at the New Harvest 2018 Conference at MIT Media Lab.
218 As per Ann Veneman at the Good Food Institute's 2018 Conference in San Francisco <https://www.youtube.com/watch?v=lRp9nRp-dho>, 16:20–16:40.
219 Burwood-Taylor, Louisa. It Shouldn't Be Called "Clean Meat" But It Will be Clean, Says Cultured Meat's Founder. Agfunder News, July 18, 2018 <https://agfundernews.com/it-shouldnt-be-called-clean-meat-but-it-will-be-clean.html>.
220 Brodwin, Erin. There's a Push For Lab-Grown Meat to Get a New Name. Here's the Alternative. Science Alert, September 11, 2018 <https://www.sciencealert.com/meat-grown-in-labs-will-no-longer-be-called-clean-meat-here-s-why>.
221 See Hopkins, Patrick D., and Austin Dacey. "Vegetarian Meat: Could Technology Save Animals and Satisfy Meat Eaters?" *Journal of Agricultural and Environmental Ethics* (2008) 21: 579–596 (particularly 586–587) <https://foodethics.univie.ac.at/fileadmin/user_upload/inst_ethik_wiss_dialog/Hopkins__P._2008_Veg_Meat_and_In_Vitro_Meat.pdf>.
222 Krantz, Rachel. "'Wild-caught,' 'Organic,' 'Grass-fed': What Do All These Animal Welfare Labels Actually Mean?" *Vox*, January 30, 2019 <https://www.vox.com/future-perfect/2019/1/30/18197688/organic-cage-free-wild-caught-certified-humane>.
223 For detailed descriptions of contemporary industrialized animal farming's use of antibiotics and hormones, see Lymbery, Philip, and Isabel Oakeshott. *Farmageddon: The True Cost of Cheap Meat* (London: Bloomsbury, 2014), and Baur, Gene. *Farm Sanctuary: Changing Hearts and Minds about Animals and Food* (New York: Touchstone, 2008).
224 As per Brian Cooley and Barb Stuckey, respectively, at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc>, 9:40–10:40.
225 Friedrich, Bruce. Cultured Meat vs. "Clean Meat": The "Clean Energy" of Food. Good Food Institute, September 6, 2016 <https://www.gfi.org/clean-meat-the-clean-energy-of-food>.
226 Bloch, Sam. "'Clean'" Meat Needs a Rebrand. Here's an Idea: Call It 'Craft' Instead." *New Food Economy*, June 11, 2018

<https://newfoodeconomy.org/clean-meat-craft-beer/>.

227 Shapiro, Paul. Clean Meat, Cultured Meat, or Something Else? Medium, June 18, 2018 <https://medium.com/@PaulShapiro/clean-meat-craft-meat-or-something-else-3afb41eb9df3>.

228 As per Chris Bryant and Barb Stuckey at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc&t=117s>, beginning at 15:01.

229 Locklear, Mallory. Cultured Chicken Nugget Available by End of Year. Engadget, October 24, 2018 <https://www.engadget.com/2018/10/24/cultured-chicken-nugget-available-end-of-year/>.

230 Bird, Susan. This Clean Meat Company Plans to Get Lab-Grown Chicken on Your Plate by 2019. Care 2, July 3, 2018 <https://www.care2.com/causes/this-clean-meat-company-plans-to-get-lab-grown-chicken-on-your-plate-by-2019.html>.

231 New Age Meats. About, n.d. <https://www.newagemeats.com>.

232 Oxford Dictionaries. Umwelt, n.d. <https://en.oxforddictionaries.com/definition/umwelt>.

233 Kate Krueger made all these observations at the 2018 Ivy League Future of Food Conference in Philadelphia, PA <http://www.ivyffc.com/schedule>

234 Clean Meat. Clean Jobs, n.d. <https://cleanmeat.com/clean-jobs/>.

235 Watson, Elaine. "New Age Meats: People Are Being Fooled into Thinking Clean Meat Is Just Around the Corner." *Food Navigator*, August 14, 2018 <https://www.foodnavigator-usa.com/Article/2018/08/15/New-Age-Meats-People-are-being-fooled-into-thinking-clean-meat-is-just-around-the-corner>.

236 For more, visit Biocellion, n.d. <https://biocellion.com>.

237 These problems were crisply summarized by Kate Krueger at the 2018 Ivy League Future of Food Conference in Philadelphia, PA <http://www.ivyffc.com/schedule>, and by her at the 2017 New Harvest Conference in Brooklyn, NY <https://www.youtube.com/watch?v=m2sQ5PSvegw&t=22s>.

238 Smit, N. P., *et al*. "Stimulation of Cultured Melanocytes in Medium Containing a Serum Substitute: Ultroser-G." *Pigment Cell Research* (February 1995) 8(1): 19–27 <https://www.ncbi.nlm.nih.gov/pubmed/7540755>.

239 For more on alternative media for cellular growth (as of 2015), see Kadim, Isam T., *et al.* "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* (2015) 14(2): 226–227.

240 See Mandelbaum, Ryan F. "Behind the Hype of 'Lab-Grown' Meat." *Gizmodo*, August 14, 2017 <https://gizmodo.com/behind-the-hype-of-lab-grown-meat-1797383294>.

241 Cassiday, Laura. Clean Meat. AOCS: Your Global Fats and Oils Collection. AOCS, February 2018 <https://www.aocs.org/stay-informed/inform-magazine/featured-articles/clean-meat-february-2018>.

242 Cassiday, Laura. Clean Meat. AOCS: Your Global Fats and Oils Collection. AOCS, February 2018 <https://www.aocs.org/stay-informed/inform-magazine/featured-articles/clean-meat-february-2018>.

243 Reynolds, Matt. "The Clean Meat Industry Is Racing to Ditch Its reliance on Foetal Blood." *Wired*, March 20, 2018 <https://www.wired.co.uk/article/scaling-clean-meat-serum-just-finless-foods-mosa-meat>.

244 Watson, Elaine. "Cultured Fish Co Finless Foods Aims to Achieve Price Parity with Bluefin Tuna by the End of 2019." *Food Navigator*, December 12, 2017 <https://www.foodnavigator-usa.com/Article/2017/12/21/Finless-Foods-co-founder-talks-clean-meat-clean-fish-cultured-meat>.

245 Triton Algae Innovations, n.d. <https://www.tritonai.com>.

246 Xun Wang of Triton described his innovations at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA. For more information on this process, see his slideshow for the March 2018 Future of Food Technology Conference <https://futurefoodtechsf.com/wp-content/uploads/2018/03/Xun-Wang-Triton-Algae-Innovations.pdf>.

