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AgriTech investor and informant perspectives about cellular agriculture

RESEARCH ARTICLE

Mark A. Gagnon[ⓘa], Garrett Broad[b], Kelia Grandison[c] and Robert M. Chiles[d]

[a]*Harbaugh Entrepreneur and Innovation Faculty Scholar, Entrepreneurship & Innovation Program, Associate Teaching Professor, Agribusiness, Department of Agricultural Economics, Sociology and Education, College of Agricultural Sciences at Penn State, Room 6E Armsby, University Park, PA 16802, USA*

[b]*Associate Professor, Department of Communication and Media Studies, Fordham University, Faculty Memorial Hall, Room 454, New York, NY 10023, USA*

[c]*Workplace Planning Associate, Fidelity Investments, 2070 Broadway Ave, New York, NY 10023, USA*

[d]*Assistant Professor of Rural Sociology, Research Associate, Rock Ethics Institute, Penn State, 110C Armsby, University Park, PA 16802, USA*

Abstract

Investor and venture capital activity within food, agriculture and bio renewables (AgriTech) continues to accelerate. Investors recognize promise in AgriTech due to pressing demand to provide food and bio renewable materials for our growing population. Cellular agriculture, meat produced *in vitro* versus *in vivo* is one specific space where exceptional investor activity is occurring. This work captures investor and key informant perspectives primarily from North America about cellular agriculture by utilizing thematic analysis from qualitative interview data. Findings highlight the role and perspectives of strategic capital as a necessary mechanism to fund bringing cellular meat technologies to the marketplace. The data also indicated that cellular agriculture products would likely complement existing meat products like plant-based meats and that massive infrastructure is required to produce these products at scale. In addition, respondents posited that higher income, urban and politically liberal consumers would likely be early adopters of cellular meat products and that a significant challenge will be providing availability to the wider less affluent population.

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ⓘCorresponding author: mag199@psu.edu

1. Introduction

Cellular agriculture is an emerging field of research and practice in which products traditionally derived from animals (meat, dairy, leather, etc.) are created instead through a biotechnological cell-culturing process. Cell-cultured meat production, specifically, requires animal cells to be cultured and proliferated in an *in vitro* environment, assembled on a scaffold, and fed a serum to promote growth in a bioreactor. At the time of this writing, cell-cultured meat remains in an early stage of development, attracting widespread interest from scientists, investors, and the public at large. The first commercial sale of a cell-cultured meat product took place in 2020 in Singapore, and a variety of technological, regulatory, and consumer-facing challenges remain before it has any chance to achieve widespread distribution (Post *et al.*, 2020).

The case for cellular agriculture and cell-cultured meat centers on the negative externalities of contemporary animal food production, which brings with it a host of environmental, economic, ethical, and nutritional challenges. Cell-cultured meat advocates believe the technology has the potential to provide a stable and nutritious source of protein for the world in a way that boosts sustainability while aligning with human, animal, and other ecosystem needs. It is part of a broader movement for alternative proteins – a landscape that also includes plant-based analogues and products derived through fermentation – that positions itself as key to addressing the global meat and protein demands that arise from growing population and increased affluence (Eibl *et al.*, 2021).

Notably, there is significant contestation over the place of alternative proteins in the future of the food system, as there is about the ideal place of meat and other animal products more broadly. Katz-Rosene and Martin (2020) outline three emerging pathways for 'greening' meat – while not necessarily mutually exclusive, the approaches in this framework help characterize the current state of meat debates. In this interpretation, those who advocate for 'modernizing meat' champion technological innovation and further intensification of conventional animal food production to improve efficiency; those who call for 'replacing meat' insist on alternative sources of protein and dietary shifts away from conventional meat; and those who promote 'restoring meat' call for agro-ecological approaches and small-scale meat production practices that integrate livestock into farm ecosystems.

Importantly for this article, in recent years, investment capital has become actively involved in curating the start-ups within the 'replacing meat' arena that are attempting to innovate alternative proteins that might substitute for conventional animal products. Attracted by the appeal of potentially transformative and profitable agrifood technology, the sector has garnered hundreds of millions of dollars in the hopes of developing 'unicorn' technologies that will have the power to create billion-dollar brands (Good Food Institute, 2020a). These investments have been championed by some as evidence of the sector's potential but critiqued by others who worry about the socio-economic and environmental implications of for-profit food system innovation (Chiles *et al.*, 2021; Howard, 2021). However, research on investor perspectives remains limited while this population is posited to play a significant role in cellular agriculture development and commercialization. This paper contributes to this conversation by speaking to members of the investor class themselves, aiming to understand how they understand the key possibilities and challenges of this emerging field.

We begin with a review of cellular agriculture focusing on technology adoption utilizing an agribusiness perspective. Once a sufficient backdrop has been established, additional information will be provided on the study, approach, and methodology. Qualitative, thematic research analysis was utilized (Creswell and Poth, 2016; Strauss and Corbin, 1997) to draw out common and divergent themes in the interview data. After several iterations reviewing the textual data, our results indicated that respondents frequently stated that low cost and large economies of scale were needed to produce cellular meat products to be near the price of existing meat products. Further, respondents indicated that population growth and income dynamics will radically shape cellular agriculture development. In addition, respondents frequently mentioned that societal reactions with cellular agriculture are likely to occur as with similar disruptive technologies such as microwave cooking and genetic modification. The implications for a transformational shift in our global

food system could bring about radical reapplication of extant production agricultural infrastructure. This change could be similar to iron and steel production in the United States that resulted in repurposing and or abandonment of considerable infrastructure. After reviewing the results, connections are provided with the body of literature in cellular agriculture, conclusions and future directions for cellular agriculture entrepreneur and investor and agribusiness research will be explored.

2. New technology, social contestation, and the case of cell-cultured meat

Social polarization often occurs when a potentially disruptive technology like cell cultured meat is developed and new modes of production are introduced (Breemersch *et al.*, 2019). For example, historic and current accounts reflect differences of opinion in society with the introduction of electricity and artificial intelligence (Schwab, 2016). Electricity offered the promise to displace gas lighting as its first victory, and then revolutionize society by expanding into what we now witness today as a world powered by a vast number of electric machines. Of course, this was not without its challenges, perils, and problems. A significant number of sceptics criticized the safety of electricity (Jonnes, 2004; Juma, 2016).Today, similar debates are occurring around innovations like artificial intelligence, as many influential thinkers believe machine technology will solve detrimental problems and advance humanity along a new evolutionary path (Kurzweil, 2005), while others posit it being a source of our eventual demise (Korinek and Stiglitz, 2019) so poignantly demonstrated in films like 'The Terminator' (Cameron and Hurd, 1984).

The food industry, in general, and the meat industry, in particular, offer a relevant area of study to explore social contestation over new technologies. Food supply chains are posited to accelerate digitization and automation because of COVID-19 and the $2 trillion global meat industry will likely be impacted as well (Hobbs, 2021). Approximately 100 billion pounds of meat is produced in the US alone and the $1.1 trillion US industry represents about 5.4% of US GDP, employing 5.4 million workers and is growing at about 2-3% per year (Dent, 2020), note Table 1.

