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# Speculating on collapse: Unrealized socioecological fixes of agri-food tech

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## Abstract

Circa 2023, after receiving much hype and investment, two agri-food technologies touted for their world-changing potential, bioengineered animal protein substitutes and vertical (indoor) farms, began to falter economically. Tech sector observers attributed the fall to typical hype cycle dynamics; this paper provides a deeper read. Based on research involving over ninety interviews with agri-food tech sector actors and observation at nearly 100 industry events, we show an unrealized socioecological fix as first conceptualized by Ekers and Prudham. As attempts at preemption, these technologies were able to attract excess capital to an area believed to be in need of fixing, and their backers anticipated and in some cases tried to promote the devaluation of legacy production systems. But the technologies on offer failed to become cost competitive in a timely way since legacy production systems continued to be productive and profitable. It was these new companies that became uncompetitive and overvalued, which in turn turned investments in them into bad ones. Ironically, the agri-food tech sector has eschewed a path which might have made their products competitive, which is social regulation of legacy production systems. Instead they effectively speculated that such systems would implode under their own contradictions.

## Keywords

Agri-food tech sector, alternative protein, vertical farming, socioecological fix, strategic devaluation

> Venture capital was suited to high-tech investing because it involved making long-term projections of the rate and direction of technological progress, and venture capitalists could appropriate large payoffs from their investments when their visions of the future turned out to be right.
>
> —Tom Nicholas, *VC: An American History*, p. 267

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> Nearly 20 years after the first vertical farm opened, with capital drying up like heads of romaine under an unrelenting California heat wave, one now has to wonder two things: Is it even possible to compete with the economics of outdoor farming? And how did investors think that they could find Silicon Valley-style returns in . . . lettuce?
>
> —Adele Peters, 'The vertical farming bubble is finally popping', *Fast Company*

Circa 2023, as pandemic fears began to calm and food delivery robots no longer seemed essential, a heretofore much-hyped agri-food tech sector began to show signs of flagging. This fall from grace was especially striking in the case of those technologies touted for their world-changing potential, those that were supposed to transform completely what food is and how it would be produced: bioengineered animal protein substitutes and vertical (indoor) farms. In the realm of alternative protein, Beyond Meat, whose wildly successful stock market debut in 2019 had buoyed hopes for the entire industry, saw its share price decline from over $100 a share in 2021 to under $10 a share by the end of 2023, while fellow plant-based burger company Impossible Burgers were quietly removed from the menu at McDonald's. Meanwhile, despite the USDA's regulatory approval of lab-grown chicken, the cellular meat industry continued to struggle with viability, including the prominent 2023 failure of cell-based sausage startup New Age Meats (Watson, 2023). In the realm of indoor farms, the casualties were even more spectacular: US-based vertical farming startups Fifth Season, AppHarvest and Aero Farms all filed for bankruptcy, while Elon Musk's brother's vertical farming company Square Roots paused commercial production and laid off most of its staff as it attempted a pivot to contract growing for clients (Lore, 2023; Peters, 2023).

Many reasons were given for these failures: the already commercialized plant-based burgers were just a wee bit too expensive, consumers realized they weren't that healthy, fast food joints couldn't handle the logistics of a menu item that doesn't sell that well (Reiley, 2022). As for vertical farms, capital costs were high, and margins were low if existent at all (Moss, 2023). In both domains investor interest had apparently soured. Some tech sector observers attributed the rise and fall of these flagship products as indicating the 'trough of disillusionment' of the Gartner Hype Cycle (Bayer, 2023; Marston, 2023). This model describes typical maturation dynamics of emergent technologies. An initial peak of inflated expectations, the model posits, is followed by the aforementioned trough, an inevitable low point of investor sentiment after which refinements in both the technology and expectations will lead to wider investment and adoption, although not to the degree previously hyped.

While acknowledging the truth of these accounts, in this paper we want to provide a deeper read – perhaps we might even say a first round post mortem (though only time will tell whether this is truly death or just a coma) – more relevant to the actual technologies being forwarded and the problems they were intended to address. These were no gadgets, some of which fall by the wayside (e.g. 8-track cassettes) while others (e.g. smartphones) become indispensable. Rather, these were pitched on the idea that they were urgently needed to forestall or replace an agri-food system nearing collapse, especially in relation to the rehearsed-to-ad-nauseum neo-Malthusian notion that the planet would too soon reach a human population of 10 billion. For that matter, they were also premised on the idea that only technology, rather than societal regulation, could address the multiple crises of the agri-food system in the face of climate change, soil damage, water shortages, animal abuse and more.

