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# Zymurgeography? 11

## Biotechnological Ferments and the Risks of Fermentation Fetishism

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### Fermentation Matters

In the biotechnological age the manipulation of living matter continually transforms humans' relationships to the more-than-human world and opens up new possibilities for production. While the science of genetic engineering that typically exemplifies biotechnology in the twenty-first century is fairly new, fermentation, which humans have fostered for millennia, could be considered the first "biotechnology" (Bud 1993). Beginning with Louis Pasteur and extending into the twentieth century, fermentation became biologized, and what we now recognize as biotechology evolved in tandem with fermentation and fermentative industry. Now, when technologies of genetic engineering are more precise and more capable than ever, innovations in the biotechnology of fermentation continue to transform fermentative production. Unlike some of the earlier biologically informed adjustments to fermentation, these transformations affect more than efficiency and reliability. By altering the genetic code, protein expression, and metabolic pathways of microorganisms, they more fundamentally alter fermentation itself, expanding both the biological definition of the word and the role that it can play in transforming landscapes. These ferments produce more than alcohol and the other foodstuffs with which the word "fermentation" is still usually associated in common parlance; they produce fuels (and not just ethanol), pharmaceuticals, and sophisticated food substitutes.

Echoing some of the sentiments from when fermentation first became an object of biotechnological fascination in the mid-twentieth century, those in the new fields of synthetic biology and metabolic engineering have touted fermentation as capable of addressing some of the world's most pressing issues. They position fermentation as capable of not just breathing new life into agricultural landscapes and lifeways but also dealing with energy and medicine shortages and the environmental and animal welfare tolls of industrial dairy.

The contributors to this volume experiment with using fermentation as a metaphor and a way of theorizing landscape change. They are not alone in identifying fermentation's conceptual appeal. Other social scientists have recently taken to thinking of fermentation as a useful metaphor (Bobrow-Strain 2012; DuPuis 2015), particularly one that suggests a theoretical or political orientation that rejects untenable notions of purity and instead favors imperfection and constant change (Shotwell 2016). Although fermentation can be a productive metaphor to think with, it can also be unwieldy. And like the microbial metabolic process itself, fermentation's meaning is effectively inflected by those in the natural and engineering sciences. The shifting nature and meaning of fermentation contribute to discrepancies of understanding. While flows of and through microbes and their metabolisms are manipulated more quickly and more profoundly than ever before, other forms of fermentation—its traditional or "craft" forms—soar in popularity and visibility, and fermentation gains currency as a theoretical tool in the social sciences. These concurrent trends result in disparities between the ways in which natural scientists and engineers, typical consuming publics, and social scientists—who are perhaps just now beginning to take a serious interest in microbial matters—understand what fermentation is and does. In the politically fraught worlds of biotechnology and production, such disparities run the risk of setting the scene for future conflict.

This collection represents both a call to pay attention to the ways in which fermentative industry transforms landscapes and an exploration of whether fermentation provides a unique lens for theorizing landscape change, whether that change is specifically related to fermentative industry or not (see chapter 13, this volume). Both noble aims face risks related to a failure to engage more closely with fermentation's complex history and diverse—and diversifying—forms. Drawing on insights from science studies, analysis of synthetic biology, and metabolic engineering discourse, as well as findings from ethnographic fieldwork among "biohacking" community-based synthetic biologists, I argue that fermentation's essential complexity and contestedness pose significant challenges for attempts to understand it in any general sense or to apply it as a metaphor. Deriving theory from only certain of fermentation's forms can result in what I call "fermentation fetishism," which itself poses further risks worth considering. First, it may merely draw convenient parallels to fermentation by defining its scope based merely on forms that make a nice conceptual fit with existing ways of theorizing landscape change. In other words, it may simply be that certain of fermentation's forms are compatible with how we already think about landscape change, in which case its use as a metaphor is of little benefit. Second, and I think more important, is that it may contribute to an already prevalent narrow focus on familiar, traditional, or trendy forms of fermentation at the expense of developing a broader understanding of how fermentation's newest technologized forms also stand poised to transform landscapes in profound ways. Put succinctly, new meanings and applications of fermentation can come at the expense of a better understanding of fermentation itself.

Like Marx's commodity fetishism, this fetishism involves both the impression of equivalence and a collective forgetting or unawareness of the underlying grounds for this equivalence (see Marx 2004). For Marx, this superficial equivalence comes in the form of the exchange value of different commodities and at the expense of a forgetting of the essential incommensurability of these commodities' use-values and the origins of this value in labor. In this case it involves comparisons between various forms of fermentation and may come at the expense of attention to important process details: the bases for technical comparison, the ways in which bioengineering is pushing the limits of such comparisons, the human cultures of fermentation, and biotechnology's history and future likelihood of eluding control and inciting controversy. This fetishism already appears in fermentation discourse, and its presence showcases some of the dangers it poses for building better collective understandings of technoscience and production. If using fermentation as theory or metaphor is to avoid these dangers, it will necessitate remaining mindful of how bioengineered fermentation will likely continue to grow its capabilities and influence as the nascent field of synthetic biology grows and matures and the biological sciences tighten their embrace of engineering epistemologies (Roosth 2017).

