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Creating an infrastructure for cultured meat

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1 Introduction

While industrial animal agriculture feeds billions globally, its growth is creating an industry that propagates the inhumane treatment of animals while accelerating the adverse effects of climate change.[1-7] In addition, the production of animals at a high density increases the risk of spreading epidemic viruses, foodborne illness, and antibiotic resistance, deeply threatening human and animal health as well as food security.[8–10] For example, the mass slaughtering of animals is a common technique used to mitigate the spread of disease, resulting in food supply chain disruptions, increased cost of consumer products, and reduced accessibility to nutritious food. Thus, the practice of factory farming greatly reduces the resilience of food systems, which is particularly concerning in a climate-changed world. To address these issues, one proposed alternative is the use of cellular agriculture technology to create animal products such as meat, milk, and eggs from cell cultures rather than whole animals.[11]

Cellular agriculture is a new, interdisciplinary field of study and burgeoning industry with the potential to end the global dependence on animal agriculture. Over the past decade, US$4 billion has been privately invested in over 100 global companies, aiming to develop agriculture products from cell cultures rather than whole plants or animals.[12] While some are developing products such as leather, milk, and eggs from cell cultures, the

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majority of companies are focused on creating cultured meat or advancing aspects of cultured meat supply chains. By contrast, in the same time period, less than US$100 million has been invested into public sector research and development via philanthropy and government grants.[13] In all, public investment is approximately 2.5% of private investment as of the time of this chapter's writing.

To assess the state of public and private funding within the field of cultured meat, it is helpful to compare it to an existing funding trajectory seen within an adjacent field. For example, complex biotechnology such as biopharma would follow a typical pathway from discovery to market as described (Fig. 1).

The first third of the pathway is publicly funded by government grants and other public sources with the typical intention of building education and knowledge infrastructure for the field. The middle, or the notorious 'valley of death,' is the region where most translational research efforts aim to intervene.[14] The last third is funded by venture capital (VC) with the intention of building intellectual property (IP) and driving the translation of developed technologies. This multi-stakeholder, multi-funder discovery pipeline is typical for highly complex technologies. Due to a series of compounding factors, such as a lack of dedicated funding streams through government funding agencies and the boundless availability of private investment capital, cultured meat sees a disproportionate amount of private funding for the translation and scale-up of technologies (Fig. 2). This scenario in favor of private entities raises concerns, given that the concurrent focus on IP often leads to a lack of available information for policymakers and consumers, as well as shortages of independent and unbiased experts who can develop, evaluate, and optimize

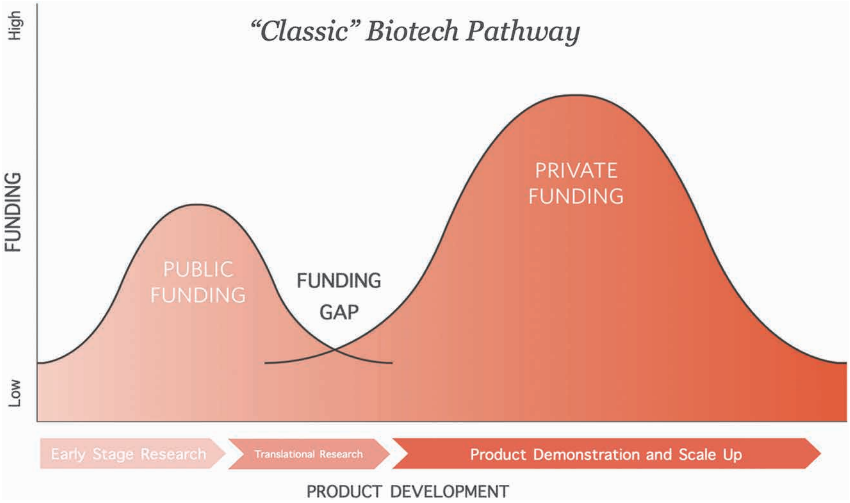

Figure 1 Classic biotechnology product development pathway

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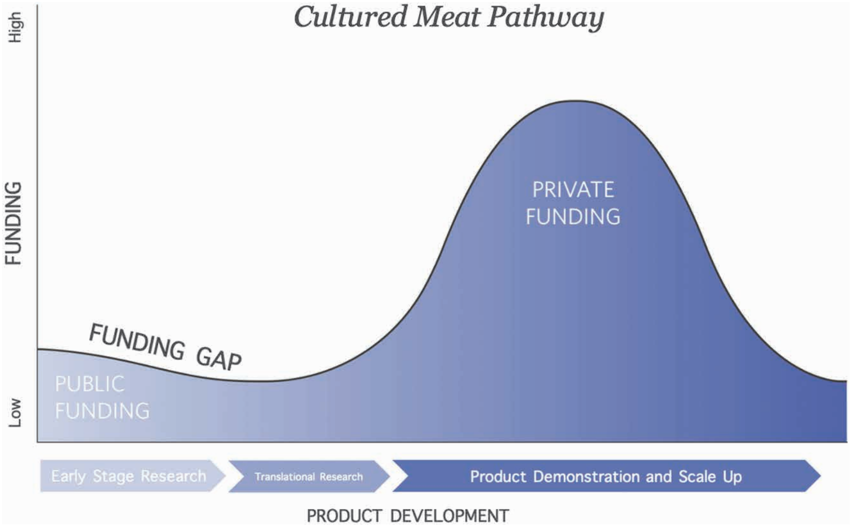