This was not the first time the tech sector had trained its sights on ecological systems in trouble. Between 2006 and 2011 the cleantech industry – which promised more environmentally sustainable technologies to fight climate change – attracted more than $25 billion in venture capital only to collapse having produced little return for its investors. While the demise of cleantech was also popularly attributed to the hype cycle, as well as the financial crisis of 2007–2009, scholars have suggested something else. In particular, Goldstein (2018) noted a mismatch of temporalities between the demands of venture capital for near term profits and the real time it takes for creative inventors to develop technologies that can meaningfully address energy needs, while Knuth (2017) posited that clean tech could not compete against a fossil fuel industry that was seeing especially low prices, thanks to a boom in unconventional extraction. Like Goldstein, we suggest that bioengineered protein and vertical farms suffer from a temporal mismatch, though one of slightly different kind. Building on Knuth, we suggest that these technologies did not sufficiently evidence realizable returns in relation to the industry they intended to disrupt. Developers of these technologies had expected to *preempt* a crisis of conventional food production by creating new infrastructures and innovative food products that would reshape life. Yet since that crisis failed to manifest in the ways they imagined – climate catastrophe was more than evident but the economics of food did not yet reflect that – these technologies effectively became nonviable and hence of less interest to investors.

This article is based on research into the Silicon Valley-oriented agri-food sector conducted between 2018 and early 2023. The agri-food tech sector as an investable domain emerged on the scene quite soon after the demise of cleantech, securing its existence as a sector with Monsanto's 2013 purchase of the Silicon Valley data company Climate Corporation. Since then, hundreds of companies producing a wide range of products have associated with the sector, from digital farming technologies and robotic harvesters, to probiotic soil amendments and low tech consumer packaged goods (Guthman and Butler, 2023). Our research involved over ninety semi-structured interviews with entrepreneurs, funders, conveners and sector observers, as well as participant observation at nearly 100 conferences, pitch nights, demo days and other industry events. (The quotes we use below are from interviews unless noted otherwise.) All of our interviews and some of our event field notes were transcribed and coded in respect to our research questions. Although our initial research questions largely focused on the narratives and imaginaries of Silicon Valley-style agri-food tech, such as their problem and solution framings, as the research progressed and we reached saturation on these questions, we followed the lead of our interviewees to also examine issues they raised related to the political economic dynamics of the sector. These latter questions took on an added urgency when in 2022 and 2023 the formerly booming sector began to falter, which was a development we could not have anticipated at the outset of the research. While this was due in part to the general negative effect of high interest rates on startup funding (Jin and Rattner, 2024), for agri-food technologies like bioengineered protein and vertical farming the problems were much more fundamental.

Convinced of the win-win promises of green capitalism, venture capitalists and entrepreneurs invested in bioengineered protein and vertical farming technologies were essentially anticipating the ruination of existing production systems as a path to profitability. They were, in effect, speculating on collapse. We situate this argument in relation to the dynamics of the socioecological fix first conceptualized by Ekers and Prudham (2017). We find three aspects of the fix particularly relevant: its ability to absorb excess capital, its tendency to displace and/or devalue existing industries, and its dependence on well-aligned temporalities to both fix problems and ensure profitability. While others studying the agri-food sector have noted its attractiveness to excess capital (e.g. Carolan, 2022; Sippel and Dolinga, 2023), we argue that profitability can only be realized, much less contribute to the broader effort to preempt crisis, if the other two conditions are in place: legacy production systems must show signs of failing, and they must do so in a timely manner. The significance of this unrealized fix for a sector convinced of its abilities to save the world and make money, too, is not negligible. In attracting so much attention as well as capital, these investments have in some sense side-lined other efforts that might more effectively address the multiple crises associated with conventional food production.

## Agri-food tech as socioecological fix

Of the many technologies and technological systems currently emanating from the agri-food tech sector, alternative proteins and vertical farming most attempt to remake food and farming by decoupling them from the existing conditions of production (Bomford, 2023; Jönsson et al., 2019). So-called de-coupling is supposed to address climate change, unsustainable resource use and the degradation of the biophysical basis of food production, including animal bodies, brought by existing production systems. That this aspiration is largely a chimera is not the focus of this paper (but see Guthman and Biltekoff, 2021; Guthman and Fairbairn, 2023; Jönsson et al., 2019; Reisman, 2021 and many others for how the production of something from nothing tends to invisibilize the source of production materials). Rather, we are interested in how these technologies work as socioecological fixes in relation to existing forms of food production (Ekers and Prudham, 2017). It is through this framework that we can begin to understand how it was the failure of anticipated ruin (Paprocki, 2022) to materialize that led to poor performance.

The notion of the socioecological fix borrows directly from Harvey's (1982) spatio-temporal fix. For Harvey, drawing on Marx, capitalism's central contradiction is a tendency towards over-accumulation such that more wealth is created than can be put to work profitably. This 'crisis' of over-accumulation can be (temporarily) fixed in two ways: by spatial expansion (colonialism being the paradigmatic example) or by switching capital flows into the creation of physical and social infrastructure that will contribute to returns in the future. In calling it a fix, Harvey was not only interested in how these processes fix a problem of stalled accumulation by absorbing excess capital; he was also interested in how they affect existing fixed capital – that which has been fixed in space by previous rounds of accumulation (Carton, 2019; Ekers and Prudham, 2017; Knuth, 2017). In opening up new spaces of accumulation for newer industries the spatial fix frequently devalues the fixed capital of legacy industries or regions, although these may already be losing value through declining profit margins.