247 Yuki Hanyu described this process at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA. For his presentation at the 2017 New Harvest Conference in Brooklyn, NY, visit <https://www.youtube.com/watch?v=ENYdiMtASjs>.

248 Wan, Lester. "Lab-made 'Foie Gras': Japan Firm Claims Product Could Be Commercially Viable by 2021." *Food Navigator*, November 1, 2017 <https://www.foodnavigator-asia.com/Article/2017/11/01/Lab-made-foie-gras-Japan-firm-claims-product-could-be-commercially-viable-by-2021>.

249 For more details of these processes, see Jessica Krieger at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA <https://www.youtube.com/watch?v=8u6SUqvqx_g>, 3:45–9:05.

250 Kadim, Isam T., *et al.* "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* (2015) 14(2): 227.

251 Kadim, Isam T., *et al.* "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* (2015) 14(2): 228.

252 Jessica Krieger made these observations at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA <https://www.youtube.com/watch?v=8u6SUqvqx_g>, 1:12–1:45.

253 See Good Food Institute's cellular agriculture "mind-map" here: <https://ars.els-cdn.com/content/image/1-s2.0-S1369703X1830024X-gr1_lrg.jpg>. For an in-depth description of the science, see Specht, Elizabeth A., *et al.* "Opportunities for Applying Biomedical Production and Manufacturing Methods to the Development of the Clean Meat Industry." *Biochemical Engineering Journal* (April 2018) 132: 161–168 <https://www.sciencedirect.com/science/article/pii/S1369703X1830024X#fig0005>.

254 Cassiday, Laura. Clean Meat. AOCS: Your Global Fats and Oils Collection. AOCS, February 2018 <https://www.aocs.org/stay-informed/inform-magazine/featured-articles/clean-meat-february-2018>.

255 For more on "beads" and ground beef, see Kadim, Isam T., *et al.* "Cultured Meat from Muscle Stem Cells: A Review of Challenges and Prospects." *Journal of Integrative Agriculture* (2015) 14(2): 227.

256 Ecovative Designs. Technology, n.d. <https://ecovativedesign.com> and Bolt Threads <https://boltthreads.com/technology/mylo/>.

257 New Harvest. Welcome New Harvest's Three New Research Fellows. Plant-Derived Scaffolds for Supporting In-Vitro 3D Cell Culture at Small and Large Scales, September 14, 2017 <https://www.new-harvest.org/welcome_new_harvest_s_three_new_research_fellows>.

258 Briggs, Helen. "Artificial Meat: UK Scientists Growing 'Bacon' in Labs." *BBC News*, March 19, 2019 <https://www.bbc.co.uk/news/science-environment-47611026>.

259 Quinn-Szcesuil, Julia. Glenn Gaudette: Seeing Unlimited Potential in Common Spinach Leaves. Worcester Polytechnic Institute, March 30, 2017 <https://www.wpi.edu/news/glenn-gaudette-seeing-unlimited-potential-common-spinach-leaves>.

260 Touloumes, George. Making Steak out of Spinach: How

Bioengineering Could Change Meat Production. Harvard University Blog, February 27, 2018 <http://sitn.hms.harvard.edu/flash/2018/making-steak-spinach-bioengineering-change-meat-production/>.

261 As discussed by Kate Krueger at the Ivy League Future of Food Conference, 2018 in Philadelphia, PA <http://www.ivyffc.com/schedule>.

262 New Harvest. Scalable Modular Bioreactor Design for Cultured Meat Production, n.d. <https://www.new-harvest.org/scalable_modular_bioreactor_design_for_cultured_meat_production>. Jessica Krieger talked about the Bioreactor 2.0 at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA <https://www.youtube.com/watch?v=8u6SUqvqx_g>, 16:38–17:25.

263 For some of putative dates for putative products, see: When Will There Be Cost-Competitive Cultured Animal Products? Animal Charity Evaluators, August 2017 <https://animalcharityevaluators.org/research/other-topics/cost-competitive-timeline/>.

264 Watson, Elaine. "New Age Meats: People Are Being Fooled into Thinking Clean Meat Is Just Around the Corner." *Food Navigator*, August 14, 2018 <https://www.foodnavigator-usa.com/Article/2018/08/15/New-Age-Meats-People-are-being-fooled-into-thinking-clean-meat-is-just-around-the-corner>.

265 Justin Kolbeck made this observation at the 2018 Ivy League Future of Food Conference in Philadelphia, PA <http://www.ivyffc.com/schedule>.

266 Shirazi, Alex. Cultured Meat and Future Food Podcast, Episode 05 <https://www.youtube.com/watch?v=OfmyuDawepY>, 22:03–24:18.

267 See The Better Meat Company, n.d. <https://www.bettermeat.co>.

268 This observation was made by Tobias Citron at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA <https://www.youtube.com/watch?v=gxH4Ma-fm-8>, 20:25–21:33.

269 David Benzaquen made these comments at the 2018 Ivy League Future of Food Conference in Philadelphia, PA <http://www.ivyffc.com/schedule>.

270 As per Chris Bryant at the Good Food Institute Conference 2018 in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc>, 27:55–28:15.

271 Tobias Citron made these observations at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA <https://www.youtube.com/watch?v=gxH4Ma-fm-8>, 16:15–18:43.

272 Purdy, Chase. "In Four Years, the Price of Lab Grown Meat Has Fallen by 99%. There's Still a Long Way to Go." *Quartz*, June 5, 2017 <https://qz.com/997565/in-four-years-the-price-of-lab-grown-meat-has-fallen-by-96-theres-still-a-long-way-to-go/>.

273 Adam Flynn made his comments at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA.

274 Ridley, Christian. Why Are Algal Biofuels in Decline? World Economic Forum, May 2016 <https://www.weforum.org/agenda/2016/05/why-are-algal-biofuels-in-decline>.

275 For more on the controversy surrounding JUST Mayo, see: Crosby, Jackie. "Target Officially Stops Selling JUST Mayo and Other Hampton Creek Foods." *Los Angeles Times*, August 22, 2017 <https://www.latimes.com/business/la-fi-just-mayo-target-20170822-story.html>.

276 Ricardo San Martin made these observations at the Good Food Institute Conference 2018 in San Francisco <https://www.youtube.com/watch?v=X_vviu0391E&t=1107s>, 15:10–17:12.

277 Watson, Elaine. "FDA, USDA, to Share Regulatory Oversight of Cell-Cultured Meat." *Food Navigator*, November 17, 2018 <https://www.foodnavigator-usa.com/Article/2018/11/17/FDA-USDA-to-share-regulatory-oversight-of-cell-cultured-meat>.