Figure 2 Cultured meat product development pathway

cultured meat technologies. In short, cultured meat is beginning to follow an atypical funding trajectory that has traditionally formed the foundation for scientific innovation and industrial growth.[15]

If we think of cultured meat technologies as a city, it is currently one without public infrastructure. Privately owned 'houses' are under development, but the roads, bridges, sewers, and public squares – all of which are crucial to a thriving ecosystem – remain unbuilt. Thus, switching focus toward developing foundational knowledge, frameworks, tools, and techniques that are openly accessible would accelerate and strengthen the field of cultured meat by filling in the current gaps in infrastructure.

On the surface, it might seem that simply pouring public funding into classic institutions would address this problem. However, as cultured meat is an atypical field, the required infrastructure may go beyond traditional institutional support. There seems little chance that traditional avenues for publicly funded research could keep pace in a meaningful way with innovations in the highly funded private sector.

Right now, most research in cultured meat is performed by private companies, creating several obstacles to efficient progress in the field, such as:

1. The desire to protect potential IP drives an intentional lack of data sharing, blocking the common scientific practice of peer review. This, in turn, generates information 'silos' that may result in the duplication of research efforts, including lines of research that will fail, and slows down the overall pace of innovation. Additionally, it leads to a lack of public

information critical for evidence-based decision-making, delaying the education of regulators and of safety approvals.

2. The need to attract investors may create incentives for companies to obscure the actual state of their technology, which can lead to the misallocation of funding when successful marketing strategies are rewarded by investors over otherwise promising lines of scientific research.
3. Wanting to appear farther along than competitors encourages the misallocation of resources into a premature race to the market; funding projects to gain access before others, with immature ‘products’ that serve only publicity goals, regardless that it takes money and time away from actual research. But such ‘publicity products’ that do not address the animal welfare, environmental impact, sustainability, and safety goals offered by the technology are not desirable, are contrary to arguments made by private developers themselves to fund research, and in the end, are unlikely to achieve long term success if they are not sustainable. This makes such diversions away from research an inherent misallocation that, unfortunately, attracts further misallocation by others to appear competitive.
4. Both over-hyped marketing practices and premature access to markets can create false expectations and confusion for the public and investors, possibly hindering the proper development or roll-out of the technology. For example, beyond the potential for both private investors and the public at large to lose interest in cultured meat if claims are discovered to be empty, stakeholders may not realize where and to what degree public research might be useful to speed development. Should private interest in cultured meat collapse, it is possible that academic interest may rise and sustain the field until viable technologies are established. With proper infrastructure, such a collapse can be avoided in the first place.

If academic research largely avoids these obstacles, the need to follow the academic incentive system presents its own challenges. Time and resource requirements for publication are added burdens not essential for commercial decision-making, making publication prohibitive to much of the industry as well as a diversion for their research teams. Additionally, the lack of, or high cost for, open access in some high-end journals can present another unintentional block to data sharing.

Proposing research infrastructure which is purpose-built for cultured meat as it exists today would create opportunities to overcome these obstacles by avoiding the obligations that divert industry and academia. For example, without marketing requirements, an independent institute could be fully transparent with its research in a way that for-profit, IP-centered companies seeking investment in a competitive field simply cannot. Without the publication requirements of academic labs, an institute would be capable of operating at the speed of industry to develop the data and evidence stakeholders need, potentially even working directly with stakeholders to develop solutions. This unique niche could provide benefits to both industry and academia: offering potentially faster insights, tools, or products to the former and data spurring more extensive research opportunities for the latter. It can also innovate mechanisms to share data outside slower-paced and often closed publication platforms. Finally, being informed and designed from the outset along principles of responsible research and innovation, the proposed institute could work to ensure benefits reach those who will actually build or adopt the technologies (e.g. consumers, farmers, and others within the current animal product value chains) and highlight the issues these underrepresented stakeholders face.

This chapter aims to illustrate potential pitfalls of the existing infrastructure ecosystem for cultured meat, highlight what's missing, and propose potential avenues for remedying these pitfalls as the field evolves. Outlined are also some key points on how cultured meat technology has the potential to advance faster when stakeholders work together as compared to working in isolation.

2 Gaps in existing infrastructure

2.1 The talent gap

An unprecedented and growing talent gap exists within Science, Technology, Engineering, and Math (STEM) sectors. Demands for highly qualified personnel (HQP) within STEM sectors have increased by over 80% within the last 30 years.[16] Cellular agriculture, and specifically the subsector of cultured meat, is unlikely to be immune from these talent gaps. Due to the particular and cross-disciplinary skills required for alternative protein and cultured meat development, talent acquisition and retention could be significant limitations for the sector's growth if not immediately addressed.

