NARRATIVES IN THE ANTHROPOCENE ERA

Charles Travis, Vittorio Valentino (Editors)

Preface by Kirill O. Thompson

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Geographies of the Anthropocene

Narratives in the Anthropocene era

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12. Bio-deconstructing Bioremediation: Tailings Ponds, Oil-eating Bacteria, and Microbial Agency

Aaron Bradshaw[1]

Abstract

The Anthropocene is characterised by the paradox of a human agency that both creates and must respond to the rapid degradation of the environment. At the same time, certain forms of nonhuman agency display profound resilience and ability to respond to these changes. Using the case study of the Albertan oil-sands, this chapter analyses the relation between human and nonhuman agency in the discourse and practice of using microbial bioremediation to detoxify the waste products generated by this industry. These products are stored in tailings ponds now containing ~1 trillion litres of highly toxic water that must be detoxified before they can be reclaimed and host the kinds of ecologies which they have replaced. Certain microbial strains indigenous to these waste ponds that thrive on and degrade the toxic chemicals found there have driven a wave of research into isolating, engineering, and optimising these metabolic capacities for eventual reclamation of the ponds. I ask if the goal of controlling these processes, which have arisen spontaneously through the creative activities of bacteria, undermines the conditions that make this goal possible. Moving to a view of bacteria as intelligent organisms who have a fine-grained resolution of environmental conditions, and whose complex and networked activity is ontologically irreducible to the prerogatives of biotechnology, I ponder an alternate model for thinking about human-microbe relations in the goal oriented process of bioremediation.

Keywords: Oil-sands, tailings ponds, bioremediation, bio-deconstruction, naphthenic acids

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1. Introduction

If the Anthropocene is characterised by large-scale anthropogenic disruption of biogeochemical cycles and the destruction of ecological systems, this chapter asks what might be the role - and limits - of human agency in responding to these changes and disruptions in a positive way. The unintended effects of human activity on the functioning of the earth system, and the correspondent alterations of the geological record, embodies a certain kind of tension: humans are at once responsible and the effective cause of widespread and far-reaching changes to the earth - even so much as to alter its geology - and yet this same fact threatens to undermine our ability to effect change in intended and predictable directions. Instead of serving to recast the environment as a passive recipient of human activity, the fact that humanity has altered the earth so pervasively, and potentially permanently, brings nonhuman activity and inhuman processes to the fore. In other words, humanity has become one force *amongst many* in the trajectory of the earth system (Clark and Szerzynski, 2020). What is at stake, then, is not the affirmation or negation of human agency in responding to environmental issues, but a reconceptualization of its position in relation to other forms of agency in these issues.

This chapter explores two very specific instances of these agencies - human scientists and microorganisms - to ask how they are related in the goals of remediating and detoxifying polluted sites. Certain strains of bacteria are able to metabolise chemicals, often the fall-out of industrial operations, which are toxic to most other forms of life, and these microbes therefore represent potential and promise for regenerating sites that human activity has degraded. These processes, known collectively as 'bioremediation' are intensely studied by scientists, and already deployed in certain contexts like waste-water treatment. Here, these processes are contextualised with reference to the tar sands mining operation in Alberta, Canada, and the ongoing efforts to utilise bioremediation to treat some of the enormous amounts of waste produced by this operation. My aim is to question the assumptions of control that guide aspects of this research by deconstructing received wisdom about the mechanical and automaton-like behaviour of microorganisms. The analysis doesn't conclude with a negative critique of bioremediation, however, and I attempt to offer a sketch of an alternative model for understanding human-microbial relations. In line with the view of multiple forces acting in concert and sometimes conflict, this model understands bioremediation research and practices as the sharing of agencies across species boundaries, and the attendant challenges and promises of such an arrangement.