Global protein demand is predicted to increase by 73% by 2050 due to population growth and increased global affluence (Delgado, 2003; McLeod, 2011). Entrepreneurs and investors are actively pursuing new and or enhanced means for global protein production and non-animal protein sources are gaining significant market momentum. For example, plant-based proteins are growing 17% annually representing a $2.2 billion market (Bashi *et al.*, 2019). Cellular agriculture garners similar if not more interest from entrepreneurs, investors, and agribusiness (Good Food Institute, 2020a).

The science and industry of cellular agriculture is rapidly evolving. The field is generally divided into two related but distinct approaches in the creation of animal products without animal husbandry. Acellular products use genetically modified microorganisms to create organic molecules such as milk or egg proteins. This technology has long-standing precedence in pharmaceuticals and the food industry, and some acellular products like animal-free dairy and egg protein are already on the market in the United States (Eibl *et al.* 2021; Mendly-Zambo *et al.*, 2021). Cellular agriculture products are created by culturing real animal cells *in vitro,* wherein they are fed a nutrient mix and proliferated in a bioreactor until they create a 'cell-cultured

Table 1. U.S. meat production (Dent, 2020).

Protein	Percentage	Pounds (billion)	Animals (million)
Chicken	42	42.2	9,000
Beef	26	26.4	32
Pork	26	25.6	121
Turkey	6	5.9	242
Lamb	0	0.2	2

meat' end-product (alternately referred to as cultivated, cell-based, clean, or lab-grown meat, among other terms) (Broad, 2019; Eibl *et al.* 2021). At the time of this writing, cell-cultured meat has only been sold commercially in small amounts in Singapore, with regulatory approval pending in other nations around the world (Waltz, 2021).

The emergence of cell-cultured meat, which is the primary focus of the research in this paper, has been accompanied by great fanfare as well as critique. Historically, controversies over new food technologies were often dismissed by industry leaders as simply the product of scientific misunderstandings, knowledge deficits, and poor risk assessment among the consuming public. Recent scholarship has demonstrated, however, that a host of other factors – including broader moral judgements and worldviews – shape how publics respond to new innovations, in food as in other contexts (Lusk *et al.*, 2014). It is no surprise, then, that the prospect of cell-based meat has engendered a polarized set of reactions, ranging from those who insist it will be a revolutionary technology, to those who dismiss it as a biotech investment boondoggle, to those with significant ambivalence in between. In addition to those who assess its scientific foundations (Post *et al.*, 2020), recent years have seen an explosion of new social science scholarship on the topic, exploring the varied economic, environmental, and cultural implications of cell-based meats potential future (Santo *et al.*, 2020).

Stephens *et al.* (2019) traced the history of the field back to the early 2000s, demonstrating how it began primarily in the domain of university-based research and bio-arts practice, then became dominated by start-up culture and venture capital with interests in commercialization. Recent years have also seen increased governmental support for the enterprise via direct investment in research as well as public-private partnerships (Choudhury, 2018). Through it all, promissory narratives from industry advocates, amplified through media coverage, have envisioned cell-cultured meat as a potentially revolutionary force for the creation of environmentally sustainable, ethical, and abundant meat without slaughter (Painter *et al.*, 2020).

On the other end of the spectrum, a varied set of critics have derided the idea as an unnatural and unnecessary 'Frankenfood,' raising concerns not only about its safety and unproven sustainability, but also about its role as a force for malevolent corporate control of the food system (Howard, 2021; Mohorčich and Reese, 2019). These critiques have been buffered, of late, by several techno-economic analyses that have raised serious questions about the basic scientific and economic viability of cell-cultured meat production at scale (Fassler, 2021). Meanwhile, a number of researchers and industry observers have called for a cautious analysis of cell-cultured meat and its prospects at this stage. They have noted its significant potential in the context of food system sustainability challenge, but also raise a host of important questions – related to public health, the environment, animal welfare, economics, and public policy – that must be addressed if the industry has any chance of achieving its purported goals.

Much of the existing social science and critical scholarship on alternative protein, generally, and cell-based meat, specifically, has examined the promissory narratives of the technology through the lens of media coverage, statements from startups and other entrepreneurs, and avowed advocates. See, for instance; (Guthman and Biltekoff, 2021; Painter *et al.*, 2020; Sexton *et al.*, 2019). Other scholarship has documented the economic geography of the emerging field, detailing how complex assemblages of scientists, advocates, entrepreneurs, investors and other agri-food production network actors are shaping its driving moral and practical foundations (Howard *et al.*, 2021; Mouat *et al.*, 2019). Despite the recognition across this work of the important role being played by individual and institutional investors in constructing cellular agriculture, a relatively limited body of research has actually offered up the perspectives of investors, directly, in terms of how they assess the field. Investor perspectives have indeed been incorporated into broader examinations of alternative protein and cellular agriculture's development as a field (Stephens *et al.*, 2018, 2019), as well as reflections on some of its potential economic and ecological implications (Newton and Rejto, 2021). This current article is an attempt to expand the knowledge base of what perspectives this influential, but often difficult to access, class of investors is bringing to the cell-cultured meat industry at this stage.

Our research sought to obtain perspectives from a convenience sample of key informants within the international agriculture investment space (AgriTech) that were knowledgeable about cellular agriculture. We interviewed several investment fund directors and additional informants that were knowledgeable about cellular agriculture and/or were in the adjacent traditional meat production space. Respondents are actively involved in one or more of the facets of vetting, funding, growing, and advising food agriculture business start-ups and their perspectives provide an insider view of the commercialization of agri-food technologies.

Two of these paper's authors set out to explore the emerging cellular agriculture space by purposefully not being informed and intentionally did not reviewing literature about cellular agriculture even though there is considerable research that has been conducted in this space (Good Food Institute, 2020a; Hocquette, 2016; Mattick, 2018; Post, 2014; Stephens *et al.*, 2018, 2019). Two other authors have considerable expertise and knowledge of cellular agriculture and provided post hoc review and augmented our initial analysis by providing follow-on insight to informant commentary.

Several key questions drove our inquiry: (1) what opportunities and challenges exist with cellular agriculture? (2) how are contextual forces shaping development in this space? (3) what are the anticipated business models for cellular agriculture? and (4) what could be the potential implications of large-scale cellular agriculture for our global food system?

3. Methods

3.1 Sample

A convenience sample of primarily North American interview candidates was selected from the primary author's food and agriculture entrepreneurship network built from over 10 years engagement with strategic agribusinesses and AgriTech investors. This network was created from interaction at AgriTech investment focused conferences and from daily stakeholder engagement though our entrepreneurship and innovation center that is housed in a college of agriculture at a major land grant university. A total of 18 respondents engaged with our research and 17 agreed to be interviewed via telephone or in person at industry conferences held in The United States of America. Two respondents provided written answers to our questions via email, one who has submitted an email response participated in a two-person interview afterward. Three interviews were conducted with two respondents from the same organization. A total of 14 interviews, 11 which were individual, and three were dyadic, were transcribed using a commercial transcription service. The average interview was ~30 minutes. One interview failed to record so written notes of the conversation were used as a proxy. New thematic content was not appearing after the tenth interview.