Other emerging sectors such as synthetic biology, bioengineering, and clean tech can serve as examples of how to scale the global talent pool to quickly meet ecosystem needs. Additionally, several approaches can be adapted from these sectors to fill the cultured meat talent gap, including expanding the curriculum of traditional academic programs, creating fellowship programs, or launching upskilling programs for the established workforce. This subsection will explore specifically what these programs would look like for cultured meat and how their role out can be streamlined to align with sector growth.

The intuitive approach to solving this gap is introducing cultured meat courses and degree offerings into established university and college faculties. These programs have been quite successful in the brewing industry, whereby specific programs at small institutions (Olds College of Agriculture & Technology, Alberta, Canada) and dedicated Masters programs (Masters of Brewing and Distilling, Heriot-Watt University, Edinburgh, Canada) have created shovel-ready HQP that have the skills to take over established protocols with minimal mentorship. However, academic opportunities for students to pursue formal training in cultured meat and alternative protein development are limited, even at the graduate level; many that are available in the sector are often side or passion projects of established academics in affiliated faculties such as biomedical engineering, genetics, agriculture, or medicine.

Presently, students interested in pursuing coursework related to cultured meat (either out of personal interest or to increase their hireability within the sector) must piece together an array of specialized courses across institutions to supplement their standard biomedical/science education. Courses offered at Harvard University, Stanford University, Singapore's Nanyang Technological University, Technical University of Munich, and Tufts University feature broad overviews of meat alternatives. Although these courses typically feature a generalized curriculum as opposed to specific topics on cultured meat, they are dually beneficial to increasing students' hireability.[17]

The widespread implementation of specific cultured meat curricula is expected to be slow. For comparison, the emergence of synthetic biology as a sector can be traced back to the 1961 discovery of the lac operon by Francois Jacob and Jacques Modod.[18] Yet, despite significant discoveries in the field, including the pioneering of CRISPR in 2010 by Jennifer Doudna and Emmanuelle Charpentier, and the generation of 'synthetic life,' synthetic biology would not become a mainstream and impactful part of formal academic curricula until the mid-2010s.[19] Instead, universities have been able to spin out pools of highly qualified talent in synthetic biology and engineering biology by introducing students to the sector through professional development opportunities and extracurricular engagement. An example of such programs in this space is the International Genetically Engineered Machine (iGEM) Program.[18] The iGEM has defined itself as 'an independent non-profit organization dedicated to the advancement of synthetic biology, education and competition, and the development of an open, collaborative, and cooperative community.'[20] The organization is most notably known for its annual jamboree, where promising students compete as teams to develop innovative omics-enabled solutions to some of the world's most pressing issues. Most teams materialize as university student clubs with faculty sponsorship. In addition to proposing a technological solution, many of these clubs actively engage in campus and community outreach to promote the impact of synthetic biology on society.

Although implementing a global training network as extensive as iGEM might be difficult in the short term for the growing cultured meat sector, it demonstrates that student extracurricular engagement can drive emerging sectors forward. For example, recruiting campus leaders to create campus clubs focused on awareness and outreach could effectively educate local ecosystems about cultured meat (as well as cellular agriculture as a whole sector). An example of this is independent student clubs such as the Good Food Institute's Alt Protein Project, which includes more than 20 student groups around the globe dedicated to turning universities into engines for alternative protein education, research, and innovation.[21] On a smaller scale, universities and their respective innovation hubs/and commercialization offices could support competitions such as cultured meat hackathons to promote sector innovation and thought leadership.

An example of this is the Cultivate Tomorrow Hackathon, an annual student-organized hackathon focused on providing students with the opportunity to explore interests and apply their skills and knowledge to address challenges present in the field of sustainable food technology.[18] Students partner with industry mentors from leading cultured meat and precision fermentation companies to gain insights into the real-life hurdles these companies were facing. As a result, dozens of participants continued to pursue job opportunities in the sustainable food industry.

Not only have initiatives like iGEM and local technology hackathons like Cultivate Tomorrow and Thought for Food helped students supplement their curriculum knowledge of emerging sectors, but they also have the potential to create several spin-off companies from universities by bringing like-minded individuals together. iGEM, in particular, is credited with generating several major companies, including Gingko Bioworks, Hyasynth Bio, and PvP Biologics.[22] Therefore, replicating this model within the cultured meat space could produce multiple benefits: first, generating a steady pipeline of HQP ready to take on the demands of the sector, and second, support the development of innovative and impactful cellular agriculture start-ups capable of solving sector problems and addressing critical issues in the global agri-food landscape.

Smaller institutions, including colleges and polytechnics, do provide training opportunities that are easily adaptable to cultured meat research programs and companies. Technicians skilled in fermentation and general lab techniques can be trained at local technological institutions. These roles will be critical for scaling cultured meat technologies and raise an important point that emerging industries require a range of individuals across a spectrum of educational backgrounds. It is important to ensure that academic institutions are not only producing enough creative thinkers to lead research and development teams but also skilled manual workers to support product scale-up and production.

Nevertheless, all the options mentioned previously create a financial burden on institutions. For example, if initial enrollment in cellular agriculture and cultured meat-based curriculum is low, it could be challenging for universities to justify these investments. Institutions could partner with funding agencies to recruit and fund curricula in this space, or it could be an option to explore the establishment of federally and VC-funded, both private and public funding, maker spaces or centers of excellence, allowing students to benefit from onsite extracurricular professional development programs. These could include tech accelerator programs and entrepreneurship and communications fellowships, providing the opportunity to develop technology outside standard university research programs.