2. Oil extraction and tailings ponds

The mining of the tar sands in Alberta, Canada, is among the most destructive industrial projects currently unfolding on earth (Leahy, 2020). In addition to increasing the use of fossil fuels and contributing to global heating, there are more direct and localised effects of the operations. Although the tar sands boast the second largest reserve of oil in the world, the oil present there is mixed with sand, clay, silt, and other 'impurities' that prevent its extraction by conventional means like drilling. Instead, the oil-sands must be stripped from earth in huge mining operations and the evolution of the tar sands industry has centred on technological developments that make the downstream separation of oil from sand an economically viable procedure. Despite this, the viability of the industry undergoes frequent oscillations, in addition to (and partly because of) being extremely energy intensive and producing an inordinate amount of waste by-products. The process of separation essentially follows a gravity floatation mechanism in which the oil-sands deposits are mixed with large volumes of warm water - taken from the nearby Athabasca River - and pumped through chambers. Here, the oil floats to the top where it is skimmed off and transported for 'upgrading.' The water, meanwhile, containing clay, silt, as well as residual hydrocarbons from the oil, is fed out of the bottom of the chamber and transferred into huge lakes where it is stored. These lakes - termed 'tailings ponds' - are generally disused mines that have been exhausted of their valuable deposits, and sit like scars on the landscape.

The volume of water in tailings ponds is now estimated to exceed one trillion litres, and the ponds themselves cover thousands of square kilometres. Where there used to be boreal forests, interconnected with wetlands and complex ecosystems, providing habitats for numerous large fauna, flora, and microorganisms, there now stands vast reaches of toxic-gloop ponds that exclude almost all life. The issues with these pools are numerous. In addition to destroying vast areas of dense biodiversity, their polluted waters leach into neighbouring hydrological systems and produce cascading biological effects far beyond their own borders. Moreover, the operations in the tar sands inflict violence upon Indigenous peoples in the Albertan region and are intimately connected with settler-colonial violence, causing the ongoing destruction of important habitats, ecosystems, and ways of life, and the connections between them (Murphy, 2008). One of the deepest concerns about these ponds is their longevity - left in their current state, they will, in all likelihood, outlive the viability of the mining operations that produced them, leaving the responsibility of managing these fetid pools of toxicity to those who opposed the mining operations in the first place and certainly did not profit from them.

In light of growing opposition to this ecological devastation, the future of the tar sands is now quite often explicitly linked to the ability of the industry to clean up after itself and mitigate the alarming damage inflicted upon local environments. Tailings ponds are at the centre of these debates. Therefore, although these ponds are accumulating at an alarming rate, and there are at present no clear or proven means for dealing with them, their proliferation is tied into discourses around ideals of reclamation and restoration. In theory, tar sands actors are committed to returning the previous sites of tailings ponds back to their former productivity. Despite the significant (and well founded) doubts regarding the integrity and motivations of the formal regulatory procedures driving these goals, there is, at the least, a growing recognition by the tar sands industry that cleaning up their waste is becoming central to their efforts to continue mining in the region. And although it is important to be critical about promises to clean up the ponds, especially in light of their ongoing proliferation and the currently only marginal success of restoration programs, critique in this case may have the effect of inducing a sense of hopelessness that will in fact leave the ponds intact. In other words, these ponds are already there, and their effects continue to unfold, regardless of how we conceptualise and analyse their generation.

As such, it is not my aim in this chapter to discuss the ecological, economic, social, or racial violence perpetrated by the oil sands mining operations, or the shortfalls of regulatory procedure, but rather to focus instead on something that is, at face value, a technological issue - the reclamation of the ponds. However, as my analysis unfolds it becomes clear that this is not a 'technological' issue at all, at least insofar as technology is the means by which humans control and manipulate their environments, but rather an issue that takes us to the core of agency and the very ability to control and manipulate the environment. Fundamentally, my discussion offers a practical perspective on these issues that at the same time contends with the foundations of practice: what are the limits to human agency in restoring the tailings ponds (and by implication other large scale ecological destruction)? How does the capacity of nonhumans to alter the earth -

particularly microbes - inflect this understanding, and how are the two related when it comes to large scale environmental issues?

