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Adam M. Romero, Julie Guthman, Ryan E. Galt, Matt Huber, Becky Mansfield, and
Suzana Sawyer

The following are a series of essays that originated from panel on Chemical Geographies at the American Association of Geographers meeting in 2016. Although the essays explore different topics, collectively they call into question the relationship of geographic scholarship to chemistry. **Key Words: chemistry, ecology, environment.**

INTRODUCTION: SOME THOUGHTS ON CHEMICAL GEOGRAPHIES

Adam M. Romero, University of Washington Bothell

In some of his most recent work on the stages of life and death, Robert Hass, the former poet laureate of the United States, called chemistry the science of *this becomes that becomes this becomes that* (Hass 2016). Earth to earth, ashes to ashes, dust to dust. Other scholars, like environmental historian Michael Egan (2015), have called chemistry the “science of material change” to raise it to the forefront of contemporary environmental and materialist scholarship. For Hass and Egan, chemistry is literally the elemental science of transformation. In this frame, biogeochemical change becomes both an apt metaphor for the stages of human life and death and the potential basis for politically engaged materialist scholarship. However, chemistry writ large is so much more than the science of *this becomes that becomes this becomes that*.

Chemistry, as the TV commercials of my childhood told me, is the science that makes our blue jeans bluer and the things we buy better. It is the science that assays the material world, telling us what we are made of, how much gold is in our ore, how old something is, and the types of pesticides on our produce. It is the science of separation and combination, of stability and instability, of attraction and repulsion, of living and nonliving. It is the science of contradictions. It is in the inherent messiness of chemistry’s contradictions that the following essays in this compendium journey.

For decades, nature-society geographers have been highly attuned to the biological—the ways in which the materiality of “life” matters. This work has given us powerful and elegant stories about how seeds, genes, plants, disease, and each of us are coproduced in the making of commodities and everyday life. More recently, the concept of the Anthropocene has led geographers and environmental scholars to think geologically about time and planetary about scale. Monumental tales of physical geography transformed by humankind now ask us to reconsider what it means to be alive in the geological age of humans. Despite the profound nature of so much of this scholarship and the fact that it often crosses into chemical realms, these

bodies of work lack sustained attention to both the inherently chemical nature of the world and the chemicalized nature of twenty-first-century life.

Chemical geographies is not a new subfield nor does it seek to become one. Rather, it is a collection of emerging scholarship from many disciplines that uses chemistry and chemicals to rethink humanity's relationship to the living and more-than-living world. It builds on traditions in geography, environmental history, and the humanities that have long studied and interpreted chemistry, the chemical industry, their histories, and their politics. From the poetics of Victorian London's polychromatic smog to the political economy of waste and pollution, environmental scholars have already laid a foundation on which the essays in this compendium seek to build. This collection is intended to entice nature-society geographers and scholars in the humanities and social sciences to think more about chemistry and its role in shaping and interpreting the world. We seek out chemistry not to be provocative for its own sake, but instead to ask serious questions about both the living and the more-than-living world.

What happens to life when we reimagine it as chemistry, interpret it as both utterly biological and as atomic assemblages of matter and energy over time and space? What would it mean to take material change so seriously that we can see how power and politics are wielded through the ordering of atoms and the command of reactions? What would happen if we viewed the chemical industries as more than producers of toxins and pollutants—despite the fact that they are—and instead see them as always already present in everything we do, as literally part of us? What would it mean to use chemistry to think more broadly about the entropic fragility and precariousness of life in a capitalist epoch? What will a work of art mean in an age of 3D printing and nanofabrication? What would it mean to place chemical species front and center in multispecies ethnographies? What would a chemically just future look like? These are the types of questions that we seek to explore and *GeoHumanities* offers us a perfect place to begin.