The sample of 18 respondents consisted of eight strategic agribusiness investors (44.4%) that are agents who represented, or recently represented (retired executives), large corporate agribusiness interests that lead or consulted these company's start-up investment resources. Six participants (33.3%) directed food production and service operations that were knowledgeable of the meat industry and alternative proteins. Four informants (22.2%) were strictly investment with no corporate agribusiness affiliation, actively in cellular agriculture start-ups or were part of industry trade groups that engaged AgriTech investors. The sample was primarily male, 15 respondents (83%). Table 2 summarizes respondent characteristics.

Table 2. Respondent characteristics.

Respondents	Count	Percentage	Gender male count	Percentage
Agribusiness investors	8	44.4	7	87.5
Food industry	6	33.3	5	83.3
Agritech informants	4	22.2	3	75

Respondents were first provided with informed consent information and then asked for their informed consent and for consent to be audio recorded when applicable. The following open-ended questions were asked after establishing interview protocols. Respondents were encouraged to elaborate on their answers as needed. A primary goal was to allow for respondents to guide the conversation once questions were asked.

1. Can you tell me about your organization and your role?
2. What do you see as the biggest challenges for cellular agriculture? What are the biggest opportunities?
3. What business models do you think are best applicable for cellular agriculture?
   a. Probe cooperative, for profit, open sourced, etc.
4. What type of impact do you think that cellular agriculture might have on society as a whole?
5. Same as question 4 just changed question focus to explore: economy, human health and well-being, food culture and environment
6. What do you see as the ideal role for cellular agriculture in the global food system?
7. What do you see as the ideal role for animals in the global food system?
8. After the above questions were addressed, we allowed respondents to provide additional comments and ask questions that they may have about our research.

3.2. Data analysis

Qualitative thematic analysis was used for this research that is informed by qualitative research methodological approaches (Creswell and Poth, 2016; Strauss and Corbin, 1997). In essence, researchers approach the data and generate common and identify uncommon themes within and across respondents based on respondent provided content. We did our best to avoid having our interpretive bias overtake naturally present theme generation although we recognize that bias may exist and is a valid study limitation. Textual analysis of interview transcripts, email correspondence and written notes led to an initial set of themes and exemplar statements of emerging themes were capture *in vivo* when present. Themes were arranged by questions 2, 3, 4 and 5 and 6 and 7 that initially structured the five meta categories to arrange themes with *in vivo* content. Figure 1 lists the four meta categories explored.

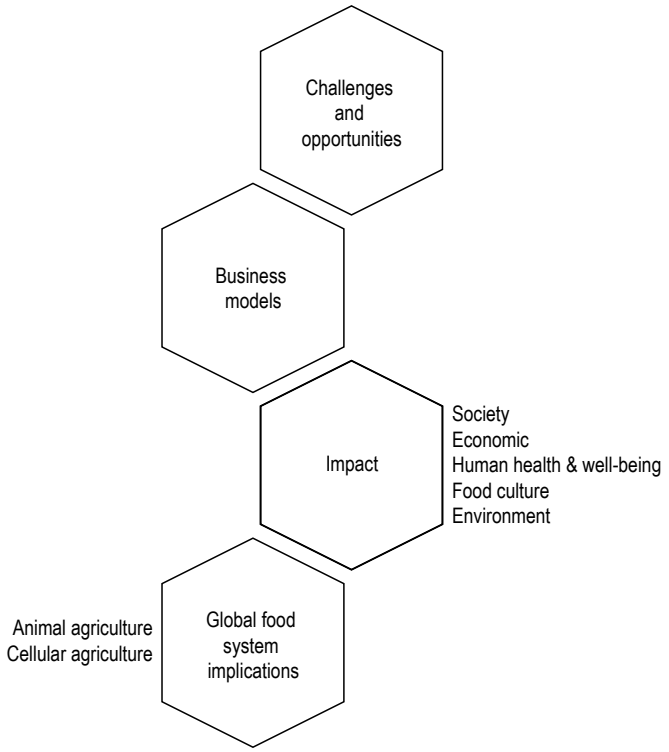

Figure 1. Meta categories.

First lists of discrete themes were extracted from interviews generating fairly long lists within each meta category for each interview. In addition, several themes spanned multiple categories within interviews. After two of the authors, one being the lead author extracted and categorized themes the next step was to identify common sets of themes and areas of coder divergence. After discussing and clarifying thematic agreement, the next step was to abstract the themes to higher level categories. Two of the authors took a month away from the data to provide additional clarity for abstraction (Gagnon, 2021). Upon completing the second level of abstraction the first author prepared and delivered a presentation utilizing second level themes generated with the addition of supporting scholarly data and information for each theme. The presentation was delivered to an advanced agribusiness entrepreneurship course and two capstone undergraduate agribusiness management courses to test thematic validity and to garner initial feedback on content. Students provided constructive feedback and the second author reviewed and commented on the recorded presentation. In addition, a written transcript of the presentation was prepared for additional textual analysis for validation of second order themes. After some minor discussion and adjustment both authors were in agreement for the second order themes that are presented and expounded upon in the results section.

Interrater reliability of two coders were calculated using Cohen's (1960) Kappa measure for the four meta categories above and rater agreement scores were (0.54) for challenges and opportunities, (0.46) business models, (0.36) impact and (0.46) global food system (Hallgren, 2012). A mutually generated list of second order themes that are presented below that will be discussed in greater detail in the results section. Kappa values within the range of 0.21-0.40 indicate fair agreement and 0.41-0.60 indicate moderate agreement (Hallgren, 2012).

Respondent generated second order themes and supporting sub-themes:

1. Need for transformational food innovation
   - Demographic drivers
   - Environmental pressures
   - Global protein consumption
2. Food and meaning
   - Food and connection
   - Food, health and well-being
   - Adoption and affluence
3. Business models and cellular agriculture
   - Cost reduction imperative
4. Future potentialities cellular and animal agriculture
   - Complementarity
   - Meat replaced
   - Meat produced

4. Results and discussion

From the perspective of the investors that were interviewed, the call for transformational innovation in our food system is driven by several intersecting global pressures – notably, demographic drivers, environmental pressures, and increases in global protein consumption.

Fundamentally, consumers demand access to nutritious and safe food at affordable prices while producers feel the need to reduce negative externalities. Current production practices that generate high volume and high yields with reduced product costs continue to need to meet massive global demand while experiencing the pressure to reduce the use of energy, fertilizer, and pesticides. On the environmental front, lower impact agricultural practices are needed that regenerate farmland and protect waterways. These challenges are heightened by the call for our food system infrastructure to be resilient to extreme weather events. Scientists, companies, and investors are developing and implementing new technologies to meet these demands (Broad, 2019; Kadim *et al.*, 2015; Rose and Chilvers, 2018; Wall and Winger, 2006). The following quote from

an investment fund manager summarizes how the heightened voice of the consumer, as exhibited through market action, is shaping investor perspectives of our food system.