To complicate a narrow or superficial conceptualization of fermentation, I begin by providing a brief history of fermentation as a biological and biotechnological object. Then I discuss the more recent rise of bioengineering, synthetic biology, and metabolic engineering and how they have transformed fermentation still further and produced a streak of fermentation fetishism.[1] I draw on ethnographic observations and interviews from grassroots DIY or community biology laboratories (or "biohackerspaces"), as well as select fermentation and metabolic engineering textbooks and academic articles.[2] My goals are to understand how fermentation is manipulated and deployed and to understand the implications and effects of these developments for understanding fermentation's potential, both for landscape transformation and as a useful metaphor for transformation itself—and to explore whether these two aims are at odds.

## From "Zymotechnology" to Synthetic Biology: A Brief History of Microbial Technoscience

The English word *fermentation* comes from the Latin *fervere*, which means "to boil." As this etymology indicates, the word first referred to the bubbly activity of alcohol and pickle production, the microbial source of which was unknown at the time. Brewers would recycle the slurry from fermentation tanks, recognizing its importance to the fermentation process and referring to it by such names as *yeste* and *godisgood* (White and Zainasheff 2010, xvi).[3] A debate developed about the underlying causes of fermentation, particularly as to whether it was a spontaneous process or one that was purely chemical or biotic.[4] Pasteur sought to settle the matter by devising controlled experiments using a sealed apparatus filled with a fermentable broth and sterilized with heat, ultimately demonstrating to the scientific community's satisfaction that fermentation was a biotic process carried out by single-celled organisms. Pasteur's studies culminated in a book, *Studies on Fermentation: The Diseases of Beer, Their Causes, and the Means of Preventing Them*, and his efforts definitively placed fermentation in the domain of the life sciences.[5]

The histories of modern fermentation and biotechnology are entangled well beyond Pasteur's path-breaking work. Fermentation deeply informed the original practical and conceptual development of biotechnology. Robert Bud (1993) describes the historical transition from fermentation technology, or "zymotechnology," to "biotechnology."[6] He explains how biotechnology, which eventually developed into a distinct field of technoscience combining conceptions of life developed within the still-young discipline of biology with engineering's emphasis on intervention and practical application, developed from a more limited set of practices concerned specifically with fermentation. Following Pasteur's breakthrough, fermentation grew into a large-scale industry as brewers hired biochemists to improve their products. They developed techniques for culturing pure strains of microorganisms, and modernized industrial fermentation and biochemistry evolved largely in tandem.

In the early twentieth century the word *biotechnology* first entered the English lexicon, and the fusion that it denoted informed both the theory and practice of working scientists (Bud 1993). Since that time biology—particularly at the cellular and molecular levels—has in many ways become an engineering discipline. At first connected with selective breeding and genetic improvement programs and later with genomics and more precise techniques of genetic modification (GM), biological engineering had many noteworthy achievements and developments in the twentieth century: artificial parthenogenesis (Pauly 1987); mammalian cloning and other advanced reproductive technologies (Thompson 2005; Franklin 2007); the polymerase chain reaction (PCR) (Rabinow 1996); full genome sequencing (Hayles 1999; Keller 2002); advanced techniques and technologies of cell culture (Landecker 2007); patentable genetically engineered organisms, including not only microbes but also plants and animals; and more precise gene-editing techniques, including the much-publicized CRISPR-Cas9, a remarkably precise and inexpensive genome-editing technology.[7] Through these and other developments, bioengineers have increased their ability to manipulate life at the cellular level and thereby rendered these organisms increasingly, albeit selectively, plastic (Landecker 2007; Murray 2018).

While the range of current bioengineering projects is broad, fermentation remains a major part of biotechnology's present. The emergence of the field of so-called "synthetic biology" has reinforced the presence of a tinkerer's epistemology—the conviction that the best way to know life is to manipulate it—in the biosciences (Calvert and Martin 2009; Calvert 2013; Roosth 2017). Spurred in part by the migration of a large number of PhD holders from engineering disciplines—including chemical, mechanical, and computer engineering—to the biosciences, synthetic biology focuses on building artificial biological organisms and systems. One major area of work among the several in synthetic biology—including, for example, building biological computers and creating de novo synthetic life forms—is the improvement of metabolic engineering (Stephanopoulos, Aristidou, and Nielsen 1998), an area of specialty that inherits the legacies of zymotechnology and chemical engineering and focuses on the manipulation of microbial metabolisms to produce high-value substances (Roosth 2017). Through efforts to use microbes as tiny protein factories and their metabolic pathways as production lines, synthetic biology and metabolic engineering are actively remaking and redefining fermentation.

According to what is probably still its most common biological definition, fermentation refers specifically to a metabolic pathway that produces ATP (adenosine triphosphate, or cells' primary energy source) in the absence of oxygen, an anaerobic alternative to oxygen-dependent cellular respiration. While ATP may be the cell's incentive for fermenting, the process also creates other (by)products: lactic acid (think sauerkraut or the "burn" of your muscles during intense exercise) or ethanol and carbon dioxide (think beer or champagne). As a result of the rise of biotechnology and the epistemic authority of its practitioners in defining biological concepts, this definition is now changing to include other processes, including modified protein expression and engineered metabolic pathways, both of which result in novel ways to produce desirable substances. According to the common definition of fermentation, these substances are beyond its productive capabilities. They include, for example, complex proteins like biopharmaceuticals and fragrances.

The present-day practice of modifying bacteria and yeasts to produce new desirable substances stretches back at least to the discovery of penicillin. This discovery opened up the possibility of producing large quantities of new substances using microbes as an input-output system. Before long, several different antibiotics were being produced in large quantities. Drawing on these innovations, Herbert Boyer, cofounder of then-young Genentech, in collaboration with California's City of Hope National Medical Center, developed a way to make an incredibly prized substance—human insulin—using similar methods (Genentech 1978).[8] Stanley Cohen and Herbert Boyer's (1980) patent for the production of insulin by genetic engineering has this to say about the technology of turning microbial metabolisms into productive forces: "Various unicellular microorganisms can be transformed, such as bacteria, fungii [*sic*] and algae. That is, those unicellular organisms which are capable of being grown in cultures of fermentation."

As genetic engineering became more established, academics and entrepreneurs began to use retooled microbial metabolisms to produce still more high-value substances. These developments were fueled both by the success of Genentech and their insulin and by major technical developments like the polymerase chain reaction, which allows the reproduction of large quantities of DNA (Rabinow 1996), and later CRISPR-Cas9, which allows cheaper precise gene editing than ever before. Ethanol of course was perhaps the earliest intentional product of human-directed microbial metabolism, but synthetic biologists applied bioengineering techniques to produce a range of other "biofuels," including a gasoline analog designed to replace car engines' combustible of choice without the corresponding need to change existing engine designs and fuel delivery infrastructures (so-called drop-in "biogasoline") (Foo et al. 2014). Synthetic biology has begun to gravitate toward the production of foods and fragrances (Hayden 2014), such as food additives and flavorings like vanillin or a sophisticated milk substitute suitable for vegans (Perfect Day 2016b). In significant biopharmaceutical breakthroughs, synthetic biologists have managed to use microbes to produce the antimalarial drug precursor artemisinic acid (Ro et al. 2006) and hydrocodone, an opioid (Galanie et al. 2015).

Fermentation textbooks that introduce the subject to students make clear that as bioengineering expands the range of microbial metabolic products, scientists and engineers have started referring to many different metabolic processes—not merely the anaerobic pathway of the classic biological definition—as "fermentation." Peter Stanbury, Allan Whitaker, and Stephen Hall (2014) place all fermentation practices on a continuum, from alcohol and vinegar production pre-1900 through the post-1979 genetic engineering and the production of "foreign compounds" using microbial cells. As the authors explain, "The production of alcohol by the action of yeast on malt or fruit extracts has been carried out on a large scale for very many years and was the first 'industrial' process for the production of a microbial metabolite. Thus, industrial microbiologists have extended the term fermentation to describe any process for the production of product by the mass culture of a microorganism" (Stanbury, Whitaker, and Hall 2014, 1).

Another textbook opens by stating that "fermentation has been known and practiced by humankind since prehistoric times, long before the underlying scientific principles were understood" (El-Mansi 2012, 1), and proceeds to describe how microbiology first shed light on and then eventually modified these ancient practices through bioengineering. By remaking microbial metabolisms, bioengineering is redefining fermentation itself. Fermentation is not merely a process of flux; it is also a process *in* flux. These changes have implications for anyone wishing to understand or use fermentation, including those who want to understand its transformative effects and metaphorical utility.

**Something New Is Brewing: Engineering and Crafting Equivalence**

The flux of fermentation, and the ways in which the word now unites more diverse efforts than ever under the same nominal umbrella, is significant because it produces a conceptual ambiguity that may impede communication and understanding among natural scientists and engineers, social scientists, and consuming publics. One example of this ambiguity in action is how bioengineering advocates skirt potentially controversial elements of their production process through superficial comparisons to other, more traditional or familiar forms of fermentation. Frequent comparisons among types of fermentation that create accessible and generally nonthreatening analogies for bioengineering are based on select technical elements, while also taking advantage of positive associations that are nontechnical in nature. This reinforces a superficial equivalence between different forms of fermentation and largely ignores or downplays other elements, like genetic engineering and the fact that many of the activities of synthetic biology and metabolic engineering only recently became classifiable as "fermentation" at all. Occasionally this practice veers into a more specific fermentative comparison, one example being brewing—or, even more specifically, "craft" brewing. This is not especially surprising given the intertwined histories of beer and microbiology, as well as the fact that brewing is a long-established technology and a popular and relatable touchstone for many consumers otherwise unfamiliar with fermentation. Using it as such a touchstone, however, also leverages support for what in the modern age are only loosely related forms of production, implicitly suggesting shared practices and values when in reality few may exist. It also fails to do justice to the diversity in brewing practices and values, which are already a site of both practical ambiguity and political struggle. The result is a gap in understanding and an analogy that risks yielding less clarity rather than more.

In the scientific literature many metabolic engineers describe their work as "fermentation," using the term's newer biological definition. Jay Keasling, a prominent synthetic biologist and metabolic engineer, is known for his production of biofuels and engineering baker's/brewer's yeast (*Saccharomyces cerevisiae*) to generate the antimalarial drug precursor artemisinic acid (Ro et al. 2006; Foo et al. 2014). His publications assert that "combining . . . natural fatty acid synthetic ability with new biochemical reactions realized through synthetic biology has provided a means to divert fatty acid metabolism directly towards fuel and chemical products of interest" and thereby "produce these products directly from abundant and cost-effective renewable resources by fermentation" (Steen et al. 2010, 559) and describe his efforts "to inexpensively produce the antimalarial drug artemisinin through a new fermentation process" (Hale et al. 2007, 198). Fellow biofuel producers Yanfeng Liu et al. (2015, 1109) argue that "significant socioeconomic benefits of microbial fermentation, such as environmentally-friendly processes and sustainability, have drawn the attention of researchers seeking to develop fermentation methods for chemical and fuel production." Christina Smolke is known for the production of opioids using metabolic engineering and also edited *The Metabolic Pathway Engineering Handbook*. Her publications describe her work as follows: "fermentation with engineered yeast is a scalable platform for production of complex plant alkaloids" (Galanie et al. 2015, 144) and "we developed baker's yeast . . . as a microbial host for the transformation of opiates . . . performing high-density fermentation" (Thodey et al. 2014, 837).

While those reading these papers are most likely knowledgeable about the practical differences between metabolic engineering and other ferments, in more public-facing communications metabolic engineers' technical references to fermentation can veer into specific comparisons to

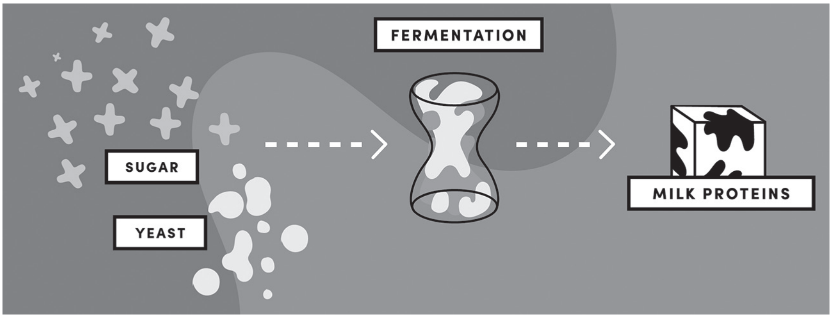


FIG. 38. This graphic depicting Perfect Day's production process shows how the term "fermentation" is used as descriptive shorthand for a complex production process that includes genetic engineering and departs from the conventional biological definition of the fermentation process. Courtesy Perfect Day.

traditions of food production and brewing. Keasling, in a CNN (2013) interview with Sanjay Gupta, said, "We use it [yeast/fermentation] to make bread, we use it to make beer, we use it to make wine. And it's been used for centuries."[9] San Francisco startup Perfect Day (formerly Muufri) provides a clear example of this type of comparison, and one worth exploring in depth, for the ways in which it showcases fermentation fetishism by skirting discussion of technical details and using fermentation as a shorthand signifier for its production process.

Perfect Day (2016b) explicitly compares its work making a vegan milk substitute to "craft" brewing: "Instead of having cows do all the work, we've developed a process similar to craft brewing. Using yeast and age-old fermentation techniques, we make the very same dairy proteins that cows make." The company reasserts but does little to expand the comparison in their FAQ section: "[Q:] Is your process kind of like making beer? [A:] Part of our process relies on old-world fermentation techniques—similar to making beer. We often describe it as dairy meets craft brewing" (Perfect Day 2016a).[10] Their mock-ups of bottles pictured on their website even say that their milk is "brewed with love in San Francisco" (Perfect Day 2016b).

These comparisons between recent bioengineering work and "Old

World" or centuries-old forms of fermentation like brewing reinforce conceptual connections enabled by the fluidity of fermentation but wade even further into ambiguous and tenuous equivalence. This targeted comparison positions bioengineering as akin to the traditional forms of food and alcohol production but comes at the expense of accurately or thoroughly characterizing either bioengineered or alcoholic ferments. Notably, Perfect Day's focus on this particular comparison also downplays other elements of their process, particularly the genetic engineering aspects and accompanying controversial associations with genetically modified organisms (GMOs). Considering the controversy that has often surrounded these technologies, reluctance on the part of consumers to accept GM methods for a broader array of foods and fragrances could prove a substantial obstacle to success (see Shiva 1997; Schurman and Kelso 2003; Jasanoff 2005; and Parthasarathy 2017). In the United States and perhaps even more so in Europe, consumers have proven wary of claims that GM technologies are desirable or their products safe for human consumption, despite broad scientific consensus that they are (National Academies of Sciences, Engineering, and Medicine 2016). Many of my research participants who are themselves engaged in genetic modification interpret this wariness as indicative of a lack of trust or knowledge and a conflation of the different types of, uses for, and threats posed by GMOs (interview, October 17, 2018; interview, October 15, 2018; interview, August 8, 2018).

In acknowledgment of the ways in which consumer concern seems to have focused increasingly on GMO consumption, Perfect Day provides assurance that no genetically modified organisms will be present in finished products. This briefly addresses concerns over the effects of GMO consumption while ignoring other facets of their creation and use. Further, while one can find this information on the company's website, it is relegated to their FAQ section, as part of a negative response to the question, "Does your milk contain GMOs?" (Perfect Day 2016a). Their homepage meanwhile describes this process as simply "cultivat[ing] . . . yeast to produce dairy proteins" and as using "age-old fermentation techniques" (Perfect Day 2016b). In this way, leveraging comparisons to "age-old" fermentation presents the technology in a way that avoids any discussion of some of the process's more controversial elements. These elements include other drivers of public backlash against GMOs—like the aggressive use of intellectual property protections or large capital interests' growing control over food production—as well as the broader landscape changes, both social and physical, that would result from reorganizing existing "ecologies of production" (Paxson 2012, chap. 2) around bioengineered microbial metabolisms. Overall, the comparison to traditions of fermentation and cultivation limits the scope of activities under consideration.

Perfect Day's comparison implies commonality with a seemingly specific and currently popular form of fermentation: craft brewing. But what makes their process like "craft" beer production? A couple of different sources provide clues as to how difficult the idea of "craft" is to pin down. The Brewers Association (BA), which certifies brewing operations with its "Independent Craft" certification and seal, defines craft beer producers based on the criteria of production volume, independent ownership, and the apparently all-inclusive focus on "traditional or innovative brewing ingredients" (Brewers Association n.d.). Discussing the concept beyond the beer industry and drawing from a variety of sources, Colin Campbell (2005) notes that "craft" production often carries associations of small scale, design oversight, and authenticity.[11]

Vague as these criteria are, almost any new metabolic engineering endeavor can claim similarity to craft brewing based on them. Production volumes for experimental ventures are going to be small, even if their ultimate aspirations are large. Startup companies like Perfect Day and craft brewing operations alike tend to be little. They are staffed by a small number of persons and generally overseen by just a few. The ownership criterion for craft breweries is to indicate that they are not majority-owned by the small collection of massive "macro" brewing corporations. Building a different kind of "brewing" operation using a venture-capital startup model also matches the criteria. The last BA criterion is both vague enough to apply almost regardless of brewing operation and representative of precisely the line that Perfect Day and others who compare bioengineered ferments to "age-old" forms of fermentation try to walk. Fermentation is a traditional process, this is merely the latest innovation, and it's an innovation to re-create a familiar product. Relatedly, authenticity is a difficult concept to judge in any case, especially in any industry that openly praises innovation. While BA does provide a few other, lower-tier "concepts related to craft beer and craft brewers," these are also vague and generally reinforce the three major criteria.

Overall, the fact that the definitions of "craft" and "craft beer" are, like that of fermentation, fluid and a bit unclear helps Perfect Day's case. Even if the fit is loose, who's to say that what they are doing isn't indeed "dairy meets craft brewing"? Perfect Day's approach takes advantage of conceptual fluidity in more ways than one and shows how taking advantage of such muddy concepts creates the impression of similarity and circumvents potentially ethically or politically fraught topics, which may also include a deeper elaboration of the technical processes involved and the social networks—commodity chains, production skills, and regulations, for example—required to sustain them.

### Differences That Make a Difference: Fermentative Ethos and Arts of Distinction

Comparisons between forms of fermentation can be less confounding when they engage the technical and practical distinctions between different forms of fermentation. Rather than focusing on superficial likenesses, these efforts more openly take on questions of technics (technical details), scale, and economics and thereby provide foundations for less fetishistic and more substantive discourse about fermentation's different forms. Drew Endy, Stephanie Galanie, and Christina Smolke (2015, 2) provide one such example, pointing out that "there are differences between industrial bioreactors and 'home-brew' fermentation." They conducted an experiment that illustrates how comparisons between different forms of fermentation break down in practice, and they did so by attempting to use a yeast engineered to produce an opiate, thebaine, under homebrew fermentation conditions. Their results suggest that the practical differences between forms of fermentation really matter—in other words, they are differences that make a difference (Bateson 1972).[12] According to Endy, Galanie, and Smolke (2015, 2), "We used yeast that make an English ale as a positive fermentation control. We observed no production of thebaine and miniscule [*sic*] amounts of reticuline, an upstream biosynthetic intermediate, in home-brew fermentations; the positive control was palatable. We suggest that additional technical challenges, some of which are unknown and likely unrelated to optimized production in large-volume bioreactors, would need to be addressed for engineered yeast to ever realize home-brew biosynthesis of medicinal opiates at meaningful yields."

The authors engaged in this experiment primarily to assuage concerns that some of their colleagues had expressed about the feasibility of homebrewing opioids in the midst of a widespread opioid addiction crisis. In other words, their colleagues expressed concern stemming from the prospect of homebrewed opioids, and only in light of this concern was it revealed that there are crucial technical elements of different fermentation processes that are not only substantively different but even "likely unrelated." The potential for controversy, then, can provoke a more considered analysis of similarities and differences, if it becomes pressing enough (or perhaps if it becomes enough of a threat to the success or profitability of a given project). This suggests the need to insist on the ethical and moral dimensions of fermentation technologies to highlight the need for more substantive discourse. In addition to social scientists and bioethicists, one group that has worked hard to insist on these dimensions is "DIY-biologists," also known as "biohackers."[13] Their work helps show that using fermentation as an analogy does not necessarily obfuscate either technical or ethical matters, even though it risks doing so.

Due to decreased costs and the perceived potential of synthetic biology, a number of community laboratories that engage in DIY-bio, or biohacking, have emerged as part of the larger synthetic biology movement. At these labs the historical entanglement of biotechnology and fermentation remains on display. Community biology laboratories, including the ones I have worked with, regularly hold events and classes related to "traditional" products of fermentation: kombucha, sauerkraut, or mead. While one community lab's fermentation instructor views the synthetic biology work in the lab as drastically different, much more "precise," and finicky (and even feels this way about certain types of beer production, which he jokingly calls "monk-y brews"), the fermentation classes do draw people into the laboratory and help indirectly introduce them to lab work and bioengineering (interview, April 18, 2018; field notes, September 27, 2017). Participant observation and interviews from community bio labs reveal how and why some of their work constitutes an ethical critique of other forms of fermentation and requires them to delve into practical distinctions. While not true of all biohacking projects, some DIY-biologists pursue genetic engineering not for profit or efficiency's sake but because they understand it as a way of "doing politics" and addressing social problems—including problems with bioengineering as currently practiced (interview, December 10, 2017; interview, January 14, 2018). While biohacking revolves around bioengineering and lab work, community biologists often adopt a specific orientation to, and broader view of, this work.

Like some of their counterparts among the community of synthetic biologists, some biohackers may also make comparisons to brewing as a way to communicate their work and mission, as well as to contextualize it in relation to other microbial production practices. According to one member of a community lab working on producing an open-source generic pharmaceutical using bioengineering,

> With brewing beer there's a very direct set of correspondences with what we're doing. We're growing yeast, and feeding it in sort of a liquid medium, and we're monitoring the conditions of that, and we're trying to keep it clean and free of contamination, and then whatever comes out of

that, we're going to have to take something out of it, and purify it and bottle it up, and that is pretty much what you do at a brewery. Purification in particular is probably a little more complex than brewing beer. . . . It's very similar. And if you tell people, "We're going to create, like, [a pharmaceutical] microbrewery" or something, then it's a lot easier to contextualize that, because it provides you with this whole other set of associations that people are much more familiar with. Where you can say, there used to just be Coors and Busch, and we want there to be a couple in every city now. And we're working with yeast, we're fermenting things, it's a lot—not exactly like brewing beer—but it's a lot like it. So you can imagine instead of a tank as big as a building, you just have a tank that is like what you would do in your garage to brew beer. (interview, December 10, 2017)

While this characterization does focus on loose similarities between types of fermentation, it also acknowledges some of the different practices of fermentation even within the realm of beer brewing. Biohackers compare their work to some kinds of fermentation working against others, rather than using fermentation itself as shorthand for a nebulous productive ethos, as Perfect Day or Jay Keasling seem to do. While they pursue small-scale, disruptive, and decentralized production using fermentation, they largely avoid fetishizing fermentation as inherently any of these. Put differently, while these community labs do seek technological fixes for social issues, they are also driven to acknowledge the deeply socially embedded nature of these technologies by virtue of their orientation against what they perceive as the abuses of technically similar endeavors. They engage in genetic engineering, but they also foreground concerns with the ways that genetic engineering efforts have leveraged patents and other intellectual property protections in the past (interview, December 10, 2017; interview, January 14, 2018). Furthermore, rather than seizing on a gap of understanding between bioengineers and "lay" publics, they approach the rapid advancement of bioengineering and synthetic biology as an opportunity for reimagining the connections between biology and publics more broadly. One lab member summarized this overarching mission: "the role of the community lab is to make [science] palatable for a bigger audience, where it becomes something that occurs more frequently in daily parlance, [and] people develop a fluency" (interview, October 10, 2018). Given their modest successes with production so far, these laboratories are perhaps less involved in producing substances through fermentation than in producing critiques of existing institutions and supply chains. They use fermentation as an analogy to highlight issues of scale, centralization, and ownership.

These community laboratories could provide a good point of entry for broader engagement, including of social scientists, into the area of biotechnologized fermentation, its pursuit of value, and its potential for controversy. Other efforts by social scientists to participate in synthetic-biology-in-the-making—including working closely with Jay Keasling—have proven frustrating, largely due to the inflexibility of existing institutions (Rabinow and Bennett 2012). In contrast, some DIY-bio labs' open-door policies and willingness to accept walk-in community members and biological nonexperts and to entertain their questions is promising. However, while they do this in good faith, it does not necessarily translate to meaningful participation or the opportunity to reshape existing projects, which in my experience are often still primarily technologically driven and revolve around a relatively small core group of people.

The self-selected nature of laboratory participation, interests in expediency, and the need to demonstrate progress can also result in skirting controversial issues. For example, one member of a lab that runs a project to bioengineer a vegan food substitute admits that they have been fortunate to deal with few complaints about GMOs: "a lot of people who might be concerned about genetically modified organisms in general also may be vegans or are sympathetic to that sort of thing, so that's also really fortunate" (interview, December 10, 2017). They generally do not shy away from the genetic engineering elements of their work, but they do at times view it as a misplaced concern and a distraction from their work. One member balks at the prospect of concerns with genetic modification, noting that "genetically modified organism" does not even really exist as a biological category (interview, January 14, 2018). Another voices a common community belief that genetic modification techniques are not substantially unique or novel but rather exist on a continuum with selective breeding and the mutation of plants via radiation (interview, October 17, 2018). Still, the lab members did express a willingness and form a plan to publicly debate genetic engineering, with the conviction that better understanding of the technology will lead to greater acceptance (interview, December 10, 2017). Dismissive of health and safety concerns over GMOs and glad not to have faced them too often, lab members are often more concerned with the politics of intellectual property rights and often critical of the ways these are leveraged by for-profit entities.

Although their disagreement with existing intellectual property regimes compels them to adopt a nuanced view of bioengineering practice, being forced to navigate a maze of intellectual property protections that are strictly "techno-legal" in nature (Parthasarathy 2017) takes up much of their time and limits their ability to reimagine bioengineering in practice (field notes, October 15, 2017). Although they interpret current intellectual property protections as broken—for being excessively bureaucratic and helping to foster wealth concentration and unequal distribution of life-saving drugs—they also acknowledge that any technological solution must either avoid infringing on intellectual property or face the consequences (field notes, September 27, 2017; field notes, October 15, 2017; interview, December 10, 2017). Although the biohacking or DIY-bio model certainly has its limitations, the existence of projects that encourage greater participation in and public understanding of technology-in-the-making provides a promising example of how and why to avoid fetishizing fermentation. Closer attention to diverse practices of fermentation includes a more engaged consideration of their technical elements, as well as of the social networks that support them and the differential social outcomes that even technically similar projects produce (see Latour 1987, 1988). Without such consideration, so-called fermentation (or bioengineering, or synthetic biology, for that matter) does not stand well on its own as a signifier of a particular kind of change in productive landscapes.

## Conclusion: Fermentation in Theory and Practice

Borrowed concepts are necessarily used to explain new technological developments; however, bioengineers' invocation of fermentation is more than a metaphor. Biotechnological developments over the last several decades have changed the definition of fermentation itself to encompass a much broader range of culturing processes and potential outputs. Perhaps due to a general lack of public engagement with the details of what fermentation is and does, these changes are not widely known. This lack of engagement has many possible causes. In industrial society the separation between production and consumption is pervasive. While alternative food movements, for example, have brought fermentative production closer to the consumer in some forms, other forms—like the modified ferments that are the product of bioengineering—remain sequestered in laboratories and specialized literatures. Bioengineered ferments, such as insulin and synthetic rennet, are rarely sold to consumers directly. Sales of the former are heavily mediated by physicians and pharmacies and protected by intellectual property, and the latter is a product aimed at another type of fermentation producer—cheesemakers. Whatever the causes of this lack of engagement, it creates a mismatch between scientific and public understandings of fermentation. This mismatch can impede the accurate communication of technoscientific developments or, as in Perfect Day's case, be used to promote bioengineering endeavors using nominal or superficial similarities and skirting more potentially controversial elements of bioengineering practice.

Alistair Elfick and Drew Endy (2014), who are synthetic biologists, seem to lament that people do not know the benefits they receive from genetic modification, but they do not delve much into *why* these benefits are not common knowledge. Along with the separation between production and consumption, the public controversy over GMOs that has emerged from some of bioengineering's uses may make bioengineers reluctant to widely publicize the genetic engineering components of production practices, even if they believe public concerns and fears are unnecessary or misplaced. "Fermentation," without much descriptive specificity, comes to serve as a shorthand that can be used to describe a process without the need for detail and to take advantage of positive associations with more visible forms of fermentative production. However, even these more visible forms—like so-called "craft" fermentation—may be nebulous, putting practical specificity and shared understanding even further out of reach. The fraught history of science and engineering work in terms of public trust, especially when it comes to genetic modification technologies, incentivizes a superficial attempt to establish novel technology as essentially familiar and benevolent.

I have described the resulting superficial equivalence of different practices that go by the name "fermentation" as a form of fetishism. This fetishism can result in a "cooperation without consensus" (Star 1993; Clarke and Star 2008) in which more familiar fermentation practices are leveraged as convenient reference points and inoculants against public skepticism and criticism. Stakeholders in fermentation's different forms end up tacitly supporting one another without delving into how their differences—whether technical, organizational, or value-based—set them apart. As bioengineering continues to transform fermentation in profound new ways, these differences and the gaps between specialists' and publics' understandings grow larger.

My goal is to demonstrate to how putting familiar terms to new uses can yield obfuscation rather than clarity, as well as how this is already happening with fermentation. The work in this volume asks, "Does theorizing landscape change as fermentation help us understand landscape change better?" In response this chapter demonstrates some potential challenges and implications that face this line of thinking and thereby raises some further questions for consideration: If theorizing landscape change as fermentation does help us understand landscape change better, might it come at the expense of understanding fermentation better? Is this an acceptable trade-off? Given fermentation's wide variety in practice, which meaning of the word is being used to theorize landscape change? And how is this particular meaning being selected? While it is not the primary goal of this volume to better grasp fermentation itself, this risk of using fermentation as a metaphorical theoretical concept should be of concern for scholars with a specific interest in understanding fermentative industry. These scholars should be wary of the ways in which fermentation can become a nebulous signifier used to avoid difficult topics, such as the use of genetic engineering in food production.

These concerns with the use of fermentation as metaphor stem from a very specific set of developments with a tendency to play fast and loose with the concept. By exploring the merits of fermentation-as-metaphor, the present volume (see chapters 10 and 12 in particular) already demonstrates a reflexive engagement that resists some of the pitfalls of fetishizing fermentation. With any success, its contents will foster a better understanding of both fermentation and landscape change. As community biologists help demonstrate, fermentation-as-metaphor need not be off the table altogether; it is simply at its best when it takes up some of the complexity of fermentation in practice, rather than using it as convenient conceptual shorthand.

With the increasing accessibility of bioengineering technology, community biology laboratories can provide for better public engagement with both the technical and ethical dimensions of fermentative production, even though their scope and outreach are limited and they face some difficult institutional constraints. At their best these spaces adopt ways of doing bioengineering that are both explicitly political (in their aims to address problems they identify with other forms of bioengineering) and relatively accessible (to nonexperts in biology, social scientists included). Even when making analogies to other forms of fermentation, members of these laboratories do so with more care and resist some—though not all—of the issues with fetishizing fermentation. Perhaps using fermentation as a conceptual tool for theorizing landscape change can avoid these issues as well, if those doing this work remain engaged with fermentation in practice and cognizant of their own values and goals (see chapters 10, 12, and 13, this volume).

**Notes**

1. Many practitioners would make distinctions between the terms "bioengineering," "synthetic biology," and "metabolic engineering," but for the purposes of this chapter the important consideration is the confluence of biology and engineering as it is applied to microbial metabolisms, which can fall under any of these labels.
2. To protect the anonymity of my research participants, I have omitted their names and the names of their organizations and cited their input as "interview," along with a date, depending on whether this communication occurred during a recorded interview. Their words have in some cases been modified slightly for clarity.
3. This hints at some of the mystical associations with fermentation, a process that always has an element of the unknown and the uncertain. To a lesser extent, this association remains, as evident in longtime Anchor Brewing Company owner Fritz Maytag's attitude toward beer making: "Beer does not make itself properly by itself. It takes an element of mystery and of things that no one can understand" (White and Zainasheff 2010, xv).
4. Of course this distinction has not always been so fundamental or so clear, and biology has had repeated clashes over vitalism and basic distinctions between biotic and abiotic matter (Bud 1993).
5. Because it refutes the theory of spontaneous generation, *Studies on Fermentation* is also a key text in the development of the germ theory of disease. This theory—that sickness is caused by single-celled organisms that, rather than appearing under certain environmental conditions, are derived from previous generations of single-celled organisms—displaced miasmic and zymotic theories of disease. The latter are named after the Greek word for ferment and grew from the simultaneous (mis-) understanding of both fermentation and infectious disease as spontaneous processes (Tomes 1998).
6. "Zymotechnology" comes from the Greek word for fermentation, *zymosi*.
7. The sequencing of the genome has contributed to the increasingly prevalent understanding of life itself as an informatic domain, a complex-yet-crackable code. As for genetically modified organisms, the patentability of single-celled organisms was enabled by the ruling in *Diamond v. Chakrabarty* (SCOTUS 1980), which later paved the way for modified plants (Kloppenburg 1988) and laboratory animals with "special" features like a predisposition to developing cancer (Haraway 1997).

8. Prior to Genentech's *E. coli*–produced insulin, which the company was making by 1978 and would introduce into the marketplace a few years later, insulin derived from nonhuman animals—usually cattle ("bovine" or "beef" insulin) or pigs ("porcine" or "pork" insulin)—was the industry standard. This insulin had significant limitations, however: it was expensive to produce, it was subject to impurities, it had a tendency to provoke immune responses in patients, and unless modified, it differed in molecular composition from the insulin produced in the human pancreas. Finding new means of producing "human" insulin—that is, synthetic insulin with the same molecular structure as that produced in human bodies—was therefore a valuable achievement for the nascent field of genetic engineering (Greene and Riggs 2015).
9. When Keasling says, "We use it," the antecedent is made somewhat unclear through video editing, but it is clear from context that Keasling is referring either to yeast or to fermentation, possibly both.
10. Note the lack here of any reference to biotechnology, genetic engineering, or bioengineering.
11. Other criteria, like the limited use of machinery, are difficult to apply consistently in the contemporary moment, to craft brewing, for example.
12. "Differences that make a difference" is a reference to Bateson's definition of the word *information*.
13. Many practitioners would make a distinction or express a preference for one term or the other. For the purposes of this chapter, the terms are synonymous. Most of my fieldwork participants use both terms and use them more or less interchangeably.

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