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DECOUPLING FROM LAND OR EXTENDING THE VIEW: DIVERGENT SPATIAL IMAGINARIES OF AGRI-FOOD TECH

JULIE GUTHMAN and MADELEINE FAIRBAIRN

ABSTRACT. Beginning around 2013, an agri-food tech sector coalesced, proffering countless technologies that promise a more sustainable food future. Yet exactly what that future looks like varies dramatically within the sector. Based on an intensive study of this sector, we examine two paradigmatic areas of innovation—alternative protein and digital agriculture—showing how the environmental promises of each translate into very different ideal uses of space. The spatial imaginary underpinning much protein innovation is contained, aiming to bring as much production as possible into highly delimited spaces, whereas the spatial imaginary of digital agriculture is expansive, facilitating farm management at a scale far beyond what a farmer can directly experience. Such divergent technological trajectories, we argue, have always existed in food and agriculture, but they are now incongruously paired within the agri-food tech sector. In addition to being contradictory in their own terms, both wrongly conflate a spatial imaginary with socio-environmental improvement. *Keywords: agri-food tech, alternative protein, controlled environment agriculture, digital agriculture, spatial imaginaries.*

> The global land area dedicated to agriculture is approximately five billion hectares. That's 38 percent of the earth's surface…Our growing system yields up to 350× more per acre than traditional farming. That means our farms are designed to grow as much produce as an entire regulation FIFA soccer field on the footprint of a single goal. Farming like this reduces monocultures, freeing up land for biodiverse uses.
>
> —Plenty (2023)

This promise of a more spatially compact—and therefore environmentally sustainable—form of agriculture figures prominently on the website of Plenty Farms. Plenty is among a new generation of controlled environment agriculture (CEA) companies, which marries Silicon Valley's tech culture to widely shared efforts to make food production better for the planet. For Plenty, like many other CEA startups, the future of food production must be a vertical one. By growing greens on stacked horizontal trays or, as in the case of Plenty, on actual vertical surfaces, these companies aim to maximize yields per acre, sparing land and other resources for nonagricultural purposes (Bomford 2023). Similar to the aspirations of so-called zero-acreage farming, a term sometimes applied to low-tech indoor and rooftop urban farms (Thomaier et al. 2015), their promises of agri-food salvation hinge on an explicit spatial imaginary in which technology

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enables abundant productivity on “a fraction of the footprint” of conventional agriculture (Plenty website). Plenty is not alone in its belief that cutting-edge technology holds potential to “secure our food future.” Beginning around 2013, a raft of funders, entrepreneurs, and consultants, located predominantly but not exclusively in the San Francisco Bay Area, declared food and agriculture to be underinvested and in need of transformation. Their efforts coalesced into a self-avowed agri-food tech sector, best delineated by the hundreds of events and conferences, and dozens of facilitating organizations with future-oriented names like FutureFood Tech, Foodbytes!, and Rethink Food. Importantly, this self-making of a sector brought many, very different technologies under the same vast umbrella.

Two iconic early moments in the development of the sector capture both its breadth and its promises of environmental improvement. August 2013 saw the first-ever tasting of a hamburger made from lab-grown meat (also known as in vitro, cellular, or cultured meat). Though the single patty cost over $300,000 dollars to produce, this event nonetheless generated considerable publicity for the awe-inspiring possibility of a future in which meat production could be divorced from animal agriculture with all its waste and greenhouse gas emissions (Fountain 2013). This “spectacular unveiling” (Jönsson 2016, 726) of the cultured hamburger helped launch a wave of innovation in producing alternative proteins with bioengineering, whether through cellular growth or through acellular processes such as fermentation. Just two months later, in October 2013, another seminal moment in agri-food tech occurred when the multinational agricultural input supplier Monsanto purchased Silicon Valley data company Climate Corporation for a breathtaking $930 million. Climate Corporation combines remotely sensed weather data with the massive troves of digital data now automatically generated by precision farming equipment to produce software products that allow farmers to visualize and assess their farming operations. Like high-tech proteins, this “smart farming” technology was touted in part for its positive environmental impacts, promising that big-data analytics would allow for more judicious use of water, pesticides, fertilizers, and other inputs within conventional crop agriculture.

The environmental promises of both bioengineered alternative protein and digital agriculture are not always explicitly spatial—as they are on the Plenty website—often inhering instead in claims to resource use efficiency. Yet, the underlying logics of both suggest ideal spatial imaginaries for future food production (see Figure 1). That these are highly divergent presents somewhat of a puzzle.

Between 2018 and 2022 our research team conducted an intensive study of the Silicon Valley agri-food tech sector, with a major focus on the discourses through which it frames it aspirations to reshape the future of food. Our research involved participant observation at over 80 events, as well as

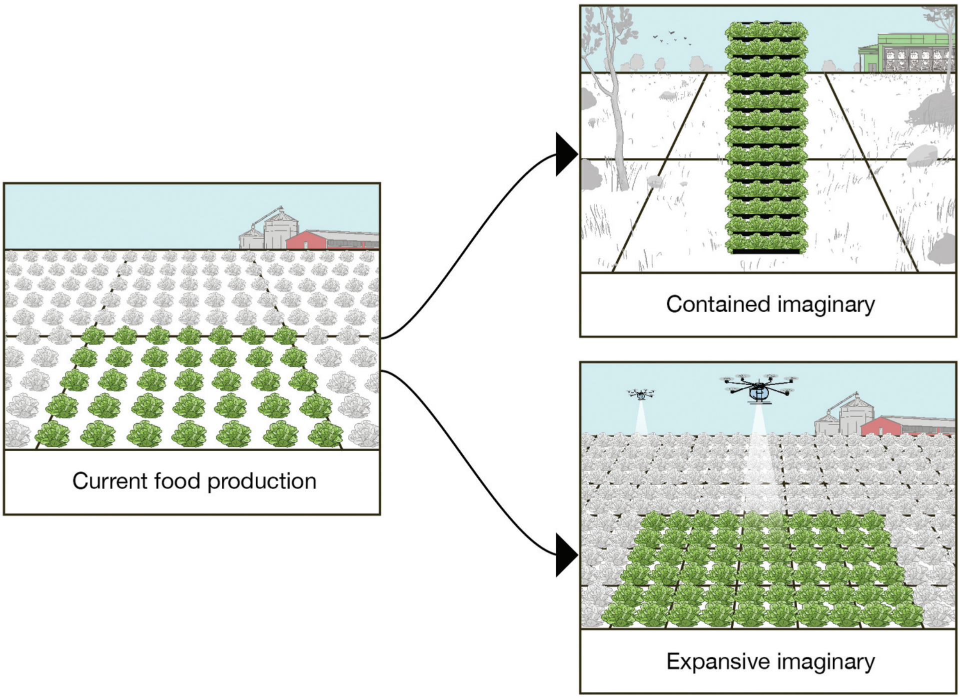

FIG. 1.—

interviews with nearly 100 start-up executives, investors, and industry consultants working on a broad array of agri-food technologies. This paper, however, is based less on a systematic review of our data than on an analysis of the two most paradigmatic areas of innovation as suggested by both popular and scholarly attention. We draw on illustrative interview and event data, as well as select company websites, to evince the environmental promises of these two paradigmatic areas and how their distinctive socio-technical imaginaries translate into ideal uses of space.

The spatial imaginary underpinning much alternative protein innovation, we argue, is contained. Cellular and acellular protein production, that is—like vertical farming—brings as much production as possible indoors, in highly delimited spaces as if the environmental problem it addresses revolves on the extensive use of space and the resources associated with such use of space. The pinnacle of this vision is a complete decoupling from land. In marked contrast, the spatial imaginary of digital technologies is expansive, as "smart farming" extends the farmer's view—and therefore their management capacity—far beyond what they can directly experience. It presumes that farming can only survive with economies of scale but can nonetheless be made less destructive through gains in resource use efficiency per unit of space. The fact that the sector is pursuing technologies with such highly divergent notions of how the future of food production should be secured presents a puzzle deserving of explanation. It also raises the question of whether either of these spatial imaginaries are adequate to address the actual problems with current modes of food production.

Technoscience, Spatial Imaginaries, and Divergent Agri-food Trajectories

Social imaginaries play a crucial role in producing the technoscientific future. Scholarship on techno-science innovation emphasizes how visions, expectations, and promises for the future shape both actions taken in the present and the contours of the future itself (Borup et al. 2006; Rajan 2006; Jasanoff and Kim 2013; Helliwell and Burton 2021). Stressing the inseparability of technological projects and notions of ideal social orders, science and technology studies (STS) scholars Jasanoff and Kim (2013) introduce the concept of socio-technical imaginaries to denote how shared understandings of desirable futures underpin national scale advances in science and technology. While most research on socio-technical imaginaries has focused on the ambitions of nation states, Sadowski and Bendor (2019) reveal that technology vendors, too, can be prominent purveyors of socio-technical imaginaries.

Geographers meanwhile have long insisted that social orders are inherently spatial and therefore that attempts to transform the social are necessarily efforts to rearrange how and where social practices are located in place and space (Watkins 2015; Davoudi et al. 2018). Although geographic scholarship on spatial imaginaries per se is voluminous and heterogeneous, speaking to many definitions and uses, virtually all agree that spatial imaginaries are deployed to articulate ideal visions of spaces, places, and scales for the future (Watkins 2015; Chateau et al. 2021). That said, the vast majority of empirical studies in this vein focus on place imaginaries—how, for instance, a specific city could look in the future (Feola et al. 2023), rather than how abstract space should be arranged.

Socio-technical and spatial imaginaries are intimately linked, as socio-technical imaginaries can underpin, convey, and perform spatial imaginaries, as well as the converse (Chateau et al. 2021). Reviewing scholarship on energy system transformation, Chateau and others argue that technological conversion drives not only social but also spatial change, effectively imbuing technological efforts with notions of ideal spaces. As they put it, a given spatial imaginary can "crystallize the benefits of a socio-technical option," suggesting that it is through a suggested spatial arrangement that the end goal of a particular technological approach becomes evident.

Importantly, such socio-technical-cum-spatial imaginaries are often subject to contestation. Yet existing scholarship on competing imaginaries has tended to focus on conflict between elites, whose more corporate imaginaries tend to dominate, and actors "from below" who assert different spatial visions, often resisting technological change (Wolford 2004; Hincks et al. 2017; Chateau et al. 2021; Gugganig 2021). This literature thus does little to help explain the agri-food tech sector, where putatively aligned actors promote clashing spatial imaginaries.

In fact, agri-food technology has long charted divergent trajectories. In their classic work of agrarian political economy, Goodman et al. (1987) describe two long-term trends in the development of technology around food and agriculture, driven by the invention of very different kinds of technologies. A trend they term "appropriationism" refers to the tendency to replace farm-made inputs and processes with improved, factory-made versions. Recounting the history of appropriationism, Goodman et al. trace how mechanical technologies replaced labor, chemical technologies increased fertility and controlled pests, and biological innovation enhanced yields. Because they aim to increase the productivity of existing land and reduce the risks inherent to farming, appropriationist technologies, according to Goodman et al., reinforce the rural basis of production. This stands in stark contrast to a second technological trajectory that Goodman et al. term "substitutionism:" the gradual shifting of food production to factories, where it could more easily be controlled. Tracing the history of substitutionist innovation, they track shifts from preserving (canning, refrigeration) to imitating (margarine) to synthetic substitutes (artificial sweeteners) to microengineering food products, effectively predicting the food fabrication and cellular technologies currently embraced by today's agri-food tech sector. Rather than reinforcing land-based production, substitutionist technologies reduce the importance of land, attenuating production from its rural basis. These divergent trajectories have usually been pursued by different types of corporate actors, not brought within the same sector.

Now centered in Silicon Valley, with its impact-conscious culture (Geiger 2020), agri-food tech innovation is increasingly treated as unified, couched in socio-technical imaginaries of environmental sustainability. These tend to define environmental improvement in relatively narrow terms of resource use efficiency (Guthman and Butler 2023). Writing on technological attempts to improve the environmental impacts of livestock, for instance, Cusworth et al. (2022) describe two visions that align closely with appropriationism and substitutionism: "sustainable intensification," which aims to reduce the "ecological hoofprint" of cattle through breeding, diets, and pharmaceutical treatments, while ultimately leaving rural production intact, and "de-animalization," (1010) which seeks to replace animals with plant-based or lab-grown alternatives. Both visions, the authors note, "celebrate the power of modern science, governance and capital to deliver increased production with fewer emissions" (1010) and presumably reduced use of resources. Yet, as we show below through the illustrative cases of alternative proteins and digital agriculture, agri-food tech subsectors with a shared focus on resource use efficiency can nonetheless promote very different spatial imaginaries.

Decoupling from Land: The Promise of Alternative Protein

Perhaps no arena of recent agri-food innovation has captured more public attention than alternative protein. Utilizing a broad range of source ingredients, including legumes, insects, food waste, algae, fungi, microbes, and the cells of animals themselves, innovators in the sector employ both cellular and acellular biotechnologies, as well as more standard food-formulation processes (for example, extrusion) to produce a large array of protein-forward products. While many of these alternative protein products are plant-based simulacra—essentially the latest generation of veggie burgers—others are more technologically advanced: from the still-to-be commercialized cellular meats, using cultured animal biopsies to produce meat without the animals, to the multifarious protein powders synthesized from mycelium, microbes, and other microorganisms, using fermentation and other fabrication technologies for manufacture into consumer-oriented edibles.

While motivated by a range of concerns with animal agriculture, the core impulse behind much alternative-protein production is to produce enough protein to "feed the world" more efficiently and with less environmental damage and greenhouse gas (GHG) emissions than achievable with animals. Indeed, alternative-protein champions routinely articulate their environmental claims as comparisons with current modes of protein production, emphasizing the amount of water and land it takes for feed to produce edible and desirable protein from cows, pigs, or chickens compared to legumes, insects, or the many, many microingredients increasingly considered as viable sources of protein (Sexton 2018; Jönsson et al. 2019). In a typical example, the website of a simulated egg products company claimed that their process uses "less water, land and energy to achieve equal or better results when compared to current production practices" while providing end products that are more "consistent, reliable and sustainable."

Sometimes the spatial imaginary of such claims is only inferred, through persistent references to the feed-conversion ratio as a marker of efficiency and therefore, implicitly, land use (Hedberg 2023). Many alternative-protein companies assert that their products require less feed per unit of protein produced. The website of a producer of a cricket-based chip producer, for instance, stated not only that cows produce 100 times the GHG emissions of crickets (illustrated with an infographic of a cow flatulence and a subtitle of "someone's gassy"), but that crickets eat 1.7 pounds of feed for every 10 pounds cows eat to produce one pound of meat. The spatial implications of such a claim is just below the surface: animal feed has to come from somewhere and likely uses land for its production.

Countless actors in the sector make their spatial claims explicit, however, emphasizing the excessive amount of land used as the main problem with current ways of producing protein, echoing the rationales of vertical farming.

At an event on plant-based futures, a spokesperson asked how we feed 10 billion people, which means 56 percent more food without using more land. They asserted that if everyone in the world ate a plant based diet, "we'd have 5 billion more football fields of land that could be returned for us." Recounting food production's biggest impacts on environments, a representative of an accelerator referred to "how much land is used for grazing, and for producing the food that's used of the animals that we eat." In an interview, a maker of egg substitutes recollected being moved by research showing that

> the demand for meat, milk, and eggs was going to grow massively. Egg production would need to increase by more than 50 percent in order to be able to meet that demand, and the math just didn't add up. There's just not enough land or water in the planet to satiate that demand.

Even companies producing simulacra produced from land-based crops refer to land efficiency. On its website, another maker of simulated eggs averred to use 13 percent less land in making eggs from mung beans.

While many alternative-protein entrepreneurs and their supporters refer to the potential for land saving relative to conventional production practices, those pursuing the most high-tech avenues make this concern a core rationale, aspiring to decouple from land as much as possible. With a website claim that "it'll take several Earth's worth of livestock farmland alone to satisfy our appetite," a cellular meat producer promoted a wholesale switch to cultivated meat production in bioreactors, in order to "save 602 million acres of land to grow food and restore biodiversity." This promise of spatial decoupling is in large part premised on the increased speed with which cellular meat production is expected to proceed. Cellular meat companies regularly promise a three-week time horizon for growing cells, suggesting that their bioreactors could produce many rounds of meat in the time it takes to raise a single animal on land (Severson 2022). Likewise, several companies work with fungal mycelium for its ability to grow quickly in laboratories. One claimed on its website that "our processes allow us to produce our protein fast, growing the equivalent of 4,200 cows overnight" while another said it takes only "2–3 days to grow its mushrooms." By speeding the temporality of protein production, the logic goes, they can also save space. A report by the think tank Rethink (n.d., 28), which advocates for a speedy transition to indoor protein production, wrote that "single molecules are the simplest and cheapest outputs to produce using modern foods, with production cycles 100 times faster than growing animals."

At the extreme end of this spatial imaginary are at least two companies that have claimed to make protein from air. Promising direct CO2 reduction in addition, one aspired to the total elimination of land-based production, claiming on an early version of its website the ability to make protein "so pure it is literally born out of thin air." Their processes, the website continued, allow them to "completely disconnect from agriculture." Its 2023 website stated that the product "does not require land and the agriculture needed happens on a cellular level." A headline announcing Air Protein's partnership with agribusiness giant Archer Daniels Midland (ADM) said they could now make "landless" protein out of CO2 (Wolf 2023).

In short, the socio-technical imaginary of alternative protein is one of minimization and containment, as if the core environmental problem of agriculture is its extensive use of land and a near total decoupling from land-based resources is possible. Notably, the impulse to bring as much production as possible indoors, in highly contained spaces, extends the logic of Goodman et al. (1987) substitutionism. While for Goodman et al. detaching food production from rural spaces was a byproduct of increasingly cheap and controllable indoor production, in the newest iteration of food tech, the reduced spatial footprint of contained production often features as a key means of environmental improvement. The byproduct has become the aim.

Extending the View: The Promise of Digital Farming Tools

This imaginary could not be more different than the one undergirding another key area of environmental innovation coming from the tech sector: digital farming. Digital farming technologies include sophisticated sensors to monitor field conditions, drones to remotely sense production from above, machine learning and AI to process these many incoming data streams, geospatial imaging to visualize and monitor production, variable rate technology to automatically apply inputs at differential rates, and much more. As with the alternative-protein sector, digital farming is largely animated by promises of improved efficiency. By putting ever more granular production data at farmers' fingertips, proponents argue, digital farming allows for higher yields while reducing use of water, fertilizer, herbicides, and other inputs (Klerkx et al. 2019).

And yet, rather than visualizing a future in which production is spatially concentrated, freeing-up land for other uses, digital farming envisions the perpetuation of today's extensive land use for agriculture. In an interview, an executive at a company that supplies data storage solutions for digital agriculture explained the primary challenge facing agriculture this way:

> You have to produce a whole lot more food, a lot more calories off of effectively the same amount of usable space with fewer inputs … Anybody that can help the industry be more efficient broadly, whether that means getting, improving yields in an existing operation, or reducing the environmental impact of some production of some crop, or reducing the input requirements, any of those things that are going to help solve that macro problem of getting more out of the same amount with less inputs. So that I think is the common thesis around why you see a lot of dollars flowing into [digital agriculture].

Technology thus allows the same land area to produce far more with fewer inputs. In fact, when asked what he thought were the most ambitious and potentially disruptive "moonshots" within agri-food tech innovation, he answered that it was "figuring out how to grow things in regions where they don't traditionally grow." Enhancing crops so that they are resistant to climate change and can grow in more northern locations, he added, is highly impactful because "it's effectively bringing new arable land into production if you can make the plants grow in new places." So far from thinking about decoupling production from land or other resources, his concern was with how technology could bring more land under production, a starkly different spatial imaginary from that put forward by alternative protein companies.

In this extensive spatial imaginary, huge expanses of farmland are necessary but can be farmed more sustainably through microlevel management with digital tools. Precise digital information, the logic goes, encourages farmers to target their treatments to hotspots only, thereby reducing the use of precious resources and toxic inputs alike (Bronson and Knezevic 2016). The idea that microlevel farm management can lead to vast sustainability improvements when applied across large scales has been a major legitimizing discourse of precision agriculture since it first emerged in the 1990s (Wolf and Wood 1997). When the field of smart farming exploded in the mid-2010s, industry started to make the case that it could manage the productivity of vast fields at even more microlevels for even greater sustainability improvements. Speaking at a 2019 ag-tech conference in San Francisco, for instance, an executive at a multinational agricultural input supplier explained the ongoing evolution within the digital farming industry: "we've historically managed whole fields, and now we're managing field zones, pretty soon we'll be managing one plant at a time." This sentiment was echoed by an executive at a major farm equipment manufacturer during a panel on agricultural automation:

> The thinking in the business has evolved. We used to think about precision farming as improving the average. But the real panacea of precision farming is the management of individual plant and animal units to their maximum potential.

During a pitch session, an ag-automation startup founder connected this more fine-grained management to the pursuit of sustainability: "We must, and we really must, accelerate our move toward sustainable agriculture. And I see the best way of doing this is by ensuring that every single plant on every single acre grown in Europe and the U.S. fulfills its genetic potential." From this perspective, enormous swaths of farmland are still essential to meeting human needs, but an ever-shrinking scale of management can ensure maximum yields with minimum inputs.

Digital agriculture simultaneously requires and enables large-scale production. It requires scale in part because, like many other production technologies that came before—think massive harvesters or herbicide-resistant seeds—most digital farming technologies are designed to function only in large, monocultural fields (Rotz et al. 2019; Bronson 2022). Scale is also required because the additional costs of such technological inputs are only affordable when implemented at scale. The continual rollout of expensive, yield-enhancing technologies over the years has led to both increasing production costs and declining crop prices (Cochrane 1979), with the result that most farmers now operate on very narrow profit margins and only those operating at scale can afford to stay in business.

At the same time, digital farming also enables large-scale production. While past technologies have contributed to farm size increases, precision agriculture explicitly responds to the problems that result from this increasing scale of production. Its very premise is that "the farm" is now too big for the farmer to know it intimately. Only through the precision vision of high-tech sensors and color-coded geospatial maps can farmers understand what is happening in their own vast fields. Thus, on the one hand, digital farming responds to farms getting bigger, while, on the other, it encourages on-going farm size increases by making such vast operations more manageable. These digital tools facilitate remote farm management of massive properties (Visser et al. 2021). Like the other appropriationist technologies discussed by Goodman et al. (1987), digital agriculture thus anticipates and bolsters a future food system in which expansive, rural production is the norm.