The maker-space model has become a cornerstone of most academic institutions, specifically within science and engineering faculties. Offering cultured meat agriculture-focused maker spaces could provide a unique revenue stream for academic institutions with already established agriculture faculties or strong biomedical engineering programs. For example, Concordia University in Montreal, Quebec, Canada, has created The Concordia Biofoundry, which not only services student innovation but also draws in revenue from across Canada to the institution for academics looking to generate and scale up the fermentation of custom microorganisms.[23] Another successful example is the Synbridge maker space at the University of Lethbridge in Alberta, Canada.[24] Although these facilities are unlikely to generate massive returns on government investment, they serve as centralized training grounds for students looking to gain specific skill sets – like those which would be necessary for successful careers in cultured meat, which, in turn, can be viewed as a larger (more altruistic) investment in the overall ecosystem

Finally, another avenue for highly skilled talent in the cultured meat sector is nestled within the already established workforce. Individuals with graduate and undergraduate training in degrees such as bioengineering, biochemistry, and genetics can easily transition between major biopharmaceutical and cellular agriculture technologies throughout their careers. Training a post-doc adept in human cell culture to culture, maintain, and genetically engineer animal cells would be straightforward, although incentivizing them to leave competitor industries may be challenging due to a perceived lack of job security and financial disincentives. Other opportunities lay in the field of adjacent sectors that have become less lucrative over time, such as general biology, where recent graduates or established professionals could be able to translate their skills to the cultured meat field with minimal training. Given the multidisciplinary workforce needed for cultured meat product development, it is important to note that expertise from established industries can be directly translated to this sector. Some examples include meat and food scientists, where existing skill sets and training can be applied to applications within cultured meat.

A relevant example of this can be found in the global energy sector which has effectively begun re-training its workforce to be ready to assume new roles in the growing cleantech sector. Examples of this include online micro-credential programs, professional accelerators, and paid fellowship opportunities. Amidst the hundreds of programs available, a notable case study in this space would be the Avatar Accelerator Program. Based in Calgary, Alberta, and funded by energy sector giants such as Cenovus, Shell, etc., this program gives established energy professionals the opportunity to explore the cleantech sector and develop skills that would enable them to lead their respective organizations in the energy transition. Translating this line of thinking to cultured meat, the traditional farming sector can glean a tremendous amount of highly skilled geneticists, and veterinary scientists, who could lend their expertise to the sector. Programs like this have begun to emerge in the cultured meat space, including the Cellular Agricultural Society Fellowship, Good Food Institute Fellowship, New Harvest Fellowship, and the Rockey FFAR Fellows Program (created in conjunction with North Carolina State University). However, increased accessibility to and funding for these programs will be critical to serving the upcoming talent gap within the sector.

Ideally, the aforementioned solutions will not be carried out in isolation. To successfully grow, the cultured meat industry will need to simultaneously develop multiple talent pipelines to fill the mass of expected jobs as the field grows. As cultured meat has the potential to reduce national greenhouse gas emissions and diversify local economies significantly, there is a strong case for government investment in these training opportunities to enable the field's growth as a whole.[25]

2.2 The funding gap

Generally, two notable funding gaps exist within the innovation ecosystem. The first is during the idea-to-prototype phase, where founders struggle to access capital.[26] Their technology and enterprises are usually too early to provide sufficient evidence of viability for investors. The second occurs later in the commercialization phase, where it can be difficult for founders to raise sufficient funding to pilot and scale their technology to commercial viability.[27,28] Achieving these milestones can be even more difficult for companies rooted in interdisciplinary sectors, such as cultured meat.

A key challenge in finding public funding for the cultured meat space is that the sector is often considered too biotech-focused for traditional agricultural departments and simultaneously too food-focused for biomedical departments. Beyond overarching themes, like reducing greenhouse gas emissions and segueing to net-zero economies, it can be difficult to contextualize cultured meat projects in the broader scope of most funding programs. This accentuates the need for funds specifically allocated to cultured meat. Governments have been incentivized to facilitate this and in 2022, the world's largest public funding for cultured meat to date was announced by the Dutch government, which earmarked €60 million (roughly US$65 million) to support education, research, and upscaling of the field.[29–31] Another important public fund was announced in the United States of America, where the U.S. Department of Agriculture granted US$10 million to create a National Institute for Cellular Agriculture in Massachusetts.[32] Led by Dr David Kaplan of Tufts University, the institute will join researchers from Virginia Tech, Virginia State, University of California-Davis, Massachusetts Institute of Technology, and University of Massachusetts-Boston. Public funds like these are important, as it requires all involved parties to discuss how to allocate resources, resulting in an optimal infrastructure, and thereby supporting the development of the cultured meat ecosystem further.