278 Deepti Kulkani gave such a presentation at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA. See also Kulkani's talk at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=lRp9nRp-dho>, 36:30–37:10.

279 As per Deepti Kulkani at the 2018 Good Food Institute Conference in San Francisco, <https://www.youtube.com/watch?v=lRp9nRp-dho>, 45:25–46:46; and Eric Schulze at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=GdwOIGPlDl0>, 41:10–41:51.

280 Celeste Holz-Schietinger and David Benzaquen made these observations at the 2018 Ivy League Future of Food Conference in Philadelphia, PA.

281 For more on this issue, see Mitchell, Dan. "Is Big Meat the Future of Plant-based Protein?" *New Food Economy*, October 11, 2016 <https://newfoodeconomy.org/is-big-meat-the-future-of-plant-based-protein/>.

282 Honig, Esther, and Madelyn Beck. "Climate Report Says U.S. Cattle And Crops Will Be Stressed By Hotter, Wetter Weather." *Harvest Public Media*, November 29, 2018 <https://www.harvestpublicmedia.org/post/climate-report-says-us-cattle-and-crops-will-be-stressed-hotter-wetter-weather>.

283 Foskolos, Andreas, and Jon Moorby. "How Climate Change Will Impact Cows and the Dairy Industry." *Independent*, August 29, 2018 <https://www.independent.co.uk/environment/climate-change-cows-dairy-industry-affect-a8512266.html>.

284 Guglielmi, Giorgia. "Are Antibiotics Turning Livestock into Superbug Factories?" *Science*, September 28, 2017 <https://www.sciencemag.org/news/2017/09/are-antibiotics-turning-livestock-superbug-factories>.

285 Rowland, Michael Pellman. "Move Over, PETA: Meat Companies Have A New Thorn In Their Side." *Forbes*, April 7, 2019 <https://www.forbes.com/sites/michaelpellmanrowland/2019/04/07/fairr/#563081ab48a5>.

286 UNFCCC. The Paris Agreement, October 22, 2018 <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>.

287 IATP, GRAIN, and Heinrich Böll Stiftung. Big Meat and Dairy's Supersized Climate Footprint, November 7, 2017 <https://www.iatp.org/supersized-climate-footprint>.

288 GRAIN and IATP. Emissions Impossible: How Big Meat and Dairy Are Heating up the Planet. July 18, 2018 <https://www.grain.org/article/entries/5976-emissions-impossible-how-big-meat-and-dairy-are-heating-up-the-planet>.

289 Williams, Ashley. "Beyond Meat Opens Second Missouri Facility." *Global Meat News*, July 2, 2018 <https://www.globalmeatnews.com/Article/2018/07/02/Beyond-Meat-opens-second-Missouri-facility>.

290 Meyer, Zlati. "Missouri Becomes First State to Regulate Use of the Word 'Meat'." *USA Today*, August 28, 2018 <https://www.usatoday.com/story/money/2018/08/28/animal-meat-missouri-law/1114285002/>.

291 The Bullvine. Dairy Industry Challenges Vegan Companies Use of "Butter," "Milk". June 18, 2019 <https://www.thebullvine.com/news/dairy-industry-challenges-vegan-companies-use-of-butter-milk/>.

292 Stephens, Neil, *et al.* "Bringing Cultured Meat to Market:

Technical, Socio-political, and Regulatory Challenges in Cellular Agriculture." *Trends in Food Science & Technology* (August 2018) 78: 155–166 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078906/>.

293 Stewart, Terence P., and Lane S. Hurwitz. "Petition for the Imposition of Beef and Meat Labeling Requirements: To Exclude Products Not Derived Directly from Animals Raised and Slaughtered from the Definition of "Beef" and "Meat." February 2, 2018 <http://www.uscattlemen.org/Templates/pdfs_USCA/2018-PDFs/2-9-18USCA-AMS-Petition-re-definition-of-beef-and-meat.pdf>.

294 Meyer, David. "Tofurky and the ACLU Are Teaming Up to Defeat Missouri's 'Fake Meat' Bill." *Fortune*, August 28, 2018 <http://fortune.com/2018/08/28/tofurky-aclu-missouri-fake-meat-bill/>.

295 Tsang, Amie. "What, Exactly, Is Meat? Plant-based Food Producers Sue Missouri Over Labeling." *New York Times*, August 28, 2018 <https://www.nytimes.com/2018/08/28/us/missouri-meat-law-tofurky.html>.

296 For the full definition, see Reese, Jacy. *The End of Animal Farming: How Scientists, Entrepreneurs, and Activists Are Building an Animal-Free Food System* (Boston: Beacon, 2018): 65.

297 The ASPCA has a chart on the various definitions on its website. ASPCA. Meat, Eggs and Dairy Label Guide, n.d. <https://www.aspca.org/sites/default/files/meat_eggs_and_dairy_label_guide.pdf>.

298 ASPCA. What Is Ag-Gag Legislation? n.d. <https://www.aspca.org/animal-protection/public-policy/what-ag-gag-legislation>.

299 Reese, Jacy. *The End of Animal Farming: How Scientists, Entrepreneurs, and Activists Are Building an Animal-Free Food System* (Boston: Beacon, 2018): 67.

300 As per Chris Bryant at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc&t=117s>, 15:01–15:09.

301 AquaBounty. Leadership, n.d. <https://aquabounty.com/about/leadership/>.

302 The details of the salmon are on Aquabounty's website. AquaBounty. Our Salmon, n.d.: <http://aquabounty.com/our-salmon/>.

303 See: PATH. Katharine Kreis, n.d. <https://path.org/leadership/katherine-kreis/>.

304 FDA. AquAdvantage Salmon, March 8, 2019 <https://www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/BiotechnologyProductsatCVMAnimalsandAnimalFood/AnimalswithIntentionalGenomicAlterations/ucm280853.htm>.

305 Schwab, Tim. GMO Salmon Declared Safe to Eat, But Not Grow, in U.S. Here's Why. Food & Water Watch, December 4, 2015 <https://www.foodandwaterwatch.org/news/gmo-salmon-declared-safe-eat-not-grow-us-here%E2%80%99s-why>.

306 Friends of the Earth. FDA's Approval of GMO Salmon Denounced, November 2015 <https://foe.org/news/2015-11-fdas-approval-of-gmo-salmon-denounced/>.

307 Grain. Golden Rice Is Unnecessary and Dangerous, March 10, 2015 <https://www.grain.org/article/entries/5177-golden-rice-is-unnecessary-and-dangerous>.