Expanding on Harvey (1982), Ekers and Prudham (2017) conceptualize the socioecological fix as addressing not only crises of over-accumulation, but also O'Connor's (1989) second contradiction of capitalism – the tendency of capital to ruin (or 'underproduce') its own conditions of production. Since capital is generally incapable of producing the biophysical basis on which it relies, it tends to use up or degrade the ores, soil, water and so forth that underpin so much production. Among other things, these essential resources can become more expensive, eventually spelling what Moore (2015) calls the end of cheap nature. Socioecological fixes are therefore efforts to restore the conditions of production or otherwise remake them, while also addressing problems of over-accumulated capital by finding new productive outlets (Castree and Christophers, 2018; McCarthy, 2015; Surprise, 2018). They are metabolic process involving both the production of space *and* transformation of socionature, often pursued to make capitalism more environmentally sustainable while also creating economic opportunities for capital (Carton, 2019; Ekers and Prudham, 2017: 1381; Fletcher, 2012; Knuth et al., 2019; Rudolph, 2023). In the latter way, they share similarities with 'disaster capitalism' in which acute crises, for example, floods, hurricanes, war and so forth create new bases for accumulation (Fletcher, 2012; Klein, 2007; Knuth et al., 2019; Reisman, 2021). The difference, as we see it, is that socioecological fixes are often pursued preemptively in expectation of future ruin, or the endogenous collapse of existing systems, as opposed to the 'surprise' or exogenous aspect of disaster or catastrophe.

Socioecological fixes can take multiple forms, however, and are undertaken by multiple kinds of actors. Infrastructural development, for example, is generally undertaken by the state, ostensibly through taxation of over-accumulated capital (Harvey, 1982; Sayre, 2010). Private sector socioecological fixes are more varied. There is a world of difference between accumulation by dispossession as a form of socioecological fix, in which privatizing and assigning monetary values to nature is supposed to save it (Heynen et al., 2007; McAfee, 1999), development of financial instruments intended to hedge on climate risk (Fletcher, 2012; Johnson, 2015) and green enterprise in which capital markets products or processes intended to replace existing modes of delivering goods and services. Capital has no singular interest in socioecological crisis, in other words, and responses follow from how problems affect different factions of capital (Carton, 2019).

Accordingly, such fixes need not necessarily materially change the conditions of production. Following directly from Ekers and Prudham (2017), Carton (2019: 757) notes an ideological dimension of the socioecological fix, such that certain actors may address public concerns *performatively* without fixing the problem itself. In the case he recounts, Exxon deployed modelling of the impacts of negative emissions technologies to promise eventual net zero emissions. This enactment of 'a political economy of deferral' was effectively an attempt for Exxon to maintain their fixed capital and continue business as usual. It is also possible to fix socioecological problems through regulation without addressing the underlying biophysical conditions. Instead, regulation makes current modes prohibitively expensive. Rudolph (2023), in fact, sees societal regulation as essential for renewable energy transitions precisely because renewable energies are currently not price competitive with fossil fuels. In different ways, Carton and Rudolph draw attention to the ongoing practices of legacy industries in relation to socioecological fixes.

To be sure, socioecological fixes, like spatio-temporal fixes, are more likely to create economic opportunity for new segments of capital by devaluing existing segments (Carton, 2019; Ekers and Prudham, 2017; Knuth, 2017). In this sense, fixes are often a zero-sum game, not really amenable to win-win possibilities. Indeed, for some green capitalists, devaluation of existing industry is not just an effect of the socioecological fix, but the name of the game. They embrace a Schumpeterian vision in which the 'creative destruction' of older, polluting industries is morally good, perhaps joining social movement actors through what Knuth (2017) calls strategic devaluation. Strategic devaluations are different than when, say, climate change happens to devalue an industry, whether through damage to the built environment or poor profitability, either of which can render assets less valuable (Johnson, 2015; Sayre, 2010). Strategic devaluations entail purposeful action – whether economic, discursive or political – aimed at taking down legacy industries or production systems. Knuth (2017) cites both the disruptive innovation of cleantech and the activism of divestment campaigns, as examples of potential strategic devaluations aimed at the fossil fuels industry. For Carton (2019), the more immediate threat to fossil fuel capital is indeed social and political reactions against the industry and the policies to which that activism might lead (also McCarthy, 2015).

The previous discussion hints at the temporal dimensions of the socioecological fix – the 'extended temporal horizons for the realization of value' (Ekers and Prudham, 2017: 1377) – which some say, has been overlooked or underplayed in uses of Harvey (Carolan, 2022; Surprise, 2018). Fixes are all about anticipating futures and in acting on those futures creating what the future will be (Anderson, 2010). Drawing on Anderson, Carolan (2022: 1448) notes that investments in vertical farming are at least as much about time as space, as certain capitals try to anticipate the future by investing in the present. This echoes our opening epigraph, which points to the possibility of large profits if visions of the future turn out to be correct (Nicholas, 2019). Indeed, while all capitalist investment involves 'fictional expectations' about the future (Beckert, 2016), venture capital-style investment in ambitious yet unproven startups hinges particularly on the 'promissory conjuration' of profitable futures (Rajan, 2006: 118). Yet, realizing future value from these investment is not a sure thing, and Surprise (2018) in particular theorizes temporality as an obstacle to the smooth resolution of the second contradiction of capitalism. Those developing fixes may encounter disjunctures between the timing of a problem's manifestation relative to the timing of the fix, and both of those relative to the timing of the needs of finance capital. Surprise (2018), for example, asks if the fix of geoengineering can stave off the climate collapse in a timely enough way to reset conditions for capital. For Carton (2019), the temporal disjuncture between the scaling up of carbon removal technologies and current imperatives to address the climate, allows current emissions to persist, resulting in a deferral of mitigation action. And that says nothing about the temporal disjunctures noted by Goldstein (2018), between the shorter term demands of venture capital and the longer term horizon for a mitigation technology to be developed and rendered feasible.