3. Emerging discourse of bioremediation

Notwithstanding the debates around the realities of reclamation, even taken at face value - that is, how the oil companies present the process - the ambitions of this project present massive technological challenges. The conceptual scheme offered by the oil sands industry is to basically reverse the process of pond formation: to remove the water, refill the pits with the topsoil that was initially removed from them, and plant shrubs and trees native to the area. Once this is out the way 'Nature' takes over to do the rest, filling in the details of this pastoral image with colonisation and ecological succession (see Suncor Energy, 2010 for a video representation). The reality of course is more complex than this highly schematised process. For instance, the presence of clay and silt in the water of the tailings ponds means instead of acting like a liquid that can easily be removed, the majority of their volume below the thin surface layer is actually a viscous colloid that sometimes acts like a liquid, sometimes like a gel. The rheological qualities of this material inhibit its intentional manipulation, meaning that prior to dewatering and refilling, the suspended clay particles need to sediment out, a process that, if left to itself, takes on the order of centuries. Before facing the rheological complexities of this colloid, even, and the remaining feats of geotechnical engineering, the surface layer of these ponds – referred to as 'oil sands process affected water' (OSPW) - also needs to be dealt with. Although this layer is water-like in its physical properties, it is saturated with chemicals that have leached from the bitumen and needs to be detoxified before it can be returned to the surrounding watersheds.

It is only once this water is removed that the processes of sedimentation in the lower layers can be accelerated, the topsoil filled back in, and ecology able to take over. It is hard to overstate the toxicity of these tailings ponds; when migratory ducks were forced by bad weather to land on them in the winter of 2008, and again in 2010, thousands of the animals were killed by just coming into contact with the ponds (The Canadian Press, 2010). These ponds are also unable to sustain aquatic organisms like fish and amphibians. They are, to ordinary perception, completely barren and lifeless. Despite this appearance of lifelessness, and the presence of active toxicity, however, these ponds are home to billions of microorganisms that thrive in the different strata of the water. The presence of microbial communities in the tailings ponds has been studied for a long time and has always been tied, in one way or another, towards understanding the biological and geological trajectories of these systems. The production of methane by microorganisms in the lower regions of these ponds, for instance, is a concern for global warming, and a lot of investigations have focused on the presence of other bacteria within the ponds that assimilate methane in their metabolic cycles thus mitigating this concern (Saidi-Mehrabad et al. 2013). Other early studies tried to understand how microbes might accelerate the sedimentation rate of the suspended clay and silt in OSPW samples (Hocking, 1977), a research avenue still followed today and considered by some as a partial solution to overcoming the issues of manipulating the colloidal lower layers of the ponds (Siddique et al. 2014). In addition to the metabolic couplings between microbial communities within the tailings ponds and the biogeochemical transformations they enact, scientists are also interested in the ability of certain indigenous microorganisms to metabolise the toxic contaminants found lurking there. Some of these chemicals, which are toxic to most organisms, are essentially food for these strains of bacteria who thrive in the upper layers of these ponds. One of the most toxic components of the OSPW is a collection of chemicals termed naphthenic acids, hydrocarbons that cause acute and chronic toxicity to aquatic organisms, and which are incredibly persistent in the environment, but which certain strains of microorganisms indigenous to the ponds have been shown to digest. Microorganisms have been known to biodegrade components of oil for a long time and the activities of these organisms have generated a lot of media attention in coverage of large oil spills, like the Exxon *Valdez* and the Deepwater Horizon disasters. To be sure, there is nothing ‘new’ about these oil-eating microbes, and it was certainly not ‘our’ actions that ushered them into being in the first place. Oil has formed over deep time and in extreme locations under the earth’s surface and these microbes - and their appetites - have evolved alongside it. Indeed, the activity of microorganisms was central to the formation of these deposits in the first place.