> And that this is driven often by demand as well, right? Maybe we could do this a decade ago, or two decades ago, but people didn't really care as much, right? And you've got to be able to really make change, I think you need this intersection of supply and demand occurring. And so, that's where we sort of sit today.
>
> (#12 Agritech investment fund manager)

As investors see it, innovation is a key driver of economic growth and measuring new product performance is critically dependent on consumer acceptance. The need for innovation is primarily due to constant changes in food trends that are attributed to the growing number of individuals who influence popular trends and eating habits. Nevertheless, many plant-based companies have entered the food industry all occupying same niche (Good Food Institute, 2020b; Guiné *et al.*, 2020; He *et al.*, 2020). However, what sets cellular agriculture apart is the potential to fully replicate the consumption experience of meat with perhaps improved nutrition with reduced environmental impact.

> I think the opportunity is ridiculous right now for innovating within regenerative animal agriculture and what that looks like. So that's just my kind of partying song-… it's an unbelievable time to be thinking about animals because nobody's thinking about it right now.
>
> (#5 Executive meat processor)

> Effectively, we were not seeing the kinds of innovation or attention placed on one of the world's most important industries as we did and say social networks or getting people to stay and sleep on your couch. So, we thought we had a way to change that, and it was built around sort of ecosystem development in venture capital.
>
> (#12 Agritech investment fund manager)

As cellular agriculture is a relatively new, innovation within the food industry, certain segments of consumers will likely start the adoption of cellular meat products. Most informants indicated that specific consumer demographics will play a major role in popularizing cellular agriculture products. Because cellular meat is initially projected to be more expensive than animal generated protein, populations with a higher income will likely be the first consumers. As noted in the quote below, willingness to pay a premium for new or traditional food products are often associated with a variety of variables such as income, health, power, and lifestyle choice.

> And again, I'm going to come back to cost again, but in certain areas, meat is very expensive, and this would, I assume, unless we figure out something or unless the production improves greatly, it's going to be more expensive than for animal meat, animal protein. So, I think it will be a challenge. I think probably more accepted and faster acceptance in higher wealth areas of the world than in other areas.
>
> (#7B AgriTech investor)

Moreover, a majority of our sample concluded that targeting the classic vegan or vegetarian in the big cities is the ideal early adopter nice for cellular agriculture. Initial research shows a correlation between plant-based meat adoption and cellular meat adoption with the additional correlates of younger age, liberal political views, and education (Slade, 2018). However, consumer willingness to pay a premium for a product is also driven by the functionality of the product (i.e. the nutrition and health benefits that can be gained from consumption). Cellular agricultural products propose to have similar, if not better health benefits as traditional animal-based meat (Good Food Institute, 2020a). In addition, potential value-added product claims such as no animal harmed may command a higher price point in the market. Investors also point to the possibility that meat produced through Cellular agriculture may be more nutritious in comparison to

traditional meat when produced at sufficient scale. Thus, the potential characteristics of cellular meat may appeal to consumers who are willing to use their economic status to purchase food that provides advantages over current alternatives. The quotes below further illustrate these ideas.

> No, actually I would say you'd probably want to circle those areas that are the big cities, more liberal political philosophy as the target audience that would be most receptive to this. Because, at least early on, you're going to be paying a premium for it because they're not producing the stuff in the lab, at least not yet at a competitive price point. But you could've said the same thing 20 years ago about organic.
>
> (#6 AgriTech industry consultant)

> And so as long as… cellular meat isn't, not providing nutrition, right, if it's providing similar nutrition as an animal based meat, I think it'll be a net positive for human health. But it's really hard to tell to what degree.
>
> (#8A Corporate agribusiness executive large firm)

Investor informants also emphasized the idea that technological and business model innovation is one means for easing the environmental problems the world has been facing as a result of intensive production practices. As the global meat demand is on the rise, the number of animals raised for consumption surpasses wildlife on earth from 15:1. The meat and dairy market alone account for leaving a significant carbon footprint. The global livestock industry plays a major role in producing greenhouse emissions, where animal agriculture accounts for 18% of human produced-greenhouse gas emissions worldwide (IPPC, 2020). The quotes below demonstrate that with an increasing population balancing animal product consumption is critical if we want to ultimately lessen our impact on the environment.

> Opportunity definitely from the market standpoint is big, because the human population is continuously growing, in terms of having enough [inaudible] to support the living of those populations, let alone from generating food and the deteriorating soil health all around the world, facing different climate change issues
>
> (#1AgriTech industry consultant)

Investors are increasingly aware that many consumers are wary of the potential risk of climate change, a reality which partially supports the demand for plant-based food products (Perez-Cueto, 2020) and meat alternatives. The abundance of plant-based meat and dairy products provides a potential model for how cellular agricultural products may enter and grow in the marketplace. The investment case hinges on the prospect that Cellular agriculture production may offer a lower carbon footprint compared to plant based proteins and be less affected by extreme climate events. The quote below illustrates these points.

> I think there's factors including the positioning of agriculture is contributing to climate change and global warming and everything that that's going to play for some people. They're going to be, in their mind, principled and not contribute to cattle production because they think it's going to increase global warming…
>
> (#6 AgriTech industry consultant)

All of this is set within the context of expected global population and protein demand increases. Investors insist that, with a global population expected to exceed 8.5 billion people by 2030 (United Nations, 2019), innovation is essential to address the increasing global protein demand. There are currently 2 billion malnourished individuals in search of a long-term supply for sustainable, healthy, and accessible protein with a majority in Southern Asian and sub-Saharan Africa (United Nations, 2019). However, it is extremely challenging for traditionally produced meat to match an anticipated doubling of current demand (~400 billion pounds) by 2050 without have significant environmental impact. Cellular based agriculture and other protein generating technologies offer promise to augment existing meat production to meet future global demand. The following respondent quotes illustrates these findings.

> I don't think that we can expect for traditional meat production to be adequate. I think we would have to go to some form of laboratory-produced meat, at least for a certain segment of part of the population.
> (#6 AgriTech industry consultant)

Cellular based meat is one innovation that offers considerable potential, however current thinking indicates that the technology must globally reach a wide spectrum of consumers to be impactful. One of plant-based meat and dairy products greatest critiques is that most of its reach is in developed markets. Cellular agriculture can potentially play a consequential role in alleviating food insecurity, malnourishment, and social and economic hardships all within sustainable boundaries (Good Food Institute, 2020a). The following respondent remarks support the potential solutions of cellular agriculture.