Temporal disjunctures may additionally revolve on whether a technology is intended to be precautionary, preemptive or preparatory (Anderson, 2010). According to Anderson, precautionary action takes place before a condition becomes irreversible, whereas preemptory action takes place before it has emerged as a definitive threat (and preparedness involves the development of capabilities to respond should an event occur). For Anderson preemptive action is more proactive than precaution; rather than attempting to prevent a condition, preemption tries to actively intervene in it. And that means preemption 'unashamedly makes and reshapes life' (Anderson, 2010: 790). Based on that distinction, Surprise (2018: 1230) deems stratospheric aerosol injection a 'preemptive spatiotemporal fix' – an attempt to preempt crisis by intervening in climate directly, which is different than preventing the condition from emerging in the first place. Whether a fix can be precautionary, preemptive or preparatory therefore depends much on both the likelihood of an identified threat and the timing of its emergence.

As is undoubtedly evident by now, a great deal of the literature on socioecological fixes is concerned with climate change and efforts to address it, whether via geoengineering – with value generated by restored conditions of production (Surprise, 2018), insurance and reinsurance in which investors bet on catastrophe – with value generated by rents of higher premiums (Johnson, 2015), or cleantech renewable energy technologies – with value generated by technology rents (Knuth, 2017). Carolan's (2022) work on vertical agriculture is an exception, and we will return to his arguments below. While this work on socioecological fixes for climate change is broadly relevant to those for food production, there are some core differences. Agri-food systems both produce and are affected by climate change; moreover, climate change is but one of several threats to and precipitated by agri-food systems. Among other things that means that the technologies that interest us – those ambitiously transformative technologies of bioengineered proteins and vertical agriculture – may help thwart climate change, at least allegedly, but they are not designed to act on climate directly nor necessarily on the other systems in which they are embroiled. Instead they are attempts to *preempt* various crises (of climate, food security, toxicity, soil depletion, animal welfare and more) by creating substitutes for existing systems, to 'reshape life' in Anderson's (2010) terms. The temporal tension arises from the fact that developers and financiers of these substitutes imagine a future in which these technologies will be necessary to sustain life. They anticipate ruin, but not in the sense of Paprocki (2022) who emphasizes processes of expropriation in the vein of accumulation by dispossession. Instead, in the vein of green enterprise, they create products and systems that they believe will heroically replace those exhausted and destructive production models currently collapsing under their own weight, and in doing so prevent future ruin.

In what follows, we show why these preemptive technologies of the agri-food tech sector have not been successful as socioecological fixes. Building on three essential aspects of the socioecological fix, we show, first, that that they were able to attract excess capital to an area believed to be in need of fixing, second, that their backers anticipated and in some cases tried to promote the devaluation of legacy production systems, but that, third, the technologies on offer failed to become cost competitive in a timely way. Since legacy production systems continued to be productive and profitable, it was these new companies that became uncompetitive and overvalued, which rendered bad the investments in them.

## Giant pools of money

One of the functions of the socioecological fix is to absorb excess capital, the giant pools of money that have flooded the global economy under neoliberal financialization. That can lead to financial positions that may otherwise seem nonsensical. Johnson (2015) writes, for instance, on how the reinsurance industry, itself a product of excess capital, paradoxically bets on catastrophe to fixed capital on the basis that it will eventually obtain higher rents in the form of insurance rates. This 'slosh pot' of money found its way to the agri-food sector, creating what Sippel and Dolinga (2023: 476) call an 'agri-food tech investment rush'. Total investment funding flowing to agri-food tech increased over tenfold, from an estimated $3.1 billion in 2012 to $51.7 billion in 2022 (AgFunder, 2022). Carolan (2022: 1457) argues that vertical agriculture alone served as a spatial and temporal fix for superfluous capital flowing from overheated real estate and stock markets – a means of 'parking excess equity in pursuit of future returns'.