Bioremediation in the wake of large scale uncontained oil spills is often promoted as a viable strategy for combating their devastating ecological effects. Deploying microbes to combat the persistent toxic chemicals found in the oil-sands tailings ponds is an extension and reapplication of this process. Although naphthenic acids are generally recalcitrant to biodegradation, with metabolism of these components occurring only slowly and incompletely, new research avenues within the field of synthetic biology are focusing on how these processes might be isolated, sped up and optimised, and configured to operate at large scales. The reflection of this research in media discourses has also proliferated over the past decade, and numerous articles discuss the potential of bioremediation as a 'natural solution' for overcoming the intractable toxicity of the tailings ponds. The content of news articles and other media coverage of research into bioremediation tend to reproduce the underlying dynamic of the research itself, in that they rely on a future-oriented discussion of the potential of these technologies. Likewise, the study of bioremediation is strongly allied to industrial-academic collaborations and biotech spinouts, and is underwritten by venture capital investment into the *promises* of bioremediation in the future, rather than its unfolding in the present (Cooper, 2008).

This dynamic is exemplified by the recent formation of Evok Innovations, a partnership between Silicon Valley entrepreneurs and companies that operate in the oil sands, including Suncor Energy and Cenovus Energy, and who are responding to "demand for environmental performance" (Evok Innovation, n.d.). One of the start-ups on the original portfolio of Evok was a biotech spinout called Metabolik Technologies whose aim was to capitalise on academic research into naphthenic acid biodegradation. In early 2021 the assets of Metabolik were absorbed by Allonia, a company with expertise in bioremediation technology that is also attempting to target PFAS chemicals in the environment (also known as 'forever chemicals'). In a press release, one of the people working on the initial project - prior to its assimilation to Allonia - suggested that although microbes indigenous to these ponds are able to degrade naphthenic acids, the process is painfully slow when reflected against the scale of the tailings ponds issue. The central issue that is generally presented in bioremediation discourse is reconciling this slow, patient, and generally promiscuous metabolism of microbes with the pressing urgencies of responding to pollution, often composed of specific chemical toxins at relatively low concentrations spread throughout large volumes. The article discusses how the researchers are attempting to isolate the genetic components of naphthenic acid biodegradation from indigenous microbes, optimise, and eventually transplant them into e-coli, a robust bacterial strain that grows rapidly and is referred to as the "the biotechnological workhouse." (DiNardo, 2017).

In 2020, Metabolik researchers filed a patent application detailing the labs' approach to defining, and eventually engineering, these pathways of naphthenic acid degradation (Chegounian and Yadav, 2020). The procedures detailed involve enriching microbial strains from the tailings ponds, and assessing all the genes that are differentially expressed in those strains versus those who have not been exposed to naphthenic acids. This information is then tied back to functional information about the respective gene products, and used to reconstruct the metabolic pathways operating in these bacteria. The patent also covers the engineering of novel bacterial strains to express and perform these functions.

These plans aim to circumscribe a naphthenic acid degrading module within a host organism, to precisely demarcate its function in space and time, to make it more efficient, and to transplant it into a novel organism. But the vision of control and containment goes further than this: by fitting the engineered strain with a 'suicide unit' that is activated only when the organism is not exposed to those chemicals it is designed to metabolise, the goal is to prevent the modified strain from entering and proliferating in neighbouring ecosystems, and to inhibit its interaction with other organisms. As the researchers note, this process is referred to as "bio-containment, or engineering a "kill switch."" (DiNardo, 2017). The article continues:

> The idea is that once the E. coli has performed its function of neutralizing the toxin, it destroys itself. "There is no chance of damaging [living organisms] in the natural environment or causing any contamination issues,"... They plan to use [the kill switch] to engineer E. coli strains that rely on signals unique to OSPW. "If it were to leave these environments, the signals that it would normally receive in the tailings pond are not going to be available and therefore the strain will then essentially start producing suicide genes. (DiNardo, 2017, n.p.)