This compendium brings together multiple and diverse approaches to thinking about chemical geographies. Julie Guthman examines the limits of spatial management and nature of toxic proof through soil fumigant regulation in California. In spatializing the movement of chemicals and people, she argues that the structure of current pesticide regulation not only privileges certain lives as more worthy of protection, it also fails to come to terms with the materiality of the chemicals they regulate, how these chemicals interact with particular populations, and how interactions with these chemicals today shape humanity's future. Ryan E. Galt ponders a few new territories chemical geographies might explore. In particular, he sees "psychotropic" and "elemental" geographies as key areas of future geographic scholarship, making a case for moving beyond "pollution" geographies and drawing attention to the seemingly unlimited realms that chemical geographies could explore. Matt Huber asks what "chemical dialectics" would look like. Drawing on the political economy of industrial nitrogen, he explores how the chemical industry embraces and overcomes the contradictions of reaction rates and reaction yields, and calls on geographers to think more broadly about the role of chemistry as a productive force.

Becky Mansfield explores what it would mean to think of life-as-chemistry. More specifically, she challenges us to think beyond the biologic, the geologic, and the molecular, to the fact that chemicals are both the building blocks of life and the mechanisms of life. Adam M. Romero bids us to think about our chemical future by prophesizing the coming of a new age chemical age. Addressing the likelihood that chemicalization will be an even greater part of future industries and everyday lives, he wonders what enchanting objects a twenty-first-century

chemical industry will bring and who will bear the brunt of these new rounds of commodity production. Suzana Sawyer takes us deep into the “dizzying complexity” of crude oil chemistry by highlighting how mixtures of thousands of hydrocarbon molecules—and how science has produced them as toxic or not—confounds and complicates claims of harm from oil pollution in the Ecuadorian Amazon. Finally, she uses the idea of “mixt” in opposition to “mixture” to probe the nature and becoming of chemical combinations.

Exploring how our lived realities, our cultures, the physical world, and our futures are inherently chemical, the pieces in this compendium make clear that chemistry is not only central to how we learn about the world, but also to how we understand the nature of being. Chemical geographies are thus always already attuned to the epistemological and ontological questions that arise from studying chemistry and chemicals. As such, it becomes possible to embrace contemporary tropes of chemistry as chemical harm as well as ask new questions about the chemicalized nature of the living and more-than-living world. Collectively, the compendium makes evident that to become “molders of a better destiny,” we must rethink—in all possible ways—humanity’s relationship to chemistry and chemicals (Stine 1942).

EXPOSURE IS NOT CONTAINED: ON THE LIMITS OF SPATIAL MANAGEMENT AND PROOF OF TOXIC AGROCHEMICALS

Julie Guthman, University of California–Santa Cruz

I enter into this discussion on “chemical geographies” in light of my recent research on the biopolitics of fumigant use in California’s strawberry industry. For about fifty years strawberry growers have used chemical fumigants to disinfect soils of weeds, nematodes, and, most important, a set of soil pathogens that cause strawberry plants to wilt and die. Many of these chemicals have come under heightened scrutiny of late because of their toxicity to humans and other creatures. In compliance with the Montreal Protocol on Ozone-Depleting Substances, the United States has just ceased allowing methyl bromide use on strawberry fields, and California’s Department of Pesticide Regulation (DPR) is strengthening mitigation measures beyond those required by the U.S. Environmental Protection Agency (EPA) for the use of other oft-employed fumigants such as chloropicrin and 1,3 Dichloropropene (1,3-D). These mitigation measures are classic technologies of security as discussed in Foucault’s (2007) *Security, Territory, Population* essays: They are based on assessments and probabilities of harm calculated in relation to ensuring commerce. They are also better suited to protect some lives more than others. Indeed, it is the implicit sorting of lives into those that count and those that are apparently dispensable that makes such regulatory apparatuses biopolitical in a Foucaultian sense. Still, as Foucault suggested in his discussion of quarantine, their uneven protection lies in their spatiality—that they are designed to contain threats geographically. In this short contribution, I want to elaborate on this point as it applies to pesticide regulation.