This expansive spatial imaginary is less intuitively virtuous than the compact vision forwarded by CEA or alternative protein, and it therefore requires vigorous defense. Our interviewees would at times spontaneously embark on such a defense, using spatial rhetoric to invalidate the contained imaginary of other technologies as a pipe dream that could never come to pass, or emphasizing their hidden environmental footprint (see below). An executive at a digital agriculture startup, for instance, in the middle of an explanation of why big data and AI are the future of agriculture, took a detour to comment on vertical farming: "It doesn't matter how many indoor greenhouses or how many vertical skyscraper farms we have. I'm not convinced that that's going to have any really big impact on a sustainable food future." An ag-tech consultant, meanwhile, when asked about the technologies with the greatest potential to produce both economic disruption and social impact, launched into a spontaneous and gleeful diatribe on the impracticalities of vertical farming for growing most crops:

> So indoor ag, right? Darling of investors. Second, maybe only the plant-based meat. I got an e-mail this week, an investor wants to know what I think about the feasibility of indoor grown alfalfa. [Laughs.] And I was like, "Excuse me?" It doesn't make sense for baby greens that you buy for $12 a box at the grocery store. How is it going to work for cow food? [...] Outside, there's free sunshine and inside, yes, the cost of LEDs keeps coming down, but you need, even if you're doing solar, the surface area [...] You basically need the full roof area times 20 in solar arrays. Think about the land use implications of that.

In critiquing CEA companies for promising a small footprint when in fact they would need far more space just to fuel their solar arrays, this consultant was also critiquing their entire environmental vision (and in the process implicitly defending her own more expansive vision). This critique also calls into question the use of the spatial, or spatial efficiency, as a proxy for environmental improvement.

Beyond Space

In envisioning the future of food, the contemporary agri-food sector is effectively offering two very different versions of environmental change. Cellular and acellular food technologies promise to minimize the use of land, while digital agricultural technologies promise to use existing rural production landscapes more efficiently. Such divergent trajectories have long existed in food and agriculture, as captured in Goodman et al. (1987) classic account. However, whereas the appropriationist and substitutionist technologies they describe were driven by different business interests and served different constituents—namely farmers versus food manufacturers—they are now lumped together under the auspices of Silicon Valley and its aspirations of environmental improvement.

Nevertheless, the fact that the sector is pursuing technologies with highly divergent notions of how the future of food production should be situated suggests a potential mismatch of vision and problem. Ultimately, what tech vendors can contribute is improvements in efficiency (Guthman and Butler 2023), improvements that often occur against a backdrop in which much else is left unchanged. Indeed, as other scholars have pointed out, technologies of containment rely heavily on resources produced or extracted from elsewhere: feed ingredients, metal for the bioreactors, countless solar panels or other energy resources, and at least some land for situating the vertical farms and indoor bioreactors (Guthman and Biltekoff 2021; Helliwell and Burton 2021; Bomford 2023; Hedberg 2023). Purveyors of cellular meat, CEA, and other indoor solutions have thus yet to arrive at an important conclusion reached by Goodman et al. (1987)—that intensive, contained production still depends heavily on spatially extensive, rural production and extraction. As such, these technologies amount less to saving space, sparing land, or even using resources more efficiently than reconfiguring where and how production takes place and invisibilizing the massive energetic and biological extraction they require (Mouat et al. 2019; Jönsson 2020; Reisman 2021).

Digital tools for more efficient agriculture, meanwhile, continue a long legacy of encouraging overproduction without replacing harmful inputs. Rather than providing farmers with alternative treatments, digital agriculture technologies generally only visualize, diagnose, and inform decision-making on how to apply existing treatments (Guthman and Butler 2023). While wreathed in legitimizing claims about their ability to reduce the use of toxic agri-chemicals, therefore, one of their primary effects is actually to further lock in intensive, chemical and fossil fuel-dependent agriculture (Wolf and Buttel 1996; Wolf and Wood 1997). Precision management of input applications can be framed as an environmental good only in a future spatial imaginary in which high-yield production across a massive land area is a virtual inevitability.

Efficient use of space, in short, is a poor proxy of environmental improvement and yet one to which the agri-food tech sector as whole has ascribed. Ultimately, then, both technological subsectors mistake a spatial imaginary for a socio-ecological one. Here we are reminded of a critical point made by Born and Purcell (2006), who argued about the folly of assuming that "local food" is more sustainable simply because of the scale at which it is bought and sold. Analogously, both of these tech-led approaches for addressing the sustainability of food production conflate a spatial imaginary with socio-environmental improvement. In our view, a socio-technical imaginary rooted, say, in biodiverse flourishing would likely not fetishize a spatial ordering at all, but instead attend to the myriad practices that harm or help the quality of soil, water, and the plant, animal, and human bodies whose lives are so entwined with food production—now and in the future.