As the passage above, with its quotes from academics working in the field make clear, the goal of bio-containment is homologous to the ideal of demarcating an essentialised module of naphthenic acid degradation. But here the logic of abstraction and dissection is applied to the whole organism, which takes on the same ontological status as a gene network or cellular module. This is part and parcel of the synthetic biology approach in which functions can be chopped and changed between various organisms to produce novel hybrids with desired functions. In the next section I explore some of the assumptions and tensions in research and discourse on the application of synthetic biology to bioremediation and ask how it re/configures understandings of microbial *and* human agency.

4. Bio-deconstructing bioremediation

Those reporting on bioremediation tend to emphasise the ‘naturalness’ of the process by reminding us that microbial metabolism of organic compounds is already occurring in nature all the time. At the same time, however, these reports focus on how these processes are in fact sub-optimal, that they need a helping hand by humans to be made more efficient and deployed in the correct contexts and at large scales. Underlying the promise of bioremediation, then, appears to be a certain paradox: on the one hand, it relies upon the open-ended innovation of microbial evolution to engage with and transform environmental chemicals into benign products, whilst on the other it is committed to the goal of controlling - essentially closing down the options of - this very ability. By ‘fixing’ the desired process, however, is the potential for the emergence of other novel processes, as the condition of possibility for that desired process, overlooked?

The biotechnological imaginary is tied to a view of microbial naphthenic acid degradation as a seamless process executed by a fully compartmentalised being, whose only lasting effects in the environment are of a positive nature. Recent research on microbes with the ability to degrade naphthenic acids, however, suggests that interacting with other microorganisms to form complex communities (i.e. their context) may underlie their ability to perform this function (Demeter et al. 2015). In other words, the inter-species metabolic couplings of detoxifying bacteria is not incidental to their function, but central to it, suggesting that their ability to detoxify naphthenic acids might not be separate - and therefore not separable - from their interactions with other organisms.

The point I want to draw from these considerations is that the contained organism capable of expressing a precisely determined function is a myth or fantasy of the biotechnological paradigm.[2] The ontological

[2] There is an interesting parallel here with the idea of a ‘posthuman biology’. Tamar Sharon (2014, 113-134) for instance, sees movements in biotechnology and synthetic biology as embodying and refracting the philosophical orientation of a radical and critical posthumanism with its commitment to the understanding of entities not as bounded individuals but in constant flux and exchange with each other and their environments. Whilst I agree there are certain important parallels between the philosophical underpinnings of posthumanism and how biotechnology conceptualises its object of study, I would argue that attempts to isolate and transplant specific functions from one context to another also has important parallels with a humanist ontology, at least insofar as it constructs a human agent who is able to manipulate the world as desired, even if it does concede a certain degree of agency to nonhuman others. A thorough discussion of the relations between

stabilisation of discrete organisms, whilst (arguably) technically possible in the restricted sense, gets in the way of understanding how that organism is able to perform the operations that may be of value in a particular context.[3] If we take cues from emerging thought in bio-deconstruction,[4] then we might argue that it is precisely through their openness to the outside - the environment, other organisms, even their own cellular context - that bacteria come to evolve their host of complex metabolic features, including those deemed ‘desirable’ by human agents. Vicki Kirby refers to this creative exploration of their environment as “the code-cracking and encryption capacities of bacteria” as they “decipher the chemistry of [their environments] and reinvent themselves accordingly.” (Kirby, 2009, 111).

Tracing the binaries that structure synthetic biological research into bioremediation ultimately converges on the question of agency and its distribution across different forms of life. Whilst biological discourse tends to describe microbial activity as composed of deterministic and predictable processes, this stance implicitly assumes a consciousness that is rational, purposeful, and self-identical, and that has the ability to characterise and control these processes. But in this view, in its characterisation of microbiological life as able only to *react* rather than to respond, are not the very assumptions of control and determination themselves a reaction, the realisation of a socio-cultural code transmitted from the depths of Western metaphysics? At the same time, who are we to adjudicate on which environmental situations are issues, and to decide upon their most favourable outcome over time? To what extent are preferences for what constitutes a ‘good response’ conditioned reflexes masquerading as insightful analyses? But bio-deconstruction doesn’t only trouble the binaries of programmatic and deterministic on the one hand, and self-aware and rational on the other by questioning human autonomy, but by also ascribing it to the non-human world.