Pesticide regulation and use have generally been more protective of consumers than agricultural workers (Wright 1990; Harrison 2011) and this is no less true for the mitigation measures I discuss here (also see Guthman and Brown 2016). Wright attributed the disregard of farm workers in pesticide regulation to public outcry, which has led chemical manufacturers to create formulations that might be acutely toxic at the work site but dissipate quickly and do not leave

residues. Here I want to argue that the failure to protect farm workers also has to do with the inherent spatiality of mitigation measures and modes of proof. Aside from requiring protective equipment for pesticide applicators and some protective gear for other field workers (evidently unevenly distributed and used), most mitigation measures attempt to control chemicals in space or allocate allowable use in space.

There is good reason for a spatial approach. The effectiveness of these fumigants in controlling unwanted organisms rests on their ability to move through space, especially soil space. Methyl bromide is accordingly missed less for its killing efficacy and more for its ability to disperse the more pathogen-suppressive chloropicrin, with which it was paired, through the soil—and much else, apparently. Therein lies the problem: These chemicals can easily move to spaces where they are not desired. Indeed, methyl bromide could not be contained much at all and was (protractedly) banned precisely because it easily volatilizes and travels into the upper atmosphere. Other fumigants are also prone to drift, causing routine injury to farm workers in nearby fields (as well as neighbors), most acutely felt as nausea, respiratory illness, burning, and neurological impairment (Harrison 2011).

Nevertheless, in attempting to contain drift, these spatially oriented mitigation measures also allow exposure in ways similar to the quarantine. Some examples will illustrate the point. As a rule, the U.S. EPA and California DPR cap the amount of any pesticide that can be applied over a certain time frame within a specific space, often delineated by the U.S. land survey coordinates. Here the assumption is that modulating the density of the chemical in space will keep it below a certain threshold of danger. Yet, a threshold value can hardly eliminate the danger. As Science and Technology Studies scholars have shown, it is an abstracted value that allows some exposure, especially to those in close proximity (Boudia and Jas 2014; Frickel and Edwards 2014). These regulatory agencies also require buffer zones for most of the soil fumigants. Buffer zones are areas between treatment and nearby land uses such as schools, houses, and work sites. The size of these buffer zones is under constant contention—most recently antipesticide activists have been fighting for one-mile buffer zones between treated fields and schools in California. The larger the buffer zone, the less the probability of exposure, but the greater the loss for farmers; strawberry plants grown in buffer zones tend to have low yields, and many wilt and die. The buffer zones are therefore determined on a utilitarian basis, always weighing commercial interests and public health (Guthman and Brown 2016).

DPR additionally incentivizes the use of plastic tarps to cover treatments, with greater “buffer zone credits” for those that are “totally impermeable” versus “virtually impermeable.” Tarps also presumably increase efficacy by keeping the chemical in the ground. Yet, field workers routinely secure tarps, repair tarps, remove tarps, and puncture tarps to plant berries, usually without protective clothing or equipment. Finally, in the use of chloropicrin, the chemical that has mostly replaced methyl bromide (Guthman 2016), DPR offers a choice between monitoring and notification. Notification requires informing neighbors within a certain distance of treated fields of pending fumigations and providing instructions should they feel any negative effects. Monitoring requires spot checks of drift by stationing people at the edge of buffer zones and asking them to report sensory irritation, effectively rendering these human monitors canaries in the coal mine. In short, spatial management of fumigants always requires human exceptions: those who must traverse the zone of containment to ensure others are protected, much like health workers do in medical quarantines.

A separate, although related problem is that spatial modes of proof are ill-equipped to demonstrate toxic exposures, owing to the dynamism of both chemicals and bodies over time. It is not only that many of the models to establish acceptable emissions are based on faulty assumptions such as linear dose–response curves, singular rather than cumulative and interactive exposures, probability rather than stochasticity (Krimsky 2014), and what Krupar (2013) called “random instantiations of scientific measures” (172). It is that people as well as chemicals are mobile, moving far beyond the boundaries of specific farms and buffer zones. With a migrant labor force, working on different crops and in different fields, exposures are multiple and virtually untraceable. These temporal and spatial disjunctures between points of pesticide contact and manifestations of illness create the more obvious challenges for spatial epidemiology.