308 Shiva, Vandana. Golden Rice: Myth, Not a Miracle. The Navdanya Diary, January 12, 2014 <http://www.navdanya.org/blog/?p=775>.

309 Greenpeace. Golden Rice, n.d. <https://www.greenpeace.org/archive-international/en/campaigns/agriculture/problem/Greenpeace-and-Golden-Rice/>.

310 Slade, Peter. "If You Build It, Will They Eat It? Consumer Preferences for Plant-based and Cultured Meat Burgers." *Appetite* (June 2018) 125(1): 428–437 <https://www.sciencedirect.com/science/article/pii/S0195666317317531>.

311 As per Barb Stuckey at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=kFRZZbioxAc>, 18:00–19:15.

312 Faunalytics. The Faunalytics Resource Hub: Clean Meat, August 1, 2018 <http://faunalytics.org/clean-meat/>.

313 Kolodny, Lara. "Impossible Foods CEO Pat Brown Says VCs Need to Ask Harder Scientific Questions." *TechCrunch*, May 22, 2017 <https://techcrunch.com/2017/05/22/impossible-foods-ceo-pat-brown-says-vcs-need-to-ask-harder-scientific-questions/>. Quoted in Reese, Jacy. *The End of Animal Farming: How Scientists, Entrepreneurs, and Activists Are Building an Animal-Free Food System* (Boston: Beacon, 2018): 70.

314 Fleming, Amy. "Pet Food Is an Environmental Disaster: Are Vegan Dogs the Answer?" *Guardian*, June 26, 2018 <https://www.theguardian.com/global/2018/jun/26/pet-food-is-an-environmental-disaster-are-vegan-dogs-the-answer>.

315 For more on cellular cat and dog food, see Ward, Ernie, *et al. The Clean Pet Food Revolution: How Better Pet Food Will Change the World* (New York: Lantern, 2019), chapter 12.

316 One company looking to develop food for companion animals in the plant-based and cellular meat spaces is Wild Earth. See Wild Earth, n.d. <https://wildearth.com/>.

317 National Institute for Animal Agriculture. "How Alternative Proteins Can Support the Animal-Agriculture Industry." *Tri-State Livestock News*, March 14, 2019 <https://www.tsln.com/news/how-alternative-proteins-can-support-the-animal-agriculture-industry/>.

318 This argument is made by Stephens, Neil, *et al.* "Bringing Cultured Meat to Market: Technical, Socio-political, and Regulatory Challenges in Cellular Agriculture." *Trends in Food Science & Technology* (August 2018) 78: 155–166 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078906/#bib79>.

319 Kate Krueger of New Harvest made these observations at the 2018 Ivy League Future of Food Conference in Philadelphia, PA.

320 New Harvest Fellow Andrew Stout talked about these possible benefits at the 2018 New Harvest Conference at the MIT Media Lab in Boston, MA <https://www.youtube.com/watch?v=a3FWKcO-lDI&>, 6:15–8:23.

321 Perls, Dana. *From Lab to Fork: Critical Questions on Laboratory-Created Animal Product Alternatives*. Friends of the Earth, July 2018 <https://foe.org/resources/from-lab-to-fork/>.

322 Stephens, Neil, *et al.* "Bringing Cultured Meat to Market: Technical, Socio-political, and Regulatory Challenges in Cellular Agriculture." *Trends in Food Science & Technology* (August 2018) 78: 155–166 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078906/#bib79>.

323 Menu items on the website Bistro In-Vitro, a provocative art experiment developed in The Netherlands to force us to think about the ethical implications of cellular meat production. Bistro in Vitro, n.d. <https://bistro-invitro.com/>.

324 Mattick C. S., *et al.* "Anticipatory Life Cycle Analysis of In Vitro Biomass Cultivation for Cultured Meat Production in the United States." *Environmental Science & Technology* (2015) 49(19):11941–11949.

325 Stephens, Neil, *et al.* "Bringing Cultured Meat to Market: Technical, Socio-political, and Regulatory Challenges in Cellular Agriculture." *Trends in Food Science & Technology* (August 2018) 78: 155–166 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078906/#bib79>.

326 Lynch, John, and Raymond Pierrehumbert. "Climate Impacts of Cultured Meat and Beef Cattle." *Frontiers in Sustainable Food Systems*, February 19, 2019 <https://www.frontiersin.org/articles/10.3389/fsufs.2019.00005/full>.

327 Shiva is critical of what she sees as the chemically based intensification model of farming superseding local agro-ecological principles where animals are part of the natural food systems. See Shiva, Vandana. A New Report Sustains Unsustainable Food Systems. Seed Freedom, January 20, 2019 <https://seedfreedom.info/poison-cartel-toxic-food-eat-report/>. An overview of her position on corporate ownership, patents on life, and the global hegemony of agribusiness can be found in Shiva, Vandana. *Stolen Harvest: The Hijacking of the Global Food Supply* (Cambridge, MA: South End Press, 2000).

328 See Slow Food Europe's website for an example of efforts to stop the patenting of plants and seeds. Slow Food. Stop Patents on Life! May 6, 2016 <https://www.slowfood.com/sloweurope/en/no-patents-on-seeds/>.

329 See Harris, Paul. "Monsanto Sued Small Farmers to Protect Seed Patents, Report Says." *Guardian*, February 12, 2013 <https://www.theguardian.com/environment/2013/feb/12/monsanto-sues-farmers-seed-patents>.

330 For more: The New School. Book Launch: Eating Tomorrow with Timothy Wise, Vandana Shiva, Mark Bittman, n.d. <https://events.newschool.edu/event/book_launch_eating_tomorrow_with_timothy_wise_vandana_shiva_mark_bittman#.XOMAz63Mz2I>.

331 See the 2019 EAT–Lancet Report: Willet, Walter, *et al.* "Food in the Anthropocene: the EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems." *The Lancet Commissions*, 2019, 393. <https://eatforum.org/content/uploads/2019/04/EAT-Lancet_Commission_Summary_Report.pdf>.

332 This quotation and Shiva's specific complaints can be found in Shiva, Vandana. A New Report Sustains Unsustainable Food Systems. Seed Freedom, January 2019 <https://seedfreedom.info/poison-cartel-toxic-food-eat-report/>. See also, Shiva, Vandana. Fake Food, Fake Meat: Big Food's Desperate Attempt to Further the Industrialisation of Food. Independent Science News, June 18, 2019 <https://www.independentsciencenews.org/health/fake-food-fake-meat-big-foods-desperate-attempt-to-further-industrialisation-food/>.

333 ETC. Group. Rise of the Petri-Proteins? April 4, 2019 <https://www.etcgroup.org/2019/rise-of-petri-proteins>.

334 ETC. Group. Tom Wakeford, n.d. <https://www.etcgroup.org/users/tom-wakeford> and <https://www.etcgroup.org/users/tom-wakeford>.

335 ETC. Group. *Who Will Feed Us? Industrial Food Chain vs. Peasant Food Web* (3rd edition 2017) <http://www.etcgroup.org/sites/www.etcgroup.org/files/files/etc-whowillfeedus-english-webshare.pdf>.

336 For more on seed-sharing and food sovereignty movements in the United States, see: U.S. Food Sovereignty Alliance. *A Preliminary Report on Seeds and Seeds Practices across the U.S.*, April 2014 <http://usfoodsovereigntyalliance.org/wp-content/uploads/2014/04/SeedReport2014_big.pdf>.

337 See Maxwell, Joe. "The Death of the American Dream for Family Farmers." *The Hill*, October 17, 2017 <https://thehill.com/opinion/energy-environment/359388-the-death-of-the-american-dream-for-family-farmers>.

338 Fassler, Joe. "Silicon Valley Wants to Give Us Eggs without Chickens? Do We Want That?" *New Food Economy*, March 1, 2018 <https://newfoodeconomy.org/silicon-valley-just-alt-protein-clean-meat/>.

339 Brown, Ethan. How Our Commitment to Consumers and Our Planet Led Us to Use GM Soy. Medium, May 16, 2019 <https://medium.com/impossible-foods/how-our-commitment-to-consumers-and-our-planet-led-us-to-use-gm-soy-23f880c93408?>.

340 For instance, Thomas, Pat. 6 Reasons Impossible Burger's CEO IS Wrong about GMO Soy. Common Dreams, May 21, 2019 <https://www.commondreams.org/views/2019/05/21/6-reasons-impossible-burgers-ceo-wrong-about-gmo-soy>; and Organic Consumers Association. Tell Impossible Foods CEO Pat Brown: GMO Soy Is Bad for Consumers, Bad for the Planet. May 21, 2019 <https://www.organicconsumers.org/node/1065306>.

341 Schütte, Gesine. "Herbicide Resistance and Biodiversity: Agronomic and Environmental Aspects of Genetically Modified Herbicide-resistant Plants." *Environmental Sciences Europe* (2017) 29(1): 5 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5250645/>.

342 Philpott Tom. "Bayer Just Lost Another Lawsuit Claiming Roundup Caused Cancer." *Mother Jones*, May 13, 2019 <https://www.motherjones.com/food/2019/05/bayer-just-lost-another-lawsuit-claiming-roundup-caused-cancer/>.

343 Honeycutt, Zen. GMO Impossible Burger Positive for Carcinogenic Glyphosate. Moms Across America, May 16, 2019 <https://www.momsacrossamerica.com/gmo_impossible_burger_positive_for_carcinogenic_glyphosate>.

344 Malkan, Stacy. "Glyphosate Fact Sheet: Cancer and Other Health Concerns." U.S. Right to Know, January 25, 2019 <https://usrtk.org/pesticides/glyphosate-health-concerns/>.

345 Perls, Dana. *From Lab to Fork: Critical Questions on Laboratory-Created Animal Product Alternatives*. Friends of the Earth, July 2018: 10 <https://foe.org/resources/from-lab-to-fork/>.

346 For more, see Nargi, Lela. "New Study Shows Organic Farming Traps Carbon in Soil to Combat Climate Change." *Civil Eats*, September 11, 2017 <https://civileats.com/2017/09/11/new-study-shows-organic-farming-traps-carbon-in-soil-to-combat-climate-change/>.

347 Garnett Tara, *et al*. *Grazed and Confused?* Food Climate Research Network (FCRN), 2017: 57 <https://www.fcrn.org.uk/sites/default/files/project-files/fcrn_gnc_report.pdf>.

348 Nordborg, Maria. Holistic Management: A Critical Review of Allan Savory's Grazing Method. EPOK—Centre for Organic Food & Farming, 2016 <http://publications.lib.chalmers.se/records/fulltext/244566/local_244566.pdf>.

349 Estabrook, Barry. "Meet Allan Savory, The Pioneer of Regenerative Agriculture." *Agriculture*, March 8, 2018 <https://www.agriculture.com/livestock/cattle/meet-allan-savory-the-pioneer-of-regenerative-agriculture>.

350 McWilliams, James. "All Sizzle and No Steak." *Slate*, April 22, 2013 <http://www.slate.com/articles/life/food/2013/04/allan_savory_s_ted_talk_is_wrong_and_the_benefits_of_holistic_grazing_have.html>; Garnett Tara, *et al. Grazed and Confused?* Food Climate Research Network (FCRN), 2017: 61 <https://www.fcrn.org.uk/sites/default/files/project-files/fcrn_gnc_report.pdf>.

351 Garnett, Tara, *et al*. *Grazed and Confused?* Food Climate Research Network (FCRN), 2017: 105–106 <https://www.fcrn.org.uk/sites/default/files/project-files/fcrn_gnc_report.pdf>.

352 Brown, Jessica. "We Don't Need Nearly As Much Protein As We Consume." *BBC*, May 23, 2018 <http://www.bbc.com/future/story/20180522-we-dont-need-nearly-as-much-protein-as-we-consume>.

353 See Gustavsson, Jenny, *et al. Food Losses and Waste: Extent, Causes and Prevention*, FAO 2011 <http://www.fao.org/fileadmin/user_upload/suistainability/pdf/Global_Food_Losses_and_Food_Waste.pdf>.

354 For this last point, see Cassidy, Emily S., *et al.* "Redefining Agricultural Yields from Tonnes to People Nourished Per Acre." *Environmental Research Letters* (2013) 8(3): 1–8 <https://iopscience.iop.org/article/10.1088/1748-9326/8/3/034015/pdf>.

355 See Lipinski, Brian. 10 Ways to Cut Global Food Loss and Waste. World Resources Institute, June 06, 2013 <https://www.wri.org/blog/2013/06/10-ways-cut-global-food-loss-and-waste>.

356 For an overview of the relative merits of insect farming and cellular or plant-based meat in using land, see Alexander P., *et al.* "Could Consumption of Insects, Cultured Meat or Imitation Meat Reduce Global Agricultural Land Use?" *Global Food Security* (2017) 15(1): 22–32 <https://doi.org/10.1016/j.gfs.2017.04.001>.

357 Alexander, Peter, *et al.* "Could Consumption of Insects, Cultured Meat or Imitation Meat Reduce Global Agricultural Land Use?" *Global Food Security* (2017): 15(1): 22–32 <https://doi.org/10.1016/j.gfs.2017.04.001>.

358 For a fact sheet on the benefits of insects as food, see FAO. The Contribution of Insects to Food Security, Livelihoods and the Environment, n.d. <http://www.fao.org/docrep/018/i3264e/i3264e00.pdf>.

359 See Kupferschmidt, Kai. "Why Insects Could be Ideal Animal Feed." *Science*, October 14, 2015 <https://www.sciencemag.org/news/2015/10/feature-why-insects-could-be-ideal-animal-feed>.

360 For the pros and cons of insect farming in general, and for pet food in particular, see Ward, Ernie, *et al. The Clean Pet Food Revolution: How Better Pet Food Will Change the World* (New York: Lantern, 2019), chapter 9.

361 For the sentience case for insects, see Reese, Jacy. *The End of Animal Farming: How Scientists, Entrepreneurs, and Activists Are Building an Animal-Free Food System* (Boston: Beacon, 2018): 152–153. For the sentience of fish and other marine life, see, Balcombe, Jonathan. *What a Fish Knows: The Inner Lives of Our Underwater Cousins* (New York: Farrar, Straus and Giroux, 2016).

362 Simon, Matt. "Tired: Eating Bugs. Wired: Eating Bug Meat Grown in a Lab." *Wired*, June 3, 2019 <https://www.wired.com/story/bug-meat-grown-in-a-lab/>.

363 For the animal welfare implications of "sustainable intensification," see Garnett, Tara, and Charles H. Godfray. *Sustainable Intensification in Agriculture*. Food Climate Research Network (FCRN), 2012 <https://www.fcrn.org.uk/sites/default/files/SI_report_final.pdf> 33ff.

364 World Economic Forum. *Meat: The Future* (Draft White Paper), January 2018 <http://www3.weforum.org/docs/White_Paper_Meat_the_Future_Time_Protein_Portfolio_Meet_Tomorrow_Demand_report_2018.pdf> 10–11.

365 As enumerated by Lusk, Jayson. "Why Factory Farms Are Good for the Environment." *New York Times*, September 23, 2016 <https://www.nytimes.com/2016/09/25/opinion/sunday/why-industrial-farms-are-good-for-the-environment.html>.

366 See Shepon, Alon, *et al.* "The Opportunity Cost of Animal Based Diets Exceeds All Food Losses." *Proceedings of the National Academy of Sciences* (April 2018) 115(15): 3804–3809 <https://www.pnas.org/content/115/15/3804>.

367 Shanker, Deena, and Lydia Mulvany. America Is Drowning in Milk Nobody Wants." Bloomberg, October 17, 2018 <https://www.bloomberg.com/news/articles/2018-10-17/america-is-drowning-in-milk-nobody-wants>.

368 For USDA statistics on the past and projected growth of corn production in the U.S. between 1990 and 2026, see this graph: Report Linker Data. Maize Production in the U.S.: Annual 1990–2026, n.d. <https://www.reportlinker.com/data/series/MHt2Ipe-ctA>. For how the overproduction of corn led to the generation of new products, see Pollan, Michael. "When a Crop Becomes King." *New York Times*, July 19, 2002 <https://www.nytimes.com/2002/07/19/opinion/when-a-crop-becomes-king.html>.

369 Cited in Carrington, Damien. "Avoiding Meat and Dairy Is 'Single Biggest Way' to Reduce Your Impact on Earth," *Guardian*, May 31, 2018 <http://www.theguardian.com/environment/2018/may/31/avoiding-meat-and-dairy-is-single-biggest-way-to-reduce-your-impact-on-earth>.

370 Eshel, Gidon, *et al.* "Environmentally Optimal, Nutritionally Aware Beef Replacement Plant-based Diets." *Environmental Science & Technology* (2016) (50): 8164–8168 <https://www.weizmann.ac.il/plants/Milo/sites/plants.Milo/files/publications/environmentally_optimal_nutritionally_aware_beef_replacement_plant-based_diets.pdf>.

371 Goldstein, Benjamin, *et al.* "Potential to Curb the Environmental Burdens of American Beef Consumption Using a Novel Plant-based Beef Substitute." *PLOS ONE*, December 6, 2017 <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0189029#pone.0189029.ref012>.

372 Lynch, John, and Raymond Pierrehumbert. "Climate Impacts of Cultured Meat and Beef Cattle." *Frontiers in Sustainable Food Systems*, February 19, 2019 <https://www.frontiersin.org/articles/10.3389/fsufs.2019.00005/full>.

373 See Ranganathan, Janet, *et. al. Shifting Diets for a Sustainable Food Future*. World Resources Institute, April 2016 <https://www.wri.org/publication/shifting-diets>, particularly Figure ES-2 on page 4.

374 For a graphic representation of the outsized impact of beef on water-use, land, and GHG emissions, see: World Resources Institute. Animal-Based Foods Are More Resource Intensive than Plant-Based Foods, n.d. <https://wriorg.s3.amazonaws.com/s3fs-public/uploads/16_Shifting-Diets-Blog-Graphics_04v5.png?_ga=2.221069274.351018773.1559336337-51557733.1547568743>.

375 For the U.S., see Durisin, Megan, and Shruti Singh. "Americans Will Eat a Record Amount of Meat in 2018." *Bloomberg*, January 2, 2018 <https://www.bloomberg.com/news/articles/2018-01-02/have-a-meaty-new-year-americans-will-eat-record-amount-in-2018>.

376 Devlin, Hannah. "Rising Global Meat Consumption 'Will Devastate Environment'." *Guardian*, July 19, 2018 <https://www.theguardian.com/environment/2018/jul/19/rising-global-meat-consumption-will-devastate-environment>.

377 For an overview of the crisis facing agriculture in the future, see World Economic Forum. Climate Change and Risks to Food Security, 2016. 2016 <http://reports.weforum.org/global-risks-2016/climate-change-and-risks-to-food-security/>.

378 See Key, Nigel, and Stacy Sneeringer. Greater Heat Stress From Climate Change Could Lower Dairy Productivity. USDA Economic Research Service, November 3, 2014 <https://www.ers.usda.gov/amber-waves/2014/november/greater-heat-stress-from-climate-change-could-lower-dairy-productivity/>.

379 See World Health Organisation. Nutrition, n.d. <https://www.

who.int/nutrition/topics/3_foodconsumption/en/index4.html>.

380 Garnett, Tara, *et al*. *Grazed and Confused?* Food Climate Research Network (FCRN), 2017: 33 <https://www.fcrn.org.uk/sites/default/files/project-files/fcrn_gnc_report.pdf>.