> As we continue towards that path of sustainability with an ever-growing global population, we're going to have to figure out a way to provide protein other than... Or an alternative. I'm not saying it will ever totally replace cattle production and meat produced in more traditional ways.
> (#6 AgriTech industry consultant)

> I think the global implication is it's going to be another choice that will be out there, and hopefully, if we can start to float the entire protein supply higher, globally, all countries, all peoples can benefit from more protein total.
> (#9 Corporate agribusiness executive large firm)

5. Food and meaning

Food being an essential element to our survival and well-being is understandably a core part of the human experience (Coveney, 2006; Rozin, 2005). Those that have access to an abundance of nutritious food are likely to realize different experiences and meanings associated with meal events as contrasted to people who subsist and must experience the uncertainty of obtaining their next meal. Study respondents reported food and ascribed meaning that the authors organized around the themes of 'connection', 'health' and 'power'. The potential of cellular agriculture to transform our global food system and move us in a new direction from thousands of years of animal-based protein production understandably calls for us to explore our ascribed meanings to food. The following respondent quote illustrates the centrality of food within our human experience.

> I think you're right to look at the different parts of the human system. There's impacts in food... (that) don't just impact food. They impact the health and energy and government and education and, spirituality. Then everything is connected to everything else at a high level, and food is of human essential. So, I'm pretty sure we're still going to need to eat no matter how far forward you'd go.
> (#2 Corporate agribusiness executive)

Respondents noted that we have survived as species due to our genetic need for interaction and imprinting for group formation and affiliation. Group affiliation secures primary resources needed for our survival with food being an essential resource and thus its central role with interpersonal relations (Moore, 1957). Certain groups like the Good Food Institute (2020a) see cellular agriculture as a means to improve and transform feeding society, whereas other groups refer to meat produced in a laboratory as a threat to human wellbeing (Pettit, 2019).

Several respondents discussed how food can be a central aspect of group affiliation and provide both connection and polarization. Certainly, food can enforce and communicate unique group identity and respondents commented on the emergence of new groups based on new food choice offerings. These findings are in accord with social identity theory (Tajfel, 2010) which states the individuals promote aspects that distinguish their group identity from others. Often these communications are conducted with in-group and out-group distinctions in mind. Notably is the abundance of food options such as vegan, gluten free, organic and GMO-free products that have strong follower identifications. Cellular agriculture will likely evoke

similar affiliation and polarization which will make mass adoption complex. We will likely witness similar reactions to historically introduced novel technologies and products.

> We've got a lot of food tribes, and the more choices we give consumers, the more food tribes emerge, right? And therefore, the health and welfare of the animal will be of more significant importance, right? There will be much greater sort of respect for the animal sacrifice involved in that, right? And those consumers will demand those types of treatment, right? It won't be commodity, high-capacity pig farms. It just won't be tolerated as much by the consumer, right? No more so that there's certain taboos in our culture, and I believe that the consumption of animals is emerging as one of those taboos.
>
> (#12 Agritech investment fund manager)

> It's [cellular agriculture] going to cause a massive disruption though in the traditional agriculture community. Which is why you're starting to see the cattlemen fighting the definition of meat. And this is very similar to the fight that's going on with defining milk.
>
> (#3 Agritech investment fund manager)

> I love the perspectives around this and you see very strongly held values and to me that, and that's the nature of food. I think that's what makes it such a great space to work in.
>
> (#13B Food manager corporate resort)

Perhaps more than anytime in human history people are seeking to better understand the food they consume. The growth in slow food (Petrini, 2013), local food movements (Martinez, 2010) and society's call for global food supply chain integrity/transparency (Arnot *et al.*, 2016; Center for Food Integrity, 2015) are notable examples. Slow food was discovered by Petrini an Italian gastronome who sought to preserve food culture, taste and tradition which relies on local sourcing and challenges cost efficient global production models. Local food consumption grew from $500 million in 1997 to $1.2 billion in 2007 in the United States alone (Martinez, 2010). Agricultural producers are under considerable pressure from consumers to clearly articulate their sourcing, practices and reporting about their social, environmental and economic impacts (Arnot *et al.*, 2016; Beulens *et al.*, 2005; Roth *et al.*, 2007; Trienekens *et al.*, 2012; Wognum *et al.*, 2011). Several respondents spoke of the need for cellular agriculture inspection and regulation practices to be at parity with conventional meat production. The following quote illustrates the perspective from current meat producers.

> I would say overall as long as the cultured meat is USDA regulated, then it's on an even playing field with what we do as meat producers.
>
> (#10 Executive food processing)

Respondents also indicated the potential for cellular agriculture production to be place adjacent to population centers and thus localize food production. Similar production models have been implemented with vertical farming and indoor agriculture where products such as microgreens are produced in or near urban population centers (Al-Chalabi, 2015; Benke and Tomkins, 2017; Despommier, 2009).

> I don't think we're going to use the really expensive Silicon Valley land to produce it [cellular meat], but go an hour away and I'm sure we could start producing food anywhere, right? And protein anywhere. And protein consumption has been increasing pretty significantly. Now, we still need inputs, right? There's no free lunch here. So, media has to come from somewhere, and that media could be glucose, which may mean that where sugarcane is an enormous market. So, we still need to grow things, but ideally, we don't deal with the trophic inefficiencies that we deal with today, right? And so, to more greatly shrink the land use that we need for animal agriculture, the water use, emissions, I think these are great byproducts.
>
> (#12 Agritech investment fund manager)

In addition, considerable attention is dedicated to food choice and health and well-being (Block *et al.*, 2011). Not only has discourse explored linkages with diet and health, but conversations have also expanded to 'food being medicine' with the ability to alleviate a host of medical conditions. Cellular agriculture offers similar, if not more promise as fortified food to dial-in human nutrition without including ingredients that may be harmful. The following quotes highlight the potential of cellular based agriculture.

> Earlier, like in 90s and 2000 everybody says a healthy lifestyle is the key for breaking obesity, and they launched different programs throughout government, throughout different countries. Then they said, oh it is also a genetic predisposition, and now a lot of paths are coming back to, no, it's what you eat. I think it's really moving from food being a medicine. It's not being called yet, but it is almost there where it would become the biggest medicine of the world. I think by having a way to produce a food which can continue to have consistent nutritional value, consistent value across different aspects of the food chain will become a big source of food really translating into wellbeing of human health.
>
> (#1 Agritech food consultant)

> I think we have the greater potential to tie inputs into and disentangle how that affects our health. We could engineer these products to also be healthier fundamentally. And so, there are those types of opportunities for sure. But remember plant-based, or sorry, cellular agriculture may also be competing with plant based, right?
>
> (#12 Agritech investment fund manager)

> That's the functional food. That is sort of the movement of future. So [interviewer name], 15 years from now your physiological needs might be different than they are today. But that steak will be aligned to what are those things that you need. Everyone has a flu shot. Wouldn't it be cool if inside that panda steak was some sort of vaccine? So, using it as a vector for delivery of medicines to human beings. So, in addition to the health outcomes, you get protein, you get an amino acid structures and all this.
>
> (#3 Agritech investment fund manager)

> I actually think it [cell ag] has a potential to be quite beneficial for global human health if successful…
>
> (#8A Corporate agribusiness executive)

6. Adoption and affluence

Cellular agriculture also shows potential for being an affordable source of globally available protein. Often discussion centered around Rogers (2010) classic treatment of societal diffusion of innovations even if he was not specifically quoted during conversations. Several respondents mentioned how cellular agriculture would first be introduced to societies' early adopters of which the majority are typically educated elites as something novel and chic. Roger's (2010) framework has been applied to plant-based meat substitutes (Szejda *et al.*, 2020). Respondent conversations correlated with current research in alternative meat adoption studies whereas findings indicated that young, educated environmentally conscious consumers were more likely to try alternative meat products (Lea *et al.*, 2006; Slade, 2018). Comparisons were also made with the fashion industry and to the introductions of foods into the US market like plant-based meats and sushi where products were first offered at high-end restaurants in California and New York. Eventually an inflection point occurs allowing for widespread product availability where adoption makes its way into the early and late majority of the populations.