Our research participants, too, repeatedly suggested that agri-food tech in general acted as a sink for otherwise aimless capital. When asked why he thought investors were suddenly so interested in food and agriculture, an ag-tech startup founder explained, 'I think there's so much capital now in the world that they're looking for more and more homes for it. That's number one'. In answer to the same question, another ag-tech entrepreneur speculated that 'there's just too much capital out there chasing not enough opportunities. [It's the] saga of our times, I guess'. A maker of fermented foods we interviewed recalled how the initial success of the Beyond Meat IPO 'started getting investors salivating and then putting money that they didn't know what else to do with into food'. An entrepreneur developing non-animal-based textiles and materials spoke of people 'throwing stupid money at those companies'. Echoing this idea, an investment company executive, speaking at an event, described 'pockets of capital which are coming in from literally everywhere', including 'from very unsophisticated sources'. A vertical agriculture industry insider, meanwhile, vividly described the situation before the Federal Reserve began hiking interest rates in 2022 as one in which investors 'were throwing money at anything' and 'the VC's were pitching the entrepreneurs, not the other ways around' [. . .] 'Because money was free, and venture capital had nowhere to go. [. . .] It literally is like where do you put it?'

Investors in agri-food tech are diverse, however, and not all fit the description of dumb money seeking outlets. The same vertical ag professional made this point, commenting on news that vertical ag startup Plenty had received major funding from both venture capital fund SoftBank and from incumbent berry firm Driscoll's (Manning, 2020). Whereas SoftBank, in his view, was just capital in search of an outlet ('It's investment thesis is the Saudis gave us a ton of money and we need to spend it on something'.), Driscoll's is a strategic investor that sees vertical farming as a hedge in case conventional strawberry production becomes less profitable due to increasing pressure from pathogens and other issues facing the industry. ('So if they fail there, they have a backstop. That backstop is probably going to cost more, but it's going to mean that Driscoll's can still exist and so it's worth it to them'.) In other words, the over-accumulated capital thesis may apply better to venture capital than to the incumbent agribusinesses that also constitute prominent investors in the sector (Fairbairn and Reisman, 2024). Over-accumulated capital is also geographically uneven, and so, therefore, are the spatial fixes it produces. This same interviewee argued that because much of the 'free money sloshing around' is in the Middle East, this is also where many of the vertical farms are being built – a spatial fix that is also clearly a socioecological fix for a region that is water-strapped but sunlight-abundant.

This variation notwithstanding, bioengineered proteins and vertical farming operations, like other faddish investment objects before them, at least initially served the first essential purpose of the 'fix': absorbing excess capital. But if investors expected to see returns, the businesses in which they were dumping cash would have needed to eventually show profitability, and this – as the Driscoll's example above suggests – depended, to at least some extent, on the devaluation of the existing production models against which these technologies competed.

## Necessary devaluations

For these specific technologies to serve as an effective fix, both in a material sense and a financial sense, devaluation of legacy production models, whether its land-based agriculture (in the case of vertical farming) or conventional livestock production (in the case of cellular meat and other alternative proteins) is a necessity. Some in the sector expected devaluation to occur organically – as climate change, changing consumer demand or various environmental problems would make the existing production model less profitable and hence the fixed capitals of concentrated animal feeding operations (CAFOs) and broad field agriculture less valuable. Others actively aspired for devaluation. While such 'strategic devaluation' (Knuth, 2017) could have taken many forms, including government regulation (Rudolph, 2023) or even the discursive denigration of 'big food', startups attempted devaluation primarily as competing capitals, through the disruptive efforts of tech sector startups to replace existing systems.

The coming devaluation of conventional production systems was frequently framed as an inevitability. In their study of agri-food tech sector discourse, Sippel and Dolinga (2023) capture the hyperbolic language with which the problems of the existing food system were typically presented. Not only is the existing agri-food system framed as unsustainable, but so unsustainable that it simply cannot and will not continue along the same path for much longer, reaching a 'tipping point' or 'nearing the world's natural limits'. According to this discourse, conventional food production is failing in nearly all respects: 'increasing food production to the requested levels is simply not possible: current agricultural systems are unsustainable and inefficient; the advances from the Green Revolution and mechanization are exhausted; and rates of yield production are trending negatively' (p.480). The devaluation of existing production models, in other words, was already well underway.

The idea that legacy systems are so unsustainable that they will soon collapse under the weight of their own contradictions was echoed in many of our own interviews. As an agri-food tech incubator executive we interviewed explained, for instance: 'There's going to be, at some point, there's going to be some sort of environmental limitation for producing this meat. So we have to have these alternatives ready, and have to have just more efficient ways to get people the protein that they want'. In these accounts, the (undeniable) ecological unsustainability of existing agricultural production models was often conflated with the (far less certain) economic unsustainability of the legacy industry.

Many within agri-food tech also saw themselves as actively working to replace existing models of food production. These aspirations were particularly prominent within the alternative protein sector, where idealistic and profit motives intermingle freely, and entities such as The Good Food Institute advocate for plant-based, fermented and cellular protein startups in an explicit effort to replace a livestock industry which they see as unsustainable and inhumane. Promoters of cellular agriculture frequently described it as an inherently more efficient way to produce meat, and as therefore destined to undermine animal agriculture (Helliwell and Burton, 2021). A prominent advocate for cellular meat, for instance, told us in an interview: 'the reality is that there are lots of ways to improve our food system. But the most important thing that we can do is find ways to retire farm animals, basically. And that is going to involve cell culture'. In another interview, a venture capital investor argued that plant-based meat could cause the conventional meat industry to 'implode':

> What happened in the dairy industry could well happen in the meat industry and probably *will* happen in the meat industry. Plants can do it better and for less, and ultimately that's going to undercut the meat industry. When you hit the point where the financial and operating leverage cannot sustain the business as it is, it'll start to implode, as did the dairy industry.