381 For an overview of the IPCC's report on the contribution of agriculture, and animal agriculture in particular, to climate change, see Waite, Richard, and Daniel Vennard. Without Changing Diets, Agriculture Alone Could Produce Enough Emissions to Surpass 1.5°C of Global Warming. World Resources Institute, October 17, 2018 <https://www.wri.org/blog/2018/10/we-cant-limit-global-warming-15c-without-changing-diets>.

382 Steinfeld, H. *et al*. *Livestock's Long Shadow: Environmental Issues and Options*. Rome: FAO, 2006 <http://www.fao.org/3/a-a0701e.pdf>.

383 Ranganathan, J. *et al*. *Shifting Diets for a Sustainable Food Future*. Working Paper, Installment 11 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute, 2016: 3 <https://wriorg.s3.amazonaws.com/s3fs-public/Shifting_Diets_for_a_Sustainable_Food_Future_1.pdf?_ga=2.127012237.1269431537.1561582032-254979502.1561582032>.

384 Mekonnen, M. and Hoekstra, A. "A Global Assessment of the Water Footprint of Farm Animal Products." *Ecosystems* (2012) 15: 401–415 <http://waterfootprint.org/media/downloads/Mekonnen-Hoekstra-2012-WaterFootprintFarmAnimalProducts.pdf>.

385 FAO Livestock Brief, n.d. *Livestock Policy Brief 3* <http://www.fao.org/3/a-a0262e.pdf>.

386 Opio, C. *et al*. *Greenhouse Gas Emissions from Ruminant Supply Chains: A Global Life Cycle Assessment*. Rome: FAO, 2013: 59 <http://www.fao.org/docrep/018/i3461e/i3461e00.htm>.

387 See, for instance, Sengupta, Somini. "Global Warming Is Helping to Wipe Out Coffee in the Wild." *New York Times*, January 16, 2019 <https://www.nytimes.com/2019/01/16/climate/climate-change-coffee.html>; and Environmental Protection Agency. Climate Impacts on Agriculture and Food Supply (snapshot January 1, 2017) <https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-food-supply_.html>.

388 CTA (Technical Centre for Agricultural and Rural Co-operation). Climate-Proofing Pastoralism in Eastern Africa, December 18, 2018 <https://www.cta.int/en/climate/all/article/climate-proofing-pastoralism-in-eastern-africa-sid003dd6fc1-b54c-4f25-a1e8-a715b95870f5>.

389 At a panel on Improving Food Recovery at the Food Tank Food Waste and Food Loss Conference in New York City 2018, Bonnie McClaff of the Global Alliance for Improved Nutrition replied to a question from Eric Darier of Greenpeace USA about the need to lower meat and dairy production as form of reducing waste. Her response was illustrative of the dilemma outlined in this section of the paper: "From a nutrition standpoint, meat, red meats, are the most bio-available form of iron, right? And this is our *biggest* problem with nutrition around the world—is anemia, iron-deficiency anemia. This is such a nuanced conversation that we have to have around this. . . . Because, yes, industrialized meat production is not sustainable; but there are many, many thousands of communities around the world that are pastoralists. This is what they live on, right? And iron, *heme* iron, is critical to reduce iron-deficiency anemia. . . ." See <https://www.youtube.com/watch?v=M-xA2lGnJig> (3:31:28–3:33:55).

390 Bialik, Kristen, and Kristi Walker. Organic Farming Is on the Rise in the U.S. Pew Research, January 10, 2019 <https://www.pewresearch.org/fact-tank/2019/01/10/organic-farming-is-on-the-rise-in-the-u-s/>.

391 Organic Trade Association. Maturing U.S. Organic Sector Sees Steady Growth of 6.4 Percent in 2017, May 18, 2018 <https://ota.com/news/press-releases/20236>.

392 Figures cited by Reese, Jacy. *The End of Animal Farming: How Scientists, Entrepreneurs, and Activists Are Building an Animal-free Food System* (Boston: Beacon, 2018): 115.

393 For more criticisms from an animal-rights and vegan perspective, see Anonymous. The Clean Meat Hoax, n.d. <https://www.cleanmeat-hoax.com>.

394 A point made less forcefully by Stephens, Neil, *et al.* "Bringing Cultured Meat to Market: Technical, Socio-political, and Regulatory Challenges in Cellular Agriculture." *Trends in Food Science & Technology* (August 2018) 78: 155–166 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078906/>.

395 Where one should spend one's vegan pound or dollar is discussed at length in Tait, Amelia. "How Veganism Went From Fringe Food Cult to Multibillion-Pound Industry." *New Statesman*, March 20, 2019 <https://www.newstatesman.com/2019/03/how-veganism-went-fringe-food-cult-multibillion-pound-industry?>.

396 For instance, see Parker, Mario. "American Farmers Confront a Mental Health Crisis." *Bloomberg*, March 20, 2019 <https://www.bloomberg.com/news/articles/2019-03-20/america-s-farmers-call-for-help-as-debts-climb-to-1980s-levels>.

397 Swenson, David. Most of America's Rural Areas Are Doomed to Decline. The Conversation, May 7, 2019 <https://theconversation.com/most-of-americas-rural-areas-are-doomed-to-decline-115343>.

398 See Wiggers, Kyle. From Pixels to Plate, Food Has Become 3D Printing's Delicious New Frontier. Digital Trends, April 19, 2017 <https://www.digitaltrends.com/cool-tech/3d-food-printers-how-they-could-change-what-you-eat/>.

399 The pizza-production and delivery company Zume is one model. See Kessler, Sarah. "An Automated Pizza Company Models How Robot Workers Can Create Jobs for Humans." *Quartz*, January 10, 2017 <https://qz.com/880283/zume-pizza-models-how-robot-workers-can-create-jobs-for-humans/>.

400 See, for instance, Holt, Steve. "Is Vertical Farming Really the Future of Agriculture?" *Eater*, July 3, 2018 <https://www.eater.com/2018/7/3/17531192/vertical-farming-agriculture-hydroponic-greens>. The scalability, utility, and lifecycle sustainability of vertical farming is a matter of controversy.

401 Trafton, Anne. The Future of Agriculture Is Computerized. MIT Media Lab, April 3, 2019 <https://www.media.mit.edu/articles/the-future-of-agriculture-is-computerized>.

402 MIT Media Lab. The Open Phenome Project, n.d. <https://www.media.mit.edu/projects/open-phenome-project/overview/>.

403 As per Lav Varshney at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=CeJXe7yK170&t=69s>, 43:35–44:30.

404 Van der Weele, Cor, and Clemens Driessen. "Emerging Profiles for Cultured Meat; Ethics through and as Design." *Animals* (2013) 3(3): 647–662 (653).

405 Van der Weele, Cor, and Clemens Driessen. "Emerging Profiles

for Cultured Meat; Ethics through and as Design." *Animals* (2013) 3(3): 647–662 (658–659).

406 See: Shojinmeat, n.d. <https://shojinmeat.com/wordpress/>.

407 See: Integriculture, n.d. <https://integriculture.jp>.

408 Maddox, Bruno. "The Future of Lab-Grown Meat." *Discover*, July 12, 2006 <http://discovermagazine.com/2006/jul/blinded>.

409 Van der Weele, Cor, and Clemens Driessen. "Emerging Profiles for Cultured Meat; Ethics through and as Design." *Animals* (2013) 3(3): 647–662 (655).

410 Van der Weele, Cor, and Clemens Driessen. "Emerging Profiles for Cultured Meat; Ethics through and as Design." *Animals* (2013) 3(3): 647–662 (656).

411 Donaldson, Sue, and Will Kymlicka. *Zoopolis: A Political Theory of Animal Rights* (Oxford: Oxford University Press, 2011).

412 Lappeenranta University of Technology, LUT. "Protein Produced with Electricity to Alleviate World Hunger." *ScienceDaily*, 19 July 2017 <www.sciencedaily.com/releases/2017/07/170719090025.htm>.

413 See: Deep Branch Biotechnology, n.d. <https://deepbranchbio.com>.

414 Soylent is a powder-based protein. Soylent. Our Products, n.d. <https://soylent.com/pages/about-soylent>.

415 Stukin, Stacie. "Is Jackfruit the Next Big Meat Substitute?" *National Geographic*, July 15, 2016 <https://www.nationalgeographic.com/people-and-culture/food/the-plate/2016/07/jackfruit-sustainable-vegetarian-meat-substitute/>.

416 Leavitt, Zoe. If Lab-cultured Meat Was as Cheap as Animal Meat: The Day Meat Died. Pro Journo Davos, January 16, 2017 <https://davos.projourno.org/what-if-lab-cultured-meat-was-as-cheap-as-animal-meat-d1e89647d8d>.

417 Eric Schulze made similar comments at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=GdwOIGPlDl0>, 15:10–15:40.

418 Watson, Elaine. "Impossible Foods Replaces Wheat with Soy Protein Concentrate in Its Plant-based Impossible Burger . . . " *Food Navigator*, January 8, 2019 <https://www.foodnavigator-usa.com/Article/2019/01/08/Impossible-Foods-replaces-wheat-with-soy-protein-concentrate-in-its-plant-based-Impossible-burger>.

419 For the sorry story of Elizabeth Holmes and Theranos, see Ramsay, Lydia. "The Rise and Fall of Theranos, the Blood-testing Startup that Went from Silicon Valley Darling to Facing Fraud Charges." *Business Insider*, April 11, 2019 <https://www.businessinsider.com/the-history-of-silicon-valley-unicorn-theranos-and-ceo-elizabeth-holmes-2018-5>.

420 For some of putative dates for putative products, see Animal Charity Evaluators. When Will There Be Cost-Competitive Cultured Animal Products? August 2017 <https://animalcharityevaluators.org/research/other-topics/cost-competitive-timeline/>.

421 Reese, Jacy. *The End of Animal Farming: How Scientists, Entrepreneurs, and Activists Are Building an Animal-Free Food System* (Boston: Beacon, 2018): 114–115.

422 Leenaert, Tobias. *How to Create a Vegan World: A Pragmatic Approach* (New York: Lantern, 2017).

423 See The Library of Congress's page on the subject: Library of Congress. Documents in American History: Morrill Act, October 26, 2017 <https://www.loc.gov/rr/program/bib/ourdocs/morrill.html>.

424 As per Ricardo San Martin at the 2018 Good Food Institute Conference in San Francisco <https://www.youtube.com/watch?v=X_vviu0391E&t=1107s>, 16:30–17:13.

FOOD DETAILS AND LOCATIONS

Cover: Beyond Meat Beyond Sausage Brat Original flavor topped with pickled jalapeños and caramelized onions, served in a pretzel roll from Bareburger at Yankee Stadium in Bronx, NY.

Page 1: Beyond Meat Beyond Sausage Hot Italian flavor served with sautéed onions, peppers, and mushrooms, roasted cherry tomatoes, navy beans, and parsley.

Page 2: Breakfast burrito with beans, seitan bacon, tomatoes, greens, and hollandaise sauce from Seitan's Helper at their pop-up in Queens, NY.

Page 4: Avocado toast made with onion marmalade, pickled jalapeños, sesame seeds, and scallions, with a side of tofu scramble and seitan bacon from Pisces Rising Vegan at Pisces Rising pop-up in Queens, NY.

Page 5: Everything bagel with chipotle mayo, spinach, tofu scramble, cassava bacon, picked onions, and avocado.

Page 10 (top): Chopped cheese sandwich and BBQ Impossible Burger from Veggie Castle II in Queens, NY.

Page 10 (bottom): Beyond Meat Beyond Burger served with lettuce, tomato, onions, pickles, cheese, and mayo at Bareburger in Brooklyn, NY.

Page 11: A breakfast plate with tofu scramble, potatoes, sausage, baked beans, and toast and a breakfast burrito with a side of tempeh bacon from Bar Velo in Brooklyn, NY.

Page 16: Fried chick'n sandwiches from Hartbreakers in Brooklyn, NY.

Page 17: Burrito made with Sweet Earth Foods Chipotle seitan, sweet potatoes, kale, and salsa.

Page 19: A reuben made with seitan pastrami, sauerkraut, spicy pickles, cashew provolone, and Russian dressing, served on marble rye from The Bonnie in Queens, NY.

Page 31: A homemade tempeh and black bean burger topped with vegan smoked gouda, sautéed mushrooms, cucumber, avocado, red onion, and romaine lettuce.

Page 34: Rueben with seitan pastrami, sauerkraut, beer cheese, and Russian dressing, on a homemade rye pretzel roll made by Hunted Gatherer at the Vegan Market pop-up in Brooklyn, NY.

Page 35: Deluxe Italian sandwich made with salami, pastrami, cheese, pepperoncini, tomato, lettuce, mayo, and mustard from Haymaker's (now closed) in Brooklyn, NY.

Page 37: Fried chick'n sandwiches, chick'n tenders, and loaded fries from Hartbreakers in Brooklyn, NY.

Brighter Green

www.brightergreen.org