> I mean it's like anything else. The haves will get it first and then it'll trickle down to the sort of haves and the have nots. I think it's going to be a positive, but I think we need to understand that when we view the global food system, we can't view it through a domestic lens.
>
> (#3 Agritech investment fund manager)

> I heard some commentary on it, that Beyond Meat, for example, was really looked at as this a cool hip new thing when it was in really posh high-end restaurants in New York. It was kind of a cool thing to be cooking with…. And then it lost a ton of luster when or, or the whole meatless thing lost it, when the Impossible Whopper came out.
>
> (#8A Corporate agribusiness executive)

> I think cellular agriculture, if it can really trickle down at all layers of the society, I think one of the biggest impacts is going to have is building back progressive society for future. That's one thing I think at a very philosophical level I think it can have a solution. I think it really will be supported by accessibility and affordability, because it should not remain... If it continues to remain in the elite of the society, then it might not reach its maximum potential, which it has the capability to do.
>
> (#1 Agritech food consultant)

> You're going to use this sort of same strategy, fashion industry you've been using for 50 years and eventually we'll push out and down…high end then it eventually trickles down. Like Angus beef, Angus beef, Angus beef eventually becomes Angus burger at a Carl's Jr. Applewood smoked bacon from Hobb's Smokehouse in San Francisco eventually becomes applewood smoked bacon on a burger at Burger King. Eventually all trickles down. All of that it became an interesting curve. I think once it kind of got pushed and marketed through the high end and when I say that restaurants as well as sort of grocery included because at a certain point you could only get it at a Whole Foods or a Sprouts or something like that before it had trickled down to mass when everybody was sort of championing for them. 'So this is going to be the greatest thing.' Once it moved to fast food, those exact same people all turned on it and turned on it in a way where right or wrong.
>
> (#13B Executive chef corporate resort)

7. Business models and cellular agriculture

The investors interviewed for this study also had several perspectives on the business models and market mechanisms through which cell-based meat might be able to achieve significant presence. The business model concept is about how organizations create, deliver, capture, and protect value generated as a result of its activities. For profit business models are often discussed since they often simply convey the value curation process. For example, a local food truck creates value by transforming food ingredients into unique meals (value protection) that appeal to its customers (value creation) who pay for the meals (value capture) that are delivered in a mobile format (value delivery). These processes represent the core elements of the business model that can be expounded upon using a framework like the business model canvas (Osterwalder *et al.*, 2011).

Business models vary in each of these elements including along dimensions of ownership (exclusive to open), profit capture (e.g. for and non-profit objectives) and stakeholder engagement (limited to full transparency). Informants were asked to anticipate future business models for scalable cellular agricultural products. Most respondents stated that if cellular agriculture was to be brought to consumers, the model would be a for profit model driven by investor capital in partnership with a current strategic agribusiness like Cargill, and Tyson. A minority of respondents envisioned that cellular agriculture would perhaps be available to small farmers and follow models of adoption similar to 3D printing. Developing cellular agriculture technologies are currently being supported by a range of investment funds that fall into the capital spectrum such as angel investors, high net worth individuals, foundations, corporate agribusiness venture funds and venture capital (Good Food Institute, 2020a). The following series of respondent quotes highlight these findings.

> No, it'll be Tyson and Cargill…I'm serious. They're five years ahead of everyone else even thinking about this…
>
> (#3 Agritech investment fund manager)

> But yeah, I think it's still going to be... Ultimately what's going to be interesting is to see how the Tyson's and Nestle's and all the big players ultimately land as this all goes forward. And can the startups really... One interesting move that I thought was really smart was the Impossible foods group partnering with OSI on the production side of things. Because if you think about, well with the plant-based ones it's like you need all these patty formers and again, you need basically need packing plants to take those ingredients and put them together and do something with it.
>
> And by partnering with OSI, they just avoided a whole lot of capital cost and time and people and growth problems. So that was a very smart move. And where right now beyond is still trying to create that infrastructure at this point.
>
> (#14 Corporate agribusiness executive)

> I think it'll go to the marketplace as a for-profit. I think, as the technology develops, I would expect that the large meat producers this would be, Tyson's and Purdue and the large agricultural people would get involved through either investing in the current companies or starting their own or doing something like that. I mean, that's what they're all doing with the plant base protein.
>
> (#10 Executive meat processor)

Although respondents predominantly mentioned that for profit models would likely advance cellular agriculture, several did allude to the potential of initial private-public partnerships that may occur. Respondents recognized the potential of university, government, and industry partnerships. However, the quote below states that even with potential alternative partnerships for profit activity will drive mass market acceptance.

> Really important technology? To me it's okay if it's university driven, especially in the beginning. I'm a real staunch capitalist and ultimately, I believe nothing really is going to stick unless a capitalist model gets behind it. But that's not to say research institutions and non-for-profits don't play some kind of a role.
>
> (#5 Executive farmer meat processor)

Most respondents stated that cellular agriculture must be cost competitive with existing meat products for widespread consumer adoption. Informants often cited current meat costs for common meat products as a referent as to where costs for cellular agriculture needs to be in order to have a chance to market. Respondents went further into the decomposition of costs, a critical business model element, by stating that improvements must occur with growth media, hormones, large scale fermenter vessel construction, scaling cellular agriculture infrastructure and securing efficient channels to reach the mass market (Figure 2).