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References

Bomford, M. 2023. More Bytes per Acre: Do Vertical Farming's Land Sparing Promises Stand on Solid Ground? *Agriculture and Human Values* 40(3):879–895. doi:10.1007/s10460-023-10472-0.

Born, B., and M. Purcell. 2006. Avoiding the Local Trap: Scale and Food Systems in Planning Research. *Journal of Planning Education and Research* 26(2):195–207. doi:10.1177/0739456X06291389.

Borup, M., N. Brown, K. Konrad, and H. Van Lente. 2006. The Sociology of Expectations in Science and Technology. *Technology Analysis & Strategic Management* 18 (3–4):285–298. doi:10.1080/09537320600777002.

Bronson, K. 2022. *The Immaculate Conception of Data: Agribusiness, Activists, and Their Shared Politics of the Future*. Montreal, Canada: McGill-Queen's University Press. doi:10.1515/9780228012535.

Bronson, K., and I. Knezevic. 2016. Big Data in Food and Agriculture. *Big Data & Society* 3 (1):2053951716648174. doi:10.1177/2053951716648174.

Chateau, Z., P. Devine-Wright, and J. Wills. 2021. Integrating Socio-Technical and Spatial Imaginaries in Researching Energy Futures. *Energy Research & Social Science* 80:102207. doi:10.1016/j.erss.2021.102207.

Cochrane, W. W. 1979. *The Development of American Agriculture: A Historical Analysis*. Minneapolis: University of Minnesota Press.

Cusworth, G., J. Lorimer, J. Brice, and T. Garnett. 2022. Green Rebranding: Regenerative Agriculture, Future-Pasts, and the Naturalisation of Livestock. *Transactions of the Institute of British Geographers* 47 (4):1009–1027. doi:10.1111/tran.12555.

Davoudi, S., J. Crawford, R. Raynor, B. Reid, O. Sykes, and D. Shaw. 2018. Policy and Practice Spatial Imaginaries: Tyrannies or Transformations? *Town Planning Review* 89 (2):97–124. doi:10.3828/tpr.2018.7.

Feola, G., M. K. Goodman, J. Suzunaga, and J. Soler. 2023. Collective Memories, Place-Framing and the Politics of Imaginary Futures in Sustainability Transitions and Transformation. *Geoforum* 138:103668. doi:10.1016/j.geoforum.2022.103668.

Fountain, H. 2013. A Lab-Grown Burger Gets a Taste Test. *New York Times*, August 5. https://www.nytimes.com/2013/08/06/science/a-lab-grown-burger-gets-a-taste-test.html.

Geiger, S. 2020. Silicon Valley, Disruption, and the End of Uncertainty. *Journal of Cultural Economy* 13 (2):169–184.

Goodman, D., B. Sorj, and J. Wilkinson. 1987. *From Farming to Biotechnology*. Oxford, UK: Basil Blackwell.

Gugganig, M. 2021. Hawai'i as a Laboratory Paradise: Divergent Socio-Technical Island Imaginaries. *Science as Culture* 30 (3):342–366. doi:10.1080/09505431.2021.1884217.

Guthman, J., and C. Biltekoff. 2021. Magical Disruption? Alternative Protein and the Promise of De-Materialization. *Environment and Planning E: Nature and Space* 4 (4):1583–1600. doi:10.1177/2514848620963125.

Guthman, J., and M. Butler. 2023. Fixing Food with a Limited Menu: On (Digital) Solutionism in the Agri-Food Tech Sector. *Agriculture and Human Values* 40(3):835–848. doi:10.1007/s10460-023-10416-8.

Hedberg, R. 2023. Bad Animals, Techno-Fixes, and the Environmental Narratives of Alternative Protein. *Frontiers in Sustainable Food Systems* 7. doi:10.3389/fsufs.2023.1160458.

Helliwell, R., and R. J. Burton. 2021. The Promised Land? Exploring the Future Visions and Narrative Silences of Cellular Agriculture in News and Industry Media. *Journal of Rural Studies* 84:180–191. doi:10.1016/j.jrurstud.2021.04.002.

Hincks, S., I. Deas, and G. Haughton. 2017. Real Geographies, Real Economies and Soft Spatial Imaginaries: Creating a 'More Than Manchester's Region. *International Journal of Urban and Regional Research* 41 (4):642–657. doi:10.1111/1468-2427.12514.