He went on to posit strategies by which the plant-based meat industry could 'facilitate' that implosion. While he used somewhat hyperbolic language to convey the possibilities of strategic devaluation – conventional milk has so far only lost about 15% of market share to plant-based milk, so it hasn't entirely 'imploded' yet (Good Food Institute, 2023) – the general sentiment that alternative protein would diminish or replace conventional production was widely shared within the sector.[1] On its website, tech sector think tank RethinkX (n.d.) makes a similarly strident claim: 'By 2030, the cattle farming industry will be bankrupt', it declares. 'By 2030, the number of cows in the U.S. will have fallen by 50% and all other livestock industries will suffer a similar fate'. Here the collapse of conventional production is predicted to take place just a few years into the future. Indeed, the timing of that decline, as well as the timing of commercial viability of the substitutes, is a matter of both considerable importance and considerable doubt.

## A matter of time

As investments in fixed capital, socioecological fixes lay the groundwork for future profitability. Vertical agriculture and alternative protein promoters expected their products and processes would eventually outcompete existing products and processes, in no small part because they imagined that the costs of production in legacy industries would inevitably increase. As put by one observer of the alternative protein sector,

> [It's] just this hypothesis that somebody is going to discover a way of creating protein that replaces the current model, and that the cost to produce the current model is going to become excessively or increasingly expensive. [. . .] air protein, I mean, again, it's the kind of thing venture capitalists love. They love these crazy ideas that can completely disrupt the economics of a supply chain.

But, in fact, transformative technologies such as cellular meat and vertical farming did not become cost competitive with the legacy industries they were expected to replace, and moreover, it appeared they would not become so any time soon. Some attributed this timing problem to the technology being insufficiently refined to bring costs down; others to the need to create infrastructure (read: fixed capital) to produce at scale.

Given the promissory environment in which they operate, many alternative protein advocates nevertheless performed bullishness that their products would soon become cost competitive with animal agriculture, particularly during pitches and other public-facing events. A representative of a venture capital firm speaking at a food tech event, for instance, argued that, while current fermentation infrastructure is limited in its capacity, rapid improvements to that infrastructure were going to cause cost to decline at a 'radical rate', similar to the revolution in computing technologies that occurred between massive mini-computers and modern day micro-chips: 'I think we'll continue to see incredible 10 fold decreases in costs over the next 5 years which will eventually make it very difficult for animal-based agriculture to have a chance to compete against these new technologies'. At a 2019 biotech conference, a cellular meat executive told the audience: 'Not only can we compete on sustainability and taste, we eventually will be able to compete on price'. He went on to describe how their first prototype lab-made sausage had declined in price from over $2,000 per sausage, to closer to $200 per sausage just months later, and projected that within 2-3 years the cost of the sausages would have declined another order of magnitude to around $20 each, enough to hit the market and appear on the menus of high-end restaurants. This narrative was accompanied by a slide projecting an exponential decline in product price over time, a vivid visualization of its rapid drive to future cost competitiveness. In this portrayal, the disruption of livestock agriculture was close at hand, drawing ever closer as the technology became more refined.

Our interviewees, however, were not always so sanguine. The challenge, according to some is that such capital-intensive production systems would require immense scaling to achieve lower prices. As one investor explained: 'Eventually when you scale in a transformative way, you can reach a lower cost. With a lower cost, then you can price it more appropriately to compete with animal ag'. But if scaling was the only way to make a return on investment, it would require even more investor capital and more time. As a plant-based protein entrepreneur explained:

> You're probably going to need a ton of investment. And then the only way to recoup that investment is to scale that technology, and scale the distribution of that product. [. . .] You can have the most revolutionary product and you can put years of research, and put a ton of money into it, to bring down the cost per pound. [. . .] [But] then the only way to make money is to scale that damn thing because you've got up to 200 million dollars in investment, you now have to go global. And you've got to go big, or you might as well just go home. [. . .] And so maybe also we have to be clear about what time horizons we're talking about. If you're talking about a solution for the next 10 years? The next 20 years? Most people will say we don't have more than 20 years before things get really bad. So we're working on pretty small time horizons, if you're talking about climate change.

Others we interviewed emphasized how refining the technology enough to outcompete animal agriculture would also take a very long time. Perhaps even *too* long from the perspective of investors, the planet or both. A fermented foods entrepreneur, for instance, argued that cellular meat would take a very long time to achieve price parity with conventional meat:

> The math looks horrible. And it will look horrible for a very, very long time and it will look horrible for a very, very long time after that. And that's when you're actually harvesting the entire cellular mass. And also, right, if it takes, say, and in a very optimistic world, it takes 20 years to get price parity. Not even price [parity], just similar price. Guess what? We're pretty fucked by then.

While he was talking about being 'fucked' from the perspective of climate change, longer time horizons also would have major implications for investor capital. A former alternative protein entrepreneur explained:

> When I took statements from a man unnamed, from certain CEOs in the States who were like 'We're going to bring an end to meat production by 2040'. I'm like 'What are you smoking?' [. . .] I hope that people will start to realize that because we have got to dig in, this is a long haul. We have got decades and decades before we really start to see. . . I mean, I would guess at this point, plant-based meat is still less than 0.5 percent of all meat consumption.

She went on to emphasize that these technologies can be a really bad bet for investors: 'At these early-stage investments, if [investors] think it's any different than walking up to a blackjack table or a roulette and putting it on then they're crazy'. A plant-based meat advocate voiced a similar concern:

> A report came out recently, funded by Open Philanthropy Project, that it's going to be extremely difficult to get the cost to be cost competitive with conventional animal agriculture. So, we don't even know if these things are going to be a reality [. . .] So there's a lot of hype around that and hype can be good, because it generates interest and I certainly have played my part in generating hype and will continue to do that [. . .] but this should terrify you if you're an advocate: billions of dollars are being poured into something that might not work.

Here the uncertainty surrounding the timeline for cellular agriculture reaching cost competitiveness was taken to its logical conclusion: perhaps it would not *ever* get there, leading to a devaluation not of the legacy meat industry but of the billions of dollars that have been poured into alternatives over the years.

## The collapse that never came

By 2023, the demise of vertical and cellular agriculture was being heralded in news articles with headlines such as 'How the multi-billion dollar vegan bubble finally burst' and 'The vertical farming bubble is finally popping' (Peters, 2023; Steafel, 2023). Though the startup failures that prompted these headlines mostly occurred after we had completed our research, concerns of overvaluation had already begun to emerge during our fieldwork. An alternative protein expert told us that many companies in the space were 'ridiculously overvalued'. A long-term observer of the sector lamented the ease with which completely unproven startups were now able to raise investor capital: 'It's like day trading. [. . .] People are writing 50, 100 million dollar checks to people that have a science experiment'. Equalling his scepticism, the vertical farming insider quoted earlier argued that many startups had no realistic path to profitability: 'It's a bad business. There is no serious path by which these companies can make money. It's sustained by a backwards optimism'.

A major concern was that agri-food tech might follow the disastrous path of cleantech before it. Indeed, a venture capital investor argued that it could easily face the same pitfall of investors with over-inflated return expectations being disappointed and consequentially turned off from the sector:

> [I] don't think it would be as crazy as a cleantech sort of draw, where people were putting in a lot of money and saying, you know what, this is one day, one day we're going to make money off of this. [. . .] It's already happening [referring to agri-food tech taking off]. And it's really happening in a scale and a cost that consumers are accepting and adopting. But is it possible that it wouldn't generate the return that they expect it would? I think very possible. I mean, I think food tech companies are incredibly overvalued right now.

Like Goldstein (2018), this investor suggested that cleantech failed in part because the timing of investment did not square up with time it would take to bring technologies on line in cost competitive way.

Yet perhaps the bigger lesson to be drawn from cleantech was that hitting the timing sweet spot – in which the new technologies become profitable before investors lose patience – isn't entirely within the control of startups. It also depends greatly on the state of the legacy industry they sought to overthrow. This connection was hinted at by a sector consultant:

> Look, our biggest challenge is, I don't want this space to look like cleantech in 2008. [. . .] You had a lot of people in that scene, in cleantech, based on the world that they wanted to see, based on the perceived market problem, which was a shortage of energy, as opposed to the market reality. And all it takes is one guy that learns to, that could drill sideways and unlock the fracking market, and all of your investment VCs are gone.

The last bit nailed an important truth, elaborated by Knuth (2017: 106): cleantech failed in large part because its 'model of disruption and its financing simply worked poorly against an entrenched fossil fuel industry, especially amid a boom in unconventional extraction that dramatically lowered commodity energy prices'. Cleantech simply couldn't succeed as long as fossil fuels were cheap and getting cheaper. The same could be said of these agri-food technologies which faced 'delays' in cost competitiveness and getting to scale. It wasn't just a matter of the alternatives not reaching price parity in time. It was also a matter of the ongoing economic viability of legacy systems. The promised 'implosion' of conventional agriculture had yet to materialize.

The cost of business-as-usual agricultural production, in other words, proved a crucial factor in determining the tech sector's ability to become cost competitive. Indeed, non-recognition of this simple truth made some investments particularly laughable. Describing a recent inquiry she'd had from investors thinking of investing in indoor alfalfa production in California, an ag-tech consultant recounted. '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?' The investor, she went on to explain, was thinking that the increasing droughts experienced by California might be an opportunity for indoor alfalfa production to feed the state's massive dairy herd. This tickled our respondent, who explained that 'we have a continental railway system in the United States that we built in the 1850s [. . .] and we have an entire other half of the continent that gets plenty of water'. As long as rail transport remains cheap, water on the east coast remains abundant and sunlight everywhere is free, she concluded, this project could never be cost competitive with simply importing alfalfa from other parts of the country.[2] On the flip side, a developer of an alternative weeding system argued vertical farming to be appropriate for the Middle East where resource constraints limit the possibilities for land-based agriculture, suggesting that under the right environmental and economic conditions it might make sense. But as long as conventional agriculture remains economically viable elsewhere, it still would be a partial solution at best.

Therein lies the rub: ‘Big Ag’ may be destroying its own conditions of production, but not to the point of making its products more expensive – at least not yet, and thus not to the point of seeing devaluation. That the crisis of industrial agriculture has not yet manifested economically (although it certainly has environmentally) owes in part to the externalities of production being absorbed elsewhere and in part to the geographical diffuseness and product variation of the industry so it is not vulnerable to a singular disaster. The agricultural industry has also proven itself highly adept at intensification, using successive rounds of mechanization, chemical innovation and biological modification to perpetually boost yields and keep food cheap (Goodman et al., 1987). The result of this ‘real subsumption of nature’ (Boyd et al., 2001) is that capital accumulation has continued apace even in the face of compounding environmental harms. To be sure, the costs of producing cheap food with existing fixed capital are far, far lower than the costs of scaling up the alternative, especially when the raw materials of systems remain cheap compared to building new infrastructures. It appears, then, that entrepreneurs and investors placed too much faith in the idea that these competing systems would collapse under their own weight and spell the end of cheap food (cf. Moore, 2015). When this collapse failed to materialize in a timely manner, the over-accumulated capital was forced to withdraw and seek other outlets. The fix, in other words, was not in yet.

## Towards devaluation otherwise

Both bioengineered proteins and vertical agriculture were originally poised to be exemplary socioecological fixes. More than other technologies emanating from the agri-food tech sector, they promised a remaking of food production, with expectations that such preemptive action could supply food more sustainably while existing food systems collapsed under their own contradictions. And so they absorbed a great deal of capital with a promise to replace legacy production systems, whose products would surely become too expensive relative to these new alternatives and seal the devaluation of an older, polluting industry. In effect, then, investors were speculating on collapse. But, alas, these new systems have yet to achieve cost competitiveness, and by all appearances they will not achieve it anytime soon. Contrary to the goal of the socioecological fix, it was the newcomer fixes that saw their value decline, not the systems they were positioned to replace.

In constructing the above case, our findings add new dimensions to the literature on socioecological fixes. First, we have extended it to a domain that has not been viewed through this lens: the green capitalism approach of the agri-food tech sector, which both offers solutions and addresses problems differing from climate fixes. Second, we have argued that the devaluation of existing industry is a necessity more than an expected effect of green capital fixes. As long as existing products remain cheap a new alternative will have great difficulty competing. Finally, we have shown that for socioecological fixes premised on the devaluation of legacy industry, temporality is key. Different than the temporal disjunctures emphasized by scholars of climate change, in which the urgent need is preceding development of workable and investable fixes, the temporal problem our research highlights is one faced by capital: the need for devaluation to happen in time.

On some level the outcome we highlight was not surprising: it is unclear that these technologies had a clear pathway to near-term success – the replacements are expensive, materially intensive and the public was not all that impressed. Add to that a tech sector culture that is driven by hype and the performance of crisis to attract investment (Fairbairn et al., 2022). To be sure, it appears that those promoting these technologies were convinced by their own performative talk, including the spectre of collapse of legacy systems on the immediate horizon. Adding to their misread, they conflated the growing environmental crisis of conventional agriculture with an imminent economic crisis of high costs.

It remains unclear under what conditions food grown with legacy systems would become more expensive and allow these preemptive technologies to take hold (assuming they are otherwise good ideas, which remains an assumption). One answer lies in a road that the tech sector and green capitalism more generally has deliberately not taken. It is strategic devaluation of the activist sort, whether campaigns to reduce consumption of legacy industry products (like meat) or, following Rudolph (2023), social regulations of these legacy production systems. Social regulation especially is exactly what would affect the costs of current production and thus lead to its devaluation. But the tech sector has quite conspicuously eschewed this road, believing instead that providing an alternative would be enough, even if it took time to get there. Many even align themselves with the very incumbent corporations responsible for big bad agri-food (Fairbairn and Reisman, 2024; Guthman et al., 2022; Howard et al., 2021), believing that this will enhance their abilities to become successful (and of course deliver the desired exits for their investors). This strategy is highly reminiscent of what the organic movement cum industry did and to the same effect. Organics became a niche market – highly recognizable but never put a major dent in conventional food and farming (Guthman, 2014).

The rocky path of vertical agriculture and bioengineered proteins reveals the shortcomings of entrusting the tech sector to address such critical and intractable problems. Rather than speculating on collapse, perhaps activists concerned with the future of food should heed the work of climate change activists and their efforts at strategic devaluation and take seriously what might be done to undermine those industries leading us to catastrophe. Other strategic devaluations are possible.

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## Notes

1. Importantly, devaluing legacy production models does not necessarily mean devaluing legacy corporations, many of which are eagerly entering the agri-food tech field (Fairbairn and Reisman, 2024; Guthman et al., 2022; Howard et al., 2021).
2. Though we don't generally use the same quote in multiple papers, this one is an exception. In the other paper, though, we use it to discuss the high resource and spatial requirements of vertical farming (Guthman and Fairbairn, 2023).

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