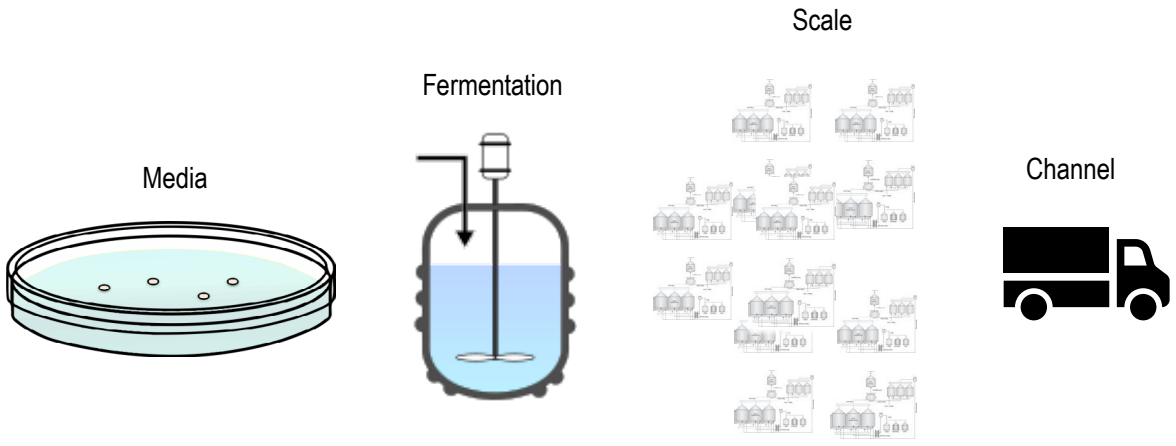

Figure 2. Cited cost drivers for cellular agriculture (Anonymous, 2022a,b; Lucio Lopes, 2016).

Cell growth media was mentioned as the first cost hurdle that scientists need to overcome since current media costs are exceptionally prohibitive (Bashi *et al.*, 2019; Specht *et al.*, 2017). Another respondent mentioned how the costs of four key growth hormones drive media cost and that costs would need to be reduced or some other less expensive method would need to be devised. In addition, a few respondents mentioned the need for the right cost-effective tissue lattice to replicate the structure and texture of animal generated meat products.

Once cell growth elements were cost effective, the next major hurdle mentioned was capital investment in large scale food grade fermenters. Respondents mentioned the massive amount of fermentation vessel materials such as stainless steel that would have to be secured to facilitate cellular agriculture meat production on an unprecedented industrial scale. The following quotes illustrate these concepts related to cost.

> The math is that you need something like say 10 to 40 liters of media to produce a kilogram of meat. Right? And so, if a liter of media costs $500, you can kind of quickly come to the conclusion that that's not a viable product. So, you effectively need to bring media costs down to something on the order of 50 cents, or a dollar, $2, and something in between. Media cost is largely driven by four hormones. But as you sort of understand that there's not really any sort of principled reason why we couldn't bring those costs down, right? And there are some different types of strategies that people are proposing, but it is still today an unsolved problem. And so that's one technical problem that needs be solved… The next of technical problem is around scale up, right? And so, we are not going to be able to use food grade fermenters to produce cellular meat. In part the biggest challenge, right? If you've got slow growing mammalian cells that are not going to be able to out compete the growth proliferation rates of disease. So, how you have a hyper sterile system for these products, and then what do those bioreactors look like? Medical grade bioreactors are extraordinarily expensive. And there's lineups down for time on those systems by major pharma companies who are not producing things for $5 a kilogram, they're producing it for $50,000 a kilogram. So, it's very difficult to compete with the pharma industry…
>
> (#12 Investment manager food and agriculture)

> It's really the cost competitive driver. I mean you've got to have the taste, the mouth feel, that's all I've got to land and it'd be a parody, right?
>
> (#13B Executive chef corporate resort)

8. Future potentialities cellular and animal agriculture

Study participants frequently mentioned two scenarios about the global future of cellular and animal agriculture. One being that conventional animal agriculture and cellular agriculture would co-exist and a second where cellular agriculture would replace animal agriculture. This brings to mind the work of Katz-Rosene and Martin (2020), outlined earlier, in that investor mindsets primarily reflected elements of the 'modernizing meat' and 'replacing meat' perspectives. In only a minority of cases did investors see the 'restoring meat' approach as having significant viability, although some did believe that small-scale agro-ecological and regenerative approaches might continue to co-exist alongside large-scale conventional meat production and cell-based meat.

Figure 3 illustrates scenarios where both cellular and animal technologies achieve balance at scale like the near future of animal and plant-based proteins, or alternatively cellular agriculture replaces a vast amount of animal generated protein or a third, non-mentioned yet plausible, alternative where animal-based protein remains the extant mode of production and cellular agriculture exists as a small-scale technology.

One vision of the future commonly mentioned by respondents is of a world where multiple modes produce necessary proteins for humanity that involve current animal and sea-life proteins with robust plant and cellular agriculture protein alternatives being produced at scale. In essence, each production mode will be at cost-effective scale and occupy important segments in our global food system providing products at competitive

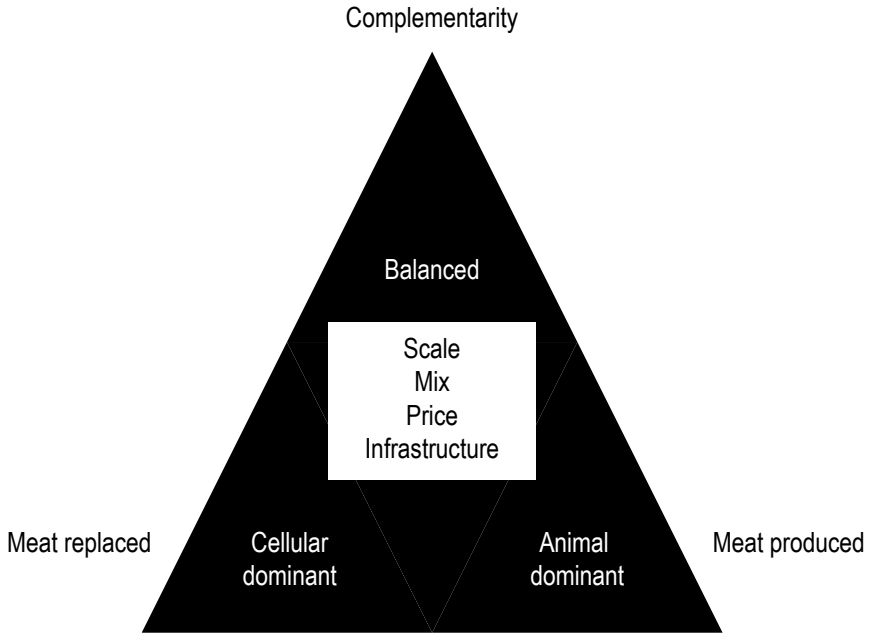

Figure 3. Three cellular-animal agriculture scenarios.

prices. In this scenario certain meat products will be produced by current and perhaps better animal husbandry and sea-harvesting methods. In addition, plant-based proteins and cellular generated proteins will augment our current protein supply. Significant infrastructure will be built for cellular generated protein to achieve large scale fermentation and assist with meeting mass demand for certain meat products. Questions remain about what type of protein and what types of products will be produced, suggesting interesting product mix scenarios for the meat case of tomorrow. For example, will lower end meat products like ground beef be produced via cellular agriculture and/or will high end wagyu beef or seafood products like tuna steaks be produced by cellular agriculture? Informant quotes below illustrate complementary visions of the future.

> I think it's going to be not either/or. It's going to be all of the above. I see cellular agriculture as augmenting existing systems that we are using to convert carbohydrates and natural resources into edible protein. So our first and foremost way of doing that today, from a global perspective, is through animal protein systems, through crop origination that then results in soy and pea and beans, etc. So, to me, I think the global implication is it's going to be another choice that will be out there, and hopefully, if we can start to float the entire protein supply higher, globally, all countries, all peoples can benefit from more protein total.
>
> (#9 Corporate agribusiness executive)

> Well, I think that they're not making any more land. And when you see things happening like in the Amazon where they're still burning down forests to plant crops and have pastures for cattle, I mean, that's not going to continue. It's not sustainable. And as we continue towards that path of sustainability with an ever-growing global population, we're going to have to figure out a way to provide protein other than... or an alternative. I'm not saying it will ever totally replace cattle production and meat produced in more traditional ways.
>
> (#6 Agritech food consultant)

> I think animals will continue to have the role they have continued to have for thousands of years and they should, because in the process of trying to regenerate planet and process to rejuvenate, we cannot afford to flatten the whole planet, neither we can afford to skew the whole planet. The world is continuing, I think what has happened is that because of the mass production of animals for the

> food sources, it has squeezed the pyramid a little bit. I think their role will continue to be the role they have had for millions of years, because that role is the help in bringing back the Earth to the newest balance again.
>
> (#1 Agritech food consultant)

> I mean, I think it's very much not mutually exclusive that it's either going to be all meet someday grown in a lab or grown on factory farms. Like, no. There's going to be lots of different things going on. So, I'm really bullish on... I'm probably not going to be a consumer of lab meat, but the fact that there are people looking for that, it bodes really well for us and you guys, I think. But I do think there's a future where regenerative agriculture and lab meats occupy a significant market share and factory farm stuff starts to decline. I mean, I think that's going to happen. And then that's really positive for human health.
>
> (#5 Executive meat processor)

> I don't see it as having a big effect on farm raised animals. Again, if the population continues to grow, then it's just another source of providing. So I think it could be another growth business.
>
> (#10 Executive meat processor)

The second scenario involves a complete transformation to cellular agriculture and mass abandonment of current animal-based protein production. The cooccurrence of the abandonment of existing animal meat-based infrastructure with the creation of massive fermentation infrastructure to produce cellular meat is envisioned in this scenario. Of course, production scale will be needed to cost effectively provide protein for humanity at affordable price. Meat and seafood products may be formed to match existing animal product mix or may even take new forms depending on consumer acceptance. A central theme of this vision will be seeking net zero environmental impact. Informants also raised a corollary question as to what should be done with existing dedicated animal production farmland and infrastructure. Cash crops used to feed animals such as soybeans may no longer be in demand and thus the question arises as to what to do with millions of acres of farmland. Discussions evolved around the restoration of natural lands and carbon sinks that provide ecosystems services. Indeed, these discussions conjured thoughts about historic mass shifts in industrial architecture due to the advent of new technologies or global trade shifts. For example, societal transition from transportation being by foot and/or horse, to railroad, to automobile and air. Other examples of rapid infrastructure change are US steel, textile and furniture production being sent offshore. Most of this abandoned infrastructure remains, some repurposed, yet a significant amount was allowed to decay (Belanger, 2009). Respondents provided the following insights with respect to a dominant cellular agriculture paradigm.

> So, we'll make this stuff in a fermenter and then we won't have to have as much land for making beef cattle. Yeah, that's fine, assuming the fermenter can be scaled. And then no one... I haven't seen anything where people have identified a credible use for millions of hectares of land. Yeah, you can grow, I don't know, ornamental flowers or something could happen. But what else are we going to do with that land that presently is being used to produce edible meat?
>
> (#9 Corporate agribusiness executive)

> Well, it's an exciting part of it, and I could see keeping my animals, even maybe one day using these animals for cell culture, where people can come and visit the farm, see their crops being grown in the same cycle as these animals, but the animals aren't being harvested and eaten, but they are the animals that are being used to create the cells, and you can experience them. You can see them smile, and laugh, and run around on the farm, and at the same time eating the grasses here, and then producing through their digestive system micronutrients that we don't know how to produce ourselves.
>
> (#4 Farm business owner)

A third scenario represents the failure of cellular meat technology to reach scaled production and consumer adoption. This alternative was not directly discussed by respondents as a long-term solution, rather it was

evident as another option within the set of options during analysis. Although many of the respondents critiqued ideas about whether cellular agriculture would be at sufficient scale in line with optimistic proclamations for the near future. Discussion often centered around inertia to change from utilizing existing animal meat production infrastructure that generates large volumes of protein varieties (mix) at low cost to provide low priced protein to consumers. Moreover, return on investment optimization can often drive longer adherence to existing modes of production (e.g. technology suppression) even with the presence of more efficient technologies and methods (Dunford, 1987).

9. Conclusions

The literature and this study's findings support the commercial emergence of cellular agricultural meat products is likely to occur. Cellular meat is expected to be initially offered as a unique upscale dining experience for affluent early adopters and trend setters. Cellular agriculture is appearing to naturally follow the common early adaptor, elites fist approach to new technology adoption via high end products and exceptional gastronomic experiences. The early stage of market introduction will also likely occur in developed parts of the world in trend setting high wealth concentration urban environments like New York, Singapore, Beijing and San Francisco.

The process is already being led by numerous start-ups around the globe, many of which are backed by significant venture funding. Products will initially be brought to market, optimized, and then set for scale perhaps in partnership with large agribusiness strategics like Cargill, Tyson and JBS. These companies are posited to take cellular agricultural meat and seafood products to the larger markets moving them from innovators to early adopters and majority in developed markets. Plant based meat products serve as a proximate model for adoption although timing of scalable cellular agricultural products will be at a slower pace versus plant-based meat. However, the future vision remains unclear as to whether cellular based protein products will reach into developing or underdeveloped markets. And if so, the timelines are likely to extend outward into multiple decades.

Study evidence also suggests that cellular agriculture will complement animal agriculture at first for a considerable period extending into at least the next decade or two. The initial energy and materials to create mass cellular agricultural production will be immense and will likely be supported by non-renewable energy and resources. Similar parallels can be drawn to the mass scaling of electric vehicles (Contestabile *et al.*, 2012). Thus, promised environmental benefits are not likely to be realized at first and there remains questions about the energy needed to operate mass cellular agriculture infrastructure. We ascribe that cellular agriculture has and can offer new potential and promise; however, it is not without cost. If indeed a future occurs with reduced animal agriculture and enhanced calls exist for carbon sequestration, then current pasture and grazing lands may see repurposing for increased biomass production that may be dedicated to capturing carbon and/or providing feed stocks for renewable materials. Investors naturally will occupy the dynamic places of value creation within protein production with unprecedented agility as these shifts are guided by social, economic, technological, and political forces.

Conflict of interest

The authors declare there are no conflicts of interest.

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