A different example of political involvement is funding provided for highly specific projects. A collaboration between cultured meat company Mosa Meat and food processing company Nutreco called the 'Feed for Meat' project received US$2 million in funding from the European Union to study the possibilities of using waste from the animal food chain for cultured meat production.[33] A parallel example is a collaboration between cultured meat company Meatable, and the Technical University of Delft, The Netherlands, which received around €1 million (which is equal to roughly US$1 million) from the Dutch Research Council to study the use of protein-based biopolymers for potential food and healthcare applications.[34] Although funds like these help further development of cultured meat, it is noteworthy that they are sometimes limited to specific government priorities or require substantial amounts of in-kind and cash matching contributions from established industry partners. Internal capital might therefore be required, so the aforementioned funds cannot always be utilized to bridge funding gaps.

In addition to public funding, VC investments are a resource for cultured meat companies. VC is a form of early-stage investing and finances a company's move from small to large-scale operations.[35] Generally, VC investors favor traditional sectors or established industries like energy, technology, and software, as the associated history of these sectors generates a sense of security within the investment community. The contrary is observed in the field of environmental innovations: the lack of historical data and absence of stable and competitive markets facilitates uncertainties and risks related to investments.[36] These inclinations are amplified in sub-sectors like cultured meat, due to the high technical risk, long development pipelines, and large uncertainty of the outcome.[36,37]

Despite these risks, VC investment has become increasingly consistent within the cultured meat space, as companies have matured. As of mid-2022, over US$4 billion was raised for cellular agriculture companies.[12] Although the high amount of VC investment is appreciated, it poses a large pressure on individual companies. Investment of private capital typically comes with expectations of progress within relatively constrained timeframes to generate investor returns.[38] If misaligned with realistic timelines for company growth and development, enterprises can be urged to accelerate toward the next stage of company development prematurely. While this may make the investment more liquid, it can disrupt efficient research and development, as expectations are ahead of reality. This adverse impact of VC investment is not isolated to cultured meat and is observed more often in novel industries when investor interest peaks.[39]

Introducing VC funding into a sector may also introduce more competition, especially pertaining to IP management. Although this competition can motivate companies to engage in a 'race to market' and accelerate technology development, the monetization of technology comes at the expense of openly available foundational knowledge and communal sector development of reliable business development patterns.[40] This lack of openness can detriment emerging sectors from both technical and capital perspectives. Companies on the verge of commercialization may be resolving problems already addressed by competitors, resulting in capital being spent reiteratively. Unfortunately, there is no solution to this yet. However, in a more positive light, VC does unlock the potential to increase the popularity of investment in the cultured meat space, especially with the emerging trend of celebrities investing in startups as angel investors.[28,41]

What remains unclear is if VC as an industry can adapt to the timelines of scaling the biotechnology industry. As cultured meat production technology is still immature, substantial investments are required to sustain long-term research projects.[42,43] This highlights the need for proper due diligence and investor education, to mitigate expectations on challenges and timelines for returns on investment. For instance, significant portions of investment will be allocated to scaling up the production process, and the financial requirements are expected to be comparable to scaling up in the pharmaceutical industry, where scaling up happens in steps and requires jumps in capital investment.[44]

The funding coming from VC investments is currently of great importance for the development of the cultured meat field, as the amount of public funding is not sufficient. However, as mentioned earlier, substantial investments are required to sustain long-term research projects.[43] Therefore, financial systems, like banks and institutional investors, play an important role, as they can invest large amounts of funds.[28,43] A research institute with the sole purpose of doing research and development for a technical aspect of cultured meat technologies could be an approach to close the funding gap without being dependent on VC investments. This type of organization, also known as a Focused Research

Organization (FRO) would provide effective means of learning about the latest research and sharing knowledge.[17] For example, an FRO could create the first open cell bank and share protocols for research and production, avoiding the risk of capital being spent reiteratively.

3 Possible avenues for remedy

3.1 Toward a more collaborative ecosystem

Pre-competitive collaboration occurs when two or more researchers, groups, or companies work to address common challenges within the same field to advance technology and set standards. The goal is to engage in collaborations that do not compete with or affect the success of the individual parties involved, ultimately providing mutual benefits. Due to the encouragement by VC firms, technology is often developed separately and privately within companies, resulting in zero transparency and little information sharing. Cultured meat companies are not immune to this phenomenon, with the majority of funding currently being given to IP-driven research.[12,13] Concerns have arisen on whether or not the approach is effective to accelerate the field of cultured meat. Thus, the question is, can pre-competitive collaborations assist in building a robust infrastructure to help advance the field of cultured meat more quickly?

Pre-competitive collaborations have the potential to advance the field of cultured meat through the contribution of foundational research and knowledge that is accessible to all. In doing so, there would be a reduction in public and private entities ‘reinventing the wheel’ and duplicating failed lines of research. However, building a more collaborative ecosystem between public and private organizations is often challenged due to conflicting goals as well as time and resource restrictions. A more unique challenge specific to the field of cultured meat arises due to the variety of R&D goals. Specifically, entirely different technology will likely be needed to develop different products. For example, consider the technology needed to produce ground versus structured cuts of meat, using genetically modified organisms or not, culturing cells from different animal species, and even the different cell types within the same animal species. In short, there is no such thing as a single cultured meat technology identifying where pre-competitive collaborations can exist. Thus, it will be important to identify key commonalities that every stakeholder can benefit from within the field of cultured meat and strategize how collaborations can be built to fill in the identified pre-competitive gaps.

Setting standards in the field of cultured meat is one potential area that can benefit from pre-competitive collaborations. Preliminary efforts to establish product and safety standards are currently underway. In October 2022, three industry associations including the Alliance for Meat, Poultry, and Seafood Innovation, the APAC (Asia-Pacific) Society for Cellular Agriculture and

Cellular Agriculture Europe established an alliance with the goal of facilitating information sharing for increased transparency and harmonizing regulatory requirements to promote consistency as products reach the market.[45] Given that the alliance has 30 industry companies and organizations in the field, one strategy could be for companies to contribute data that would inform regulatory agencies to establish safety guidelines and product standards. Furthermore, forming additional collaborations with food safety and environmental and consumer advocacy organizations could provide additional perspectives on areas for improvement within existing regulatory and safety frameworks.[46–48] Essentially, building a new and transformative food system will likely require multiple collaborations and perspectives to not only ensure its success but to also improve existing food systems that will be utilized within the industry.

Though it seems that pre-competitive collaborations would be a rare occurrence in industry, many examples can be referenced to determine how the concept may be utilized within the field of cultured meat. In 2013, 17 salmon aquaculture companies contributed resources to establish the Global Salmon Initiative (GSI), a pre-competitive collaboration that has since worked to have 40% of salmon companies globally receive Aquaculture Stewardship Council (ASC) certification.[49] By doing so, each company is trained to standardize salmon feeding to increase efficiency and practice strategies to mitigate disease. This standardization ultimately leads to a more efficiently produced and safer product.

While the ASC provides an example of companies working together, public–private pre-competitive collaborations also exist. The Biomarkers Consortium was launched by the National Institute of Health and the Food and Drug Administration (FDA) in collaboration with companies and nonprofits within the field of pharmaceuticals.[50] The goal of the collaboration is to collectively develop a library of biomarkers to diagnose and treat diseases. As a result, the biomarkers developed are foundational knowledge that benefits everyone in the field and no one company or organization is responsible for generating this knowledge. Today, the consortium has upwards of 70 members globally and has launched over 30 projects, resulting in dozens of publications, 9 tools available to the pharmaceutical industry to make clinical trial decisions, and has assisted with advancing 12 FDA approvals for drug therapies. A more recent example is the Center for Environmental Sustainability through Insect Farming (CEIF), which was established in 2021 by Mississippi State University, Texas A&M University, and Indiana University-Purdue University Indianapolis after being awarded funding through the National Science Foundation (NSF).[51] The goal of CEIF is to produce high-quality research in collaboration with academia and industry to advance the field of insect protein and inform regulatory agencies.

We are already seeing examples of pre-competitive collaborations forming in the field of cultured meat such as the Tufts University Center for

Cellular Agriculture which can support pre-competitive collaborations to address fundamental technical challenges in the field.[52] In 2022, RESPECTfarms was launched with the goal of bridging the current gap between farmers and scientists working on cultured meat.[53] Their plan is to establish cultured meat farms in both the Netherlands and Germany that will work on developing a platform for scientists and farmers to utilize their expertise and collaborate on cultured meat projects. RESPECTfarms additionally has plans to work toward streamlining technological implementation through the design of decentralized models that can be utilized by any farmer on their own land at a smaller production scale. Thus, in this example, we see how pre-competitive collaborations could also be beneficial in contributing social innovation to the field of cultured meat.

So, what would allow for pre-competitive collaborations to exist in the field of cultured meat? To determine areas for partnership, common problems and research questions must be identified. For example, standardizing best practices for food product safety is an area of research that will benefit all relevant stakeholders. This could be broken down into subsets that would involve parties working on a specific product type, such as ground meat versus specific cuts of meat, where the focus can be given to specific bioreactor designs and production scale-up according to the goals of each subset. Another group can focus on advancing genetically modified technology to alter cells to react identically to the same physio-chemical cues to create a universal cell media formulation. One could even imagine these efforts being overseen by one umbrella organization that is subdivided into different areas of focus.

Pre-competitive collaboration has the potential to advance the field of cultured meat and benefit all stakeholders involved. By doing so, the benefit of collaboration can be multifold and has the potential to result in significant strides toward improving our food system for the benefit of all.

3.2 Community engagement and education

Beyond research disciplines, cultured meat demands the collaboration of industry stakeholders. As this field is still in its early stages, potential opportunities exist to collectively and equitably address ecosystem needs by challenging the dominant practices, technologies, and discourse in existing innovation spaces.[54] Those in the field have the opportunity to explore alternatives to traditional technological cycles of development, pulling in social communities and relevant industries to evolve existing establishments.[55] Building a new field creates the opportunity to also include marginalized and underrepresented stakeholders at the forefront of the process to ensure that the newly developed practices benefit all who adopt these technologies. For cultured meat, some examples include those involved in traditional agricultural production, such as animal care and husbandry, and food production laborers. Policymakers, grant institutions, and departmental agencies that determine funding and standards should also be included, with representatives from diverse cultures and varying relationships to land and animals. Additionally, economic factors such as companies that produce and market new food items and consumers who choose these new technologies are also important stakeholders. In this section, we discuss the potential for community engagement through (1) bridging the gap between technological development and broader acceptance, (2) developing shared resources and knowledge, and (3) considering the location and regional context.

3.2.1 Bridging technological developments and broader acceptance

In tackling challenges around sustainability, nutrition, animal welfare, and biotechnology, grassroots and local efforts provide many valuable insights that can ground larger industrial transitions. However, bridging these efforts with more established formal scientific agencies and other institutions is complex.[54,56] Expanding beyond grassroots innovation requires a careful balance between representing local community interests and attempting to disseminate broader solutions, with the added complexity that these solutions offer answers to issues perpetuated by larger socioeconomic forces.[57] Historically, this has often meant that only some elements of a local or niche practice reach widespread adoption. For example, the push toward organic food in the UK began in the 1920s, centered around soil, plant, and animal synergies, cyclical local systems, and decentralized consumption as a critical alternative to industrial agriculture.[56] The movement was dismissed for decades, and ultimately a narrower scope of sustainability-minded organic practices gained traction in the UK in the 1980s and 1990s, focused primarily on farming without chemicals and significantly less on decentralized food systems of symbiotic animal, soil, and plant relationships.[56,58–61] Concerns remain around implications of long-distance transportation of goods, energy demands of processing and storage, packaging, and farm biodiversity, and the typical consumer will now choose between both organic and conventional foods.[56,58–61] Thus, this initially niche concept has achieved a much broader reach, with a narrower scope, reliant upon the reinterpretation and restructuring of interests by those involved in its growth.[49]

3.2.2 Building shared resources and knowledge

As cultured meat technologies continue to advance, the development of standards, oversight, and accountability within the field and externally will become increasingly critical. Open innovation networks and collaborations across industry, academia, and policy, such as Open Cell Ag, can help address this need.[62] Researchers must identify strategies for supporting open innovation and addressing translational challenges, including a focus on modularization and reproducibility, implementation of standards, policies to increase data sharing, investment in innovation hubs that bring together various stakeholders, promoting trust in the field (both externally and internally), and open communication and feedback with potential users.[62]

In addition to developing a shared language and providing open information, proponents of cultured meat can also promote more interdisciplinary STEM education to prepare future researchers and developers. Researchers have identified an 'engagement gap' in traditional engineering programs, which often do not prepare students to work with the communities for whom they will be designing solutions.[63,64] Integrating socially-directed approaches early on in the research and education process can have profound long-term impacts. The Braided River model for STEM education provides a framework for diversity of experience in science and technology careers, emphasizing variability and responsiveness, and promoting partnerships with nonscientific experts and industries, policymakers, and communities.[65] While in some ways the development of cultured meat has engaged nontechnical communities through conferences, courses, and hackathons, further scaling of the field will require sustained outreach and engagement of this type. By broadening our understanding of what scientific training encompasses, we can encourage more individuals with nontraditional experience to enter the field and emphasize collaborations, community partnerships, and broader impacts.[65] Incorporating more perspectives in STEM education at all levels can also prepare students for the complexity and nuance of community engagement.[63,64]

In recent years, more programs focused on incorporating societal perspective in engineering education have emerged, including Station1, a nonprofit higher education institution that integrates science and technology with humanistic fields and the social sciences in order to interrogate, understand, and shape technologically-driven societal impact toward more equitable and sustainable outcomes.[66] In person, cross-disciplinary workshops provide opportunities for individuals of different groups to share perspectives and better understand varied interests and concerns surrounding transitioning fields. As an example, a recent gathering on 'Social Implications of Cellular Agriculture' which brought together industry representatives, nonprofit advocates, academic researchers, members of local indigenous communities, and dairy farmers allowed participants to collectively imagine desirable food futures and 'good' transitions to cultured salmon and dairy.[67,68]

3.2.3 Physical location and regional context

The location and physical context of research and development have profound implications beyond the realm of scientific discovery, shaped by regulations, available funding models, access to resources, regional politics, and public opinion. Physical research and development spaces have consequences on multiple levels: from the labs in which this work is initially done, to the larger-scale manufacturing plants and supply chains necessary to bring cultured meat products to market. Traditional biotechnology work occurs in specialized laboratories, where the specificity of research conducted necessitates training and preparation to enter the physical spaces. As private enterprises in this field are generating prototypes, some have created opportunities for the public to visit, tour facilities, and try the products. Recent examples include cultured meat company like Upside Foods live streaming the opening of their facility in 2021, or Wildtype providing a map of their pilot plant on their website and hosting tastings. So far, these spaces remain heavily curated and niche.

As cultured meat products gain momentum, scaling the industry will require the development of manufacturing facilities. Historically, large companies have had little engagement with local communities around the impact of such facilities on local ecosystems. The development of manufacturing facilities can have a profound impact on local communities, and the degree of entanglement of companies with the community can significantly impact outcomes for relevant populations. The presence and authority of local institutions focused on civic engagement, environmental impact, and corporate oversight are very influential on emission and pollution rates for plants located far from company headquarters.[69] Life cycle assessment studies to evaluate the potential environmental impacts and broader social context around novel food products, and specifically cultured meat products, can provide useful tools for evaluating the consequences of production on local environments throughout the process.[70-73]

Recent techno-economic analyses have shed light on the challenges, costs, and viability of scaling cultured meat, considering factors such as bioreactor design, energy costs, contamination safeguards, and growth factor costs.[74,75] Together, these tools can help those in the field understand the impact of infrastructure and geographical impacts on communities, examine the cultural impacts on existing food systems, and allow them to learn from existing just transition efforts.