In other words, actions, behaviors, responses, and reactions are constantly cross-contaminating one another. Francesco Vitale (2018) characterises this situation in his analysis of Derrida’s reading of Monod, the molecular biologist who won the Nobel Prize in 1965. Derrida takes

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post/humanist ontology and biotechnology and synthetic biology is beyond the scope of the current chapter.

[3] See Schrader (2010) for an interesting example.

[4] Biodeconstruction is concerned with applying the insights of Jacques Derrida to the life sciences, and is also interested in discussing Derrida’s own engagement with the life sciences, and particularly molecular biology in his seminar *La Vie La Mort*. Francesco Vitale, Vicky Kirby and Astrid Schrader among others have adopted this term to describe some of their work.

Monod's analogy between the genetic code ('deterministic') and human memory ('self-aware') to task, arguing that the relation between them isn't one of two homologous yet separate systems, but rather differentiations internal to the same system, thus destabilising Monod's analogical device. In other words, the distinction between the 'biological' and the 'cultural' - or 'genetic memory' and 'cerebral memory' - is, in Vitale's words, more of a "quantitative than qualitative" one, characterised by a relation of "continuity" rather than "rupture." It may be tempting to see this view as a kind of biological determinism, suggesting that human consciousness and intentionality is a mere evolutionary by-product with no relation to how the world 'really is.' But just as this move challenges the view of microbes as mindless automata, in doing so it must similarly concede a degree of agency to human endeavours. In other words, this insight does not fully evacuate agency, but rather repositions it in a grander network of interaction and influence. The question of control and manipulation - that is, the goal of directing microbial behaviour for bioremediation - can be reopened in light of these thoughts. What does the ability of microbes to be "open to the outside", and the correspondent features of humans, mean for the relation between the two systems, their correspondence, or the ability for an agent within one system - i.e. the human - to intervene upon and directly influence the behavior of another - i.e. the nonhuman?

If, as Vitale notes, non/humans are, for their survival, bound by the "necessity of interpreting what comes from outside" whilst at the same time expressing their own iterations of agency - thus sending their own messages back to this "outside" - there is the sense that human research on microbes is a project characterised by bi-directional transit, communication, and translation between these two systems. In other words, human study of microorganisms isn't the story of an objective deciphering of microbial activity, but an ongoing exchange between humans and microbes, in which the two accommodate - to varying degrees – to the other. The conclusions of this are twofold. Firstly, synthetic biological research into bioremediation unfolds through a different ontology than how it is usually characterised, and secondly, this rift between the 'theory' and 'practice' of bioremediation indicates that there is a possibility to bring the two into closer alignment.

5. Participation as an alternative paradigm

Up to this point in the chapter I have approached the discourse and practice of bioremediation as a question of agency. As such, I have not discussed the limitations of biotechnological research into bioremediation as emerging from a limitation in technical capacity – as interpreted in the discourse of biotechnology itself - but rather as unfolding through an ontological irreducibility that characterises the relationship between human and microbial life. The limits to intentional manipulation of microbiological life emerge within an ontological relation between humans, microbes, and other forms of life in which the positions of subjects and objects as active and passive parties are in constant flux. Just as we humans create our experimental apparatus and material arrangements, bacteria too are engaged in their own form of "ontological epistemologising" (Kirby, 2009, 111), only bacterial interactions with the material world are far more spatially resolved than our own, and more readily able to transform themselves in the face of environmental disruption than homo-sapiens.

The practice of bioremediation, as framed this way is already a meeting of agencies, a negotiation across the borders of species and between different ways of being. My concern however, is the distinction between these two agencies, and correspondent representations of this difference. Mainstream biotechnological rhetoric paints the picture of two agencies populating either side of impassable divide: on the one side there is the rational agency of the conscious scientist who can arbitrarily impose his/ her will upon the object of their study, whilst on the other is the passive and deterministic microbe, so often the object of that study, who reacts only mindlessly to environmental conditions. However, in looking closely at the capacities of microorganisms, and of scientists researching with and on them, these two images become somewhat subverted. In the view I have sketched out here, scientific agency is reconfigured as not entirely rational, as historically constructed, socially situated and embodying its own limitations, whilst at the same time microbial agency becomes a creative force responding innovatively and intelligently – indeed, rationally - to environmental fluctuations and "reinventing [itself] accordingly" (Kirby, 2009, 111).

My suggestion, then, is that biotechnology possesses a distorted image of its own capacities, as well as of the 'object' that it works upon. And whilst the prerogatives of its technoscientific approaches may produce successes in certain applied contexts, these successes are material captures of its own disciplinary presuppositions. In other words, bioremediation is perhaps not radical enough in its attempts to 'harness' and 'exploit' the microbial world; it effectively shuts this world down by selecting and expanding those specific features of it that align with its own views. The point is that, in order to create conditions for life to thrive - of which bioremediation is one example - microorganisms need, to some extent, to be left alone and to figure out the specific ecological milieu for themselves, instead of being presented with our abstracted image of it. The difficulty here rests in cultivating a degree of trust and patience, in the capacities of microorganisms; the "abstracted image" of the environment with which microbes are presented in bioremediation experiments invariably encode a degree of urgency and a deep concern that arises out of the contemporary climate emergency. This opens ourselves up to the difficult position of understanding that what microbes *can* do versus what they may *want* to do, might not link up so well with our own ideals. Our relationship to bacteria isn't one of equal partners engaged in a negotiation; bacteria are profoundly more powerful than us, in the sense that though we depend on them for our existence, they, by and large, do not depend on ours (Clark and Hird, 2013; 2018).

This is another perspective from which to consider our attempts to precisely control and direct microbial evolution and metabolism. Our actions will likely amount to only a small ripple in the great chain of microbial existence that extends back 4.3 billion years in the planet's history, and in all likelihood forward into its deep future. However, in this reformulation of human and microbial agency the impasse between them is broken down and reconfigured in a way that may allow more meaningful transit across it. In transcending the vision of ultimate precision and fine-grained control, bacterial agency moves into spaces which are potentially of value for humans. The central point is that if bacteria are open to their environments, and not mindless automata reacting to it, then they are also open to our attempts to collaborate with and relate to them. 'We' necessarily form part of that environment to which bacteria are exposed - as clearly demonstrated by synthetic biology - and as such have some choice in how we relate to these microbiological entities.

For me, this ends up converging on the question of forming relationships with microbes that take on board their capacities not as fixed programs but as emergent and dynamic responses to a toxic world. The shift here is from viewing microbes as "chassis" or vectors for defined metabolic programs, towards viewing them as "participants" in those experiments. Participation as a "metaphor" for doing synthetic biology (Szymanski, 2018) works to embed those understandings of bacteria given above into the very rubric of experimentation. Indeed, the apparently lofty and detached insights of bio-deconstruction call for *more* experimentation with microbes, not less. But this might be a different form of experimentation that is less hubristic than anthropocentrically guided technological fixes to environmental issues, one that distributes agency across the human-microbe continuum. The fact that agency cannot be located in one place at one time but emerges continuously through intra-action is perhaps less a limitation to biotechnology than an opening (Barad, 2007). But only insofar as it dispenses with those views that would prejudicially code it as a limitation. Therefore, this model of sharing expertise across species boundaries is also strongly interdisciplinary, one that calls for engagement from scholars across the biological sciences, social sciences, the arts and humanities.

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(Serenella Iovino, University of North Carolina at Chapel Hill)

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