Jasanoff, S., and S.-H. Kim. 2013. Socio-Technical Imaginaries and National Energy Policies. *Science as Culture* 22 (2):189–196. doi:10.1080/09505431.2013.786990.

Jönsson, E. 2016. Benevolent Technotopias and Hitherto Unimaginable Meats: Tracing the Promises of in vitro Meat. *Social Studies of Science* 46 (5):725–748. doi:10.1177/0306312716658561.

__________. 2020. On Breweries and Bioreactors: Probing the "Present Futures" of Cellular Agriculture. *Transactions of the Institute of British Geographers* 45 (4):921–936. doi:10.1111/tran.12392.

Jönsson, E., T. Linné, and A. McCrow-Young. 2019. Many Meats and Many Milks? The Ontological Politics of a Proposed Post-Animal Revolution. *Science as Culture* 28 (1):70–97. doi:10.1080/09505431.2018.1544232.

Klerkx, L., E. Jakku, and P. Labarthe. 2019. A Review of Social Science on Digital Agriculture, Smart Farming and Agriculture 4.0: New Contributions and a Future Research Agenda. *NJAS - Wageningen Journal of Life Sciences* 90–91(1):1–16. doi:10.1016/j.njas.2019.100315.

Mouat, M. J., R. Prince, and M. M. Roche. 2019. Making Value Out of Ethics: The Emerging Economic Geography of Lab-Grown Meat and Other Animal-Free Food Products. *Economic Geography* 95 (2):136–158. doi:10.1080/00130095.2018.1508994.

Plenty. 2023. Our Mission. https://www.plenty.ag/mission/.

Rajan, K. S. 2006. *Biocapital: The Constitution of Postgenomic Life*. Raleigh, NC: Duke University Press.

Reisman, E. 2021. Sanitizing Agri-Food Tech: COVID-19 and the Politics of Expectation. *The Journal of Peasant Studies* 48 (5):910–933. doi:10.1080/03066150.2021.1934674.

Rethink, X. n.d. Rethinking Food and Agriculture. https://www.rethinkx.com/food-and-agriculture.

Rotz, S., E. Duncan, M. Small, J. Botschner, R. Dara, I. Mosby, M. Reed, and E. D. Fraser. 2019. The Politics of Digital Agricultural Technologies: A Preliminary Review. *Sociologia Ruralis* 59 (2):203–229. doi:10.1111/soru.12233.

Sadowski, J., and R. Bendor. 2019. Selling Smartness: Corporate Narratives and the Smart City as a Socio-Technical Imaginary. *Science, Technology, & Human Values* 44 (3):540–563. doi:10.1177/0162243918806061.

Severson, K. 2022. The New Secret Chicken Recipe? Animal Cells. *New York Times*. https://www.nytimes.com/2022/02/15/dining/cell-cultured-meat.html

Sexton, A. E. 2018. Eating for the Post-Anthropocene: Alternative Proteins and the Biopolitics of Edibility. *Transactions of the Institute of British Geographers* 43 (4):586–600. doi:10.1111/tran.12253.

Thomaier, S., K. Specht, D. Henckel, A. Dierich, R. Siebert, U. B. Freisinger, and M. Sawicka. 2015. Farming in and on Urban Buildings: Present Practice and Specific Novelties of Zero-Acreage Farming (Zfarming). *Renewable Agriculture and Food Systems* 30 (1):43–54. doi:10.1017/S1742170514000143.

Visser, O., S. R. Sippel, and L. Thiemann. 2021. Imprecision Farming? Examining the (In)accuracy and Risks of Digital Agriculture. *Journal of Rural Studies* 86:623–632. doi:10.1016/j.jrurstud.2021.07.024.

Watkins, J. 2015. Spatial Imaginaries Research in Geography: Synergies, Tensions, and New Directions. *Geography Compass* 9 (9):508–522. doi:10.1111/gec3.12228.

Wolf, M. 2023. Adm Partners with Air Protein to Make ‘Landless’ Protein from Co2. *The Spoon*.

Wolf, S. A., and F. H. Buttel. 1996. The Political Economy of Precision Farming. *American Journal of Agricultural Economics* 78 (5):1269–1274. doi:10.2307/1243505.

Wolf, S. A., and S. D. Wood. 1997. Precision Farming: Environmental Legitimation, Commodification of Information, and Industrial Coordination. *Rural Sociology* 62 (2):180–206. doi:10.1111/j.1549-0831.1997.tb00650.x.

Wolford, W. 2004. This Land is Ours Now: Spatial Imaginaries and the Struggle for Land in Brazil. *Annals of the Association of American Geographers* 94 (2):409–424. doi:10.1111/j.1467-8306.2004.09402015.x.