As people become increasingly intentional about their food choices and sources, having open access to information and to the physical spaces where their consumables are made provides an opportunity to make consumer perspectives a central motivation. Developers could even look to other specialized fields that have recently created more spaces for education, outreach, and public engagement, reducing the barrier to specialized training before entry. The DIY Bio movement has the potential to facilitate new practices and collaborations in unconventional spaces, leading to some cheaper or simpler technologies and broader public engagement.[76] This movement has been met with funding and maker space creation in a way that has allowed it to proliferate and adapt, as a potential parallel of how cultured meat could mobilize resources for public engagement. Finally, food plays a significant role in our daily lives, making it crucial to prioritize transparency, inclusivity, and openness in our approach to it. The socioeconomic and cultural factors influencing food production and consumption vary widely by region and heritage. Our engagement with animals, the products we use, and the animals we consume differ across cultures. It is important to note that cultured meat technologies are currently being developed with a focus on the needs and preferences of developed economies. However, this approach may create discrepancies because the rising demand for meat will also be needed to feed undeveloped economies. As we consider the proliferation of cultured meat products, we should take these factors into account to avoid unintentionally excluding certain populations. For example, many alternative protein companies focus on chicken, beef, or pork replacement products, which may not align with the preferences of cultures that do not traditionally consume these meats. Cultural preferences around animal consumption are influenced by complex socioeconomic factors, with certain cuts of meat becoming central to regional dishes due to their affordability and availability. It remains unclear how this will translate to cultured meat products. Therefore, it is important to consider the implications of cultured meat production beyond just the economic benefits and to explore ways to ensure that the technology can benefit all populations, regardless of their level of economic development.

4 Conclusion

The current lack of infrastructure in cultured meat technologies critically limits education, knowledge and resource sharing, and foundation building which are crucial for ongoing innovation and industry growth. A beneficial infrastructure can be established by creating more opportunities for talent generation, closing the funding gap, promoting cooperation over competition, and mobilizing the ecosystem.

To develop into an established sector, the cultured meat industry needs to develop multiple talent pipelines to avoid talent gaps and fill the mass of expected jobs as the field grows. As the cultured meat field is interdisciplinary and specific skill sets are required for the jobs that are necessary to successfully develop this emerging field, talent acquisition and retention could be a significant limitation in the sector's growth if not immediately addressed.

An intuitive approach to solving this talent gap is introducing cultured meat courses and degree offerings into established university and college faculties.

At the time of writing, academic opportunities in cultured meat are limited, and widespread implementation of cultured meat into curricula is not expected in the short term. There could be an opportunity to explore the establishment of federally and VC-funded maker spaces or centers of excellence, allowing students to benefit from onsite extracurricular professional development programs. Offering cultured meat agriculture-focused maker spaces could provide a unique revenue stream for academic institutions with already established agriculture faculties or strong biomedical engineering programs. Another approach to generating highly skilled talent is by transitioning people from already established workforces, like biopharma, agriculture technologies, or post-doc experiences with cell culture, to the cultured meat field. Expertise and skill sets from established industries like meat and food science can be directly translated and applied to the cultured meat industry.

Navigating funding gaps can be challenging for companies in any field, while it can be even more difficult for companies rooted in interdisciplinary sectors, like cultured meat. Due to its interdisciplinary origin, cultured meat cannot be easily categorized, as the sector is often considered to be too biotech-focused for traditional agricultural tranches, while simultaneously too food-focused for biomedical tranches. This causes problems when applying for funding, accentuating the need for the sector to have its own allocated resources.

So far, most investments in the cultured meat sector are obtained from VC sources with limited public investment. Private investment creates a competitive space in which developments are urged to be as fast as possible. This can be beneficial for research developments, but it can also limit the progress of the field. It causes an intentional absence of data sharing, it can lead to misallocation of funding and resources, and it can create false expectations for the public and investors. Although academic research does not have this effect, another, unintentional, lack of data sharing is presented by the lack of, or high cost of, open-access publishing in some high-impact journals.

As the cultured meat field is not a competitive industry yet, there are many pre-competitive challenges that can be solved by pre-competitive collaborations. These collaborations not only advance research faster but result in a more sustainable approach as resources can be shared, and it provides the opportunity to set standards early on in the field. In terms of infrastructure, there are going to be commonalities that every stakeholder can benefit from within the field of cultured meat, providing benefits to both public and private parties involved.

Cultured meat demands the collaboration of industry stakeholders. The relevance of food to daily life encourages the consideration of transparency, inclusivity, and openness. The socioeconomic and cultural factors influencing food production and consumption vary widely by region and heritage. Providing opportunities for engagement throughout the development and implementation process would allow individuals from diverse food cultures and those who will build or adopt emerging cultured meat technologies to have ownership and collaborate on the process with developers.

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