Yet, the intergenerational effects of certain chemicals and the historicity of bodies give further lie to spatial epidemiology as a technique to verify and potentially improve the effectiveness of spatial management. Through endocrine disruption and epigenetic mechanisms, agro-chemicals can induce bodily changes and illnesses that do not appear until much later in life and sometimes not until future generations come into being (Anway and Skinner 2006; Crews and McLachlan 2006; Bollati and Baccarelli 2010). Crucially, epigenetic research suggests that nutritive deficiencies and stresses are also embodied in ways that are passed down over generations. Effectively, certain racialized populations become particularly vulnerable to environmental insult at the same time that the specific causes become undetectable (Dolinoy and Jirtle 2008; Gravlee 2009; Kuzawa and Sweet 2009; Thayer and Kuzawa 2011). Thinking epigenetically, it therefore becomes nearly impossible to demonstrate a relationship between a site of exposure and a manifestation of illness, defying the static and atemporal relationship between population and space that spatial epidemiology assumes.

Geographical approaches to agrochemical management, in sum, are neither wholly effective nor biopolitically neutral. Still, despite the flaws, they are the basis of the few regulatory models available. To dispense with them in the new Trump world order would be an indication that even fewer lives matter.

CHEMICAL GEOGRAPHIES: USEFUL CONCEPTS AND NEW TERRITORY

Ryan E. Galt, University of California–Davis

Chemical geographies is a nascent geographical subfield that could be composed of perspectives and theories from human and physical geography, political ecology, environmental justice studies, biogeochemistry, and green chemistry. It offers opportunities to combine an examination of the spatial distribution of chemical substances and their transformations with the social, ecological/biophysical, and socio-ecological processes that cause these distributions and transformations.

As it gets going, chemical geographies will likely primarily emphasize synthetic chemicals. I note here useful concepts for chemical pollution geographies, and I also argue to push chemical geographies to expand into three critical subareas not centered around pollution. First, *elemental geographies* will focus on specific elements that are core to human survival and well-being. Second, *psychotropic geographies* will focus on those substances and their provisioning that alter human mental states. Finally, *green chemistry geographies* will examine the expanding

efforts to find and commercialize useful and less toxic chemical compounds, including natural plant chemicals (Balandrin et al. 1985). These examples show that chemical geographies can be at the cutting edge of much needed socio-ecological research.

Chemical Pollution Geographies

“Better living through chemistry,” a common saying used last century, was adopted from DuPont’s slogan (Alatzas 1999, cited in Benson 2015, 104). Synthetic chemical compounds radically transformed many human activities: agriculture, manufacture and consumption of food and durable goods, housekeeping, and pollution and waste creation (Wright 1990; Beck 1992; Steingraber 1998). These synthetic chemical compounds have a highly visible side—new durable and consumable goods—and a shadowy, largely invisible side—pollution and its harms, paid unevenly based on social differences of race, class, gender, and location vis-à-vis the Global South and Global North (Bullard 1993; Colborn, Dumanoski, and Myers 1997; Galt 2009, 2014; Moore 2012). Humans have created more than 85,000 new synthetic chemicals while knowing relatively little about their health consequences; when the United States passed the Toxic Substances Control Act in 1976, 60,000 of these were “grandfathered” in, with toxicity reviews not required (Schlesinger 2016).

Pollution by synthetic chemicals has rightfully received considerable attention. “Waste as hazard,” mostly in the form of synthetic chemicals, has been a main focus of environmental justice scholars (Moore 2012), and political ecologists have examined synthetic pesticides and fertilizer use in agriculture (Galt 2014). Pollution will undoubtedly be important within chemical geographies; thus, within this realm, I want to suggest the further utility of two concepts.

The first is in relation to detecting synthetic chemicals, which poses considerable challenges, even for institutions with large budgets and technological prowess. Here the concept of a *demiopic* (half-seeing and half-blind) analytical and regulatory apparatus is useful. My research on pesticide residues shows how some pesticide residues are fugitives, not found by the Food and Drug Administration’s analytical chemistry screens used to test imported produce for residues (Galt 2010, 2011). The concept of a demiopic analytical and regulatory apparatus shows that chemicals are approved despite the challenge and expense of detecting them. A corrective measure would be that, at the very least, suspected hazardous substances must be easily detected before being approved.

The second concept is useful in the context of linking exposures to specific health outcomes, which can be even more difficult (Brulle and Pellow 2006), but is not the only strategy for preventing harm. Van den Bosch (1980) introduced the concept of *molecular privacy*, and how pesticides violate it: “the general populace is exposed to and often absorbs molecules that, whether benign or potentially harmful, are recklessly dumped into the environment by persons who cannot be held to account. Every individual has a right to maximum molecular privacy, and it is society’s responsibility to guarantee that right” (184). Rather than descending into the argument that requires damage to be proven, the right to molecular privacy dovetails with the precautionary principle, as it does not require damage to be proven to be avoided (O’Brien 2000).

Elemental Geographies

One of the greatest challenges humanity faces is metabolic rift, the gap between the nutrients put into our agricultural systems (largely nitrogen, phosphorus, and potassium) and the failure to

return these nutrients to the soil once consumed by humans (Foster 2000). Mending the metabolic rift through *metabolic suture* means we must use our human waste on the fields that feed us. Chinese society has had a long tradition of using night soil (human feces) within their agricultural systems (McDonough and Braungart 2002), and this is still practiced today. Human urine is the main excretion route for nitrogen, phosphorus, and potassium, and it is largely free from infectious disease, so interventions that collect urine and disperse it to agricultural fields will be a crucial strategy (Steinfeld 2004). Indeed, interdisciplinary projects in Sweden and Australia have examined these systems (Mitchell, Fam, and Abeysuriya 2013). Geographers can make important contributions to metabolic suture because widespread adoption of these nutrient recycling systems requires social change centered on reimagining societal relationships with their environments.

Psychotropic Geographies

Psychotropic substances are chemical compounds that affect brain function, including changes in consciousness, perception, and mood. The vast majority of legal psychotropic consumption is through plant foods and beverages. Coffee, tea, and chocolate provide the world's legal stimulants, and the world's main depressant, alcohol, comes from yeast and plant sugars. Vast amounts of human effort go into procuring these substances, which, although nonessential for biological survival, affect human well-being in complex ways. Sipping green tea and eating dark chocolate can clearly improve well-being, yet psychotropic substances can cause considerable suffering in both producing communities (e.g., child slavery in the cacao industry in Côte d'Ivoire [Off 2008]) and consuming individuals (e.g., alcoholism). For coffee, tea, and chocolate, the commodity chains and tropical places in which they are rooted are well understood through political economic and ecological perspectives (Mutersbaugh 2002; Bacon 2005; Besky 2013), which could yield interesting insights when combined with sensory science and psychology, or with philosophy and other humanities disciplines concerned with human well-being. This is promising new ground for chemical geographies.

Green Chemistry Geographies

Green chemistry attempts to create useful and safe chemical substances while minimizing the creation and use of hazardous substances and use of nonrenewable resources (Anastas and Eghbali 2010). Iles and Mulvihill (2012) advocated for “an interdisciplinary approach to green chemistry [that] uses collaboration and integration between the various experts and actors to increase information flows along the product life cycle and feed data into repeating cycles of design based on learning about how the product performs and affects the environment” (5647). Geographers can contribute to these efforts by examining the socioecological relations across the green chemistry product life cycle.

In summary, investigating and theorizing chemical geographies by stitching together the areas I just outlined—chemical pollution geographies, elemental geographies, psychotropic geographies, and green chemistry geographies—can help solve important problems, and offer a number of insights. Examining these human–chemical relationships will further break down the false binary between human and natural, and illustrate the interconnectedness of all things.

CHEMICAL DIALECTICS

Matt Huber, Syracuse University

Chemistry is ... the study of change.

—Walter White, Season 1, Episode 1, *Breaking Bad*

There is another field that could be called “the study of change”: dialectics (Ollman 1971). Ever since *The Dialectical Biologist* (Levins and Lewontin 1985), we have grown accustomed to thinking about “life” dialectically—life as a process rooted in a relational system of energy, waste, death, and renewal. Yet the world is more than life. The world is made through larger than life chemical processes that include much “matter” that is nonliving (e.g., the “past life” of fossil fuels and nonliving elements like iron). A process-based view of dialectical chemistry would focus on chemical reactions and the molecular processes of transformation that constitute the material world. It is one thing to apply a “dialectical” analysis to capitalist society. It is quite another to apply a dialectical analysis to chemical processes of capital accumulation.

My recent research has examined nitrogen. The production and reproduction of life is at its core a chemical story of the nitrogen cycle through plants, bodies, and wastes. Nitrogen forms the basis of our biological bodies forming proteins and amino acids. How would we think about the historical specificity of nitrogen–society relations and the chemical “mode of production” (cf. Clark and Foster 2009)? Marxian analysis of the “productive forces” often equate them with mechanical energy and machines. Although we conflate mechanization with industrialization, Romero (2016, 72) pointed out we need to distinguish a process called “chemicalization.” Marx wrote during a period that was only in the early stages of what Haynes (1933) called the “chemical revolution of industry” (226). This revolution is not purely about substituting mechanical for human power, but rather a different kind of substitution, “The production of chemical substitutes for natural products” (Haynes 1933, 153).

An example is the development of synthetic ammonia as a substitute for “natural” nitrate deposits in manure, guano, or saltpeter fields. Industrial capitalism relies on a disposable workforce whose wages rise and fall directly with the price of food. As more people were displaced from agriculture, agricultural productivity hinged on access to nitrogen: Capital needed a “nitrogen fix” (see Leigh 2004). The solution lies in the atmosphere (79 percent of which is nitrogen gas, N_2), but this form of nitrogen is nonreactive. It cannot form the bonds with hydrogen to create ammonia (NH_3).

So how to make the atmospheric nitrogen into reactive nitrogen (ammonia)? How do you privatize the commons of the atmosphere? In the process of chemical production, the focus is less on mechanical power, and more on the process conditions of chemical reactions. These conditions are produced through heat and pressure that maximize the yield of a product (and create wastes). The goal of the ammonia synthesis reaction is to get nitrogen and hydrogen molecules to combine. The “problematic” of ammonia synthesis in the chemical industry reads like a classic Marxian contradiction. The thermodynamic equilibrium—conditions where the yield of ammonia would be the highest—is most favorable at lower (close to room) temperatures, but at these temperatures the rate of the reaction (referred to as kinetics) is painfully slow. The thermodynamics and kinetics are in contradiction.

Of course, capital is most concerned with the temporalities of production to maximize surplus value. The standard solution to bad kinetics (slow rate) for the chemical engineer is to raise the temperature. Yet, this makes the thermodynamic equilibrium conditions less favorable and produces a lower yield. This is also intolerable from the perspective of capital. As Haynes (1933) put it, “Maximum yield is, therefore, of prime importance in chemical enterprise; more essential to profitable operation than low labor costs” (45).

The solution is twofold. First, you can increase the thermodynamic equilibrium conditions by raising the pressure along with temperature. Here we are starting to come up against economic constraints. There are energy costs to heat and compression (natural gas is used both as fuel to create heat and drive steam turbine compression). Second, you can add a catalyst (often a metal like iron) that allows the reaction to take place at lower temperatures and pressures. This might seem easy enough, but it took scientists decades to find a suitable catalyst for ammonia synthesis. Between 1904 and 1922, it is estimated that Fritz Haber and Carl Bosch tested different catalysts 20,000 times (Appl 1976, 48). After World War I, the United States set up the Fixed Nitrogen Research Laboratory to focus principally on catalyst research (Clarke 1976). Still, synthetic ammonia production in the United States really did not take off until World War II (Appl 1976, 50–51). Only through this long process of grafting chemical processes to capital accumulation was a “fix” found to reshape agriculture and the costs of labor power.

Despite narratives of the Anthropocene, we have barely skimmed the surface of thinking dialectically about the biogeochemical world. Dialectics not only allows us to understand chemical production as a process of reactions and molecular transformation, but also allows us to grasp the relations between material forces—heat, pressure, catalysts—and social forces of capital accumulation. Since World War II, the chemical industry has promised “better living through chemistry.” Those of us seeking to build more secure lives beyond capitalism must think seriously about how we can revolutionize the chemical conditions of life itself.

LIFE-AS-CHEMISTRY

Becky Mansfield, Ohio State University

Chemicals and chemistry are a surprising theme in the range of attempts this century to rethink the nature of “life.” Humanists and social scientists explicitly aim to overcome entrenched ideas of modernity (e.g., of human–nature dualism and human exceptionalism), as biologists and earth scientists discover new ways that the boundary between nature and society, body and environment is blurry at best. In reading across these new approaches to understanding life, I have found chemicals and chemistry to play a key role. The post–World War II era offered us “better living through chemistry,” in which chemicals were an external force that could make life better. The early twenty-first century offers us life-as-chemistry: Chemicals are internal to us and, even more, chemical signaling comprises the mechanism of life.

There are a range of examples of the turn to chemicals and chemistry across these literatures. For one, I note the turn to chemicals in the posthumanities interest in metabolism and the nonliving. For example, Bennett’s (2010) book *Vibrant Matter* has a chapter specifically on vibrancy of metals. In work such as this, chemicals have properties we normally ascribe to life, such as vitality and action.

Second, I note the turn to chemicals in related work on the Anthropocene, which emphasizes hydrocarbons. This is not only in reference to climate change and changes to the earth system. In addition, for some scholars the Anthropocene is an opportunity to rethink biological life. For example, Yusoff (2013, 2015, 2016) has a series of articles arguing that life, especially the human, is not just biologic but geologic, and she emphasized rock and hydrocarbons. Mackenzie (2014) similarly referred to “having an Anthropocene body,” which is specifically about hydrocarbons.

Yusoff was explicit that her “geologic life” is a rejoinder to my third example, which is the widely commented on “molecularization” of life. As discussed originally by scholars such as Rabinow and Rose (2006) and Braun (2007), molecularization is scalar (life as microorganisms, cells, and, especially, genes) but remains resolutely biological—hence Yusoff’s criticism that these ideas are not “mineral” enough. Note, however, that even the term itself calls attention to the chemical: The *molecular* is about the chemical *molecule*.

This is made even more explicit in my fourth example. Across the natural and social sciences, the most recent work on molecularization emphasizes not the gene per se but the role of the environment. The further scientists look to the molecular, they find the wider environment. What is the environment that acts molecularly, though? It is, no surprise, molecules: It is chemicals. One fairly narrow version of this is like the Anthropocene. In this view, humans have unleashed an amazing chemical force that not only causes environmental change, but also changes the nature of the body. We, children of the twentieth and twenty-first centuries, are chemically transformed beings; we become “toxic bodies” to use Langston’s (2010) phrase.

There is also a much broader version, about which I have written with Guthman (Guthman and Mansfield 2013; Mansfield and Guthman 2015). In the emerging science of environmental exposure, in fields such as epigenetics, all environments are understood as chemicals. Ecological, biological, political, economic, cultural, social, and other dynamics all become biological as chemicals that come from outside the body (that we ingest in food and water, breathe in air, that cross directly through our skin and placentas), or as chemicals that are made inside the body in reaction to external events (e.g., stress or love). These chemicals then act (are lively!) within cells, shaping how genes themselves are expressed. In this view, genes are not the book of life, but environments—that is, chemicals—write life with genes as just one set of information.

My proposition is that it is not a surprise that all these seemingly different ideas, from across the academy, are converging around these themes. Whereas Yusoff posed the molecularization paradigm as opposed to new ways of thinking in the Anthropocene (molecular vs. mineral), I propose instead that all these ideas—including hers—are emerging part and parcel with each other. The point here is neither to celebrate nor critique, but to diagnose a new style of thought about life-as-chemistry: about bodily and earthly life, about human and nonhuman life. This is not simply “life is built out of chemical molecules.” Not simply “chemicals are like life.” Not simply “the anthropogenic chemical onslaught changes life.” Not simply “life is mineral.” Rather, what connects these is the chemicalization of life itself.

Landecker (2013, 2016) got at this in her work on signaling and metabolism. She noted that in contemporary thinking metabolism is not about the “chemical factory” (chemicals as material building blocks), but instead is about metabolism as a “regulatory interface.” This is what I think is key: Life-as-chemistry is about life as a vast system of “signal cascades.” Life is understood as the emergent property of complex flows of chemicals with great temporal and spatial complexity. Not just about lively chemicals, this is about extending the properties of chemical systems—bonds and reactions, cues and signals—to life itself.

OUR CHEMICAL FUTURE

Adam M. Romero, University of Washington Bothell

When it comes to the chemical industry, I know better than to predict the future, but I am going to try anyway. The one thing I do know—that we all know—is that industrially produced chemicals are not going away. In fact, they are likely to become an even greater part of everyday life. This seems hard to imagine, as we are always already haunted by the material specter of production past (Kallet and Schlink 1933; Randolph 1962; Jenkins 1972; Simonich and Hites 1995; Altman 2015). Nevertheless, all signs point in that direction.

I am not bold enough to predict, as chemists and futurists in the interwar years did, that one day we might eat fully synthetic food like PetroPizza or soar across the sky in planes made from plastic, although in a way we already do (Birkenhead 1930; Churchill 1932; Morrison 1937; Rosin and Eastman 1952). Nor do I share in the “chemivision” of William Hale, the prominent professor and Dow chemist who proposed that a blend of Judeo-Christian religiosity, bioeconomics, and chemistry would lead us to the promised land of a capitalist society without want (Hale 1952). What each of these would-be prophets had figured out, after all, was that with chemistry, commodity production could “not only emulate nature but even to excel her in certain fields of creation” (Stine 1942, 305). They could see how the ability to industrially manipulate the structural elements of matter meant that material possibilities were limitless.

I am willing to venture, however, that the reproduction of capital and thus the modern capitalist economy is premised on processes of substitution, replacement, simulation, opposition, and transfiguration (Marx 1976; Harvey 2007; Schumpeter [1942] 2009). The historian in me knows that chemistry and the chemical industry lie at the heart of these material transformations, especially since the late nineteenth century, when European capitalists first began transforming the wastes of production into colorful simulants and material substitutes (Haber 1958; Marsh [1864] 1965; Marx 1981). Suddenly, “better things for better living” could be “reproduced synthetically and from the cheapest stuffs” (Roberts 1936; Leslie 2005, 47).

Despite a major introduction of chemicals into U.S. industry in the late 1880s, it was World War I that solidified chemistry’s role in both capitalist production and everyday life. During the Great War, no other U.S. industry grew as rapidly as the chemical industry (Haynes 1945; Haber 1971). By the end of World War II, with the addition of petroleum as a chemical feedstock, the path-dependent nature of our current chemical trajectory was already apparent. In hindsight, it wasn’t whether Love Canal, DES, fire retardants, the plastic soda bottle, or those late-night mesothelioma infomercials would happen, but when. Now we all live downstream, some of us closer to the river than others (Steingraber 1998; Singer 2011; Gross 2015).

Whether we like it or not, we all stand witness to the dawn of a new chemical age. New material desires like wearable and implantable devices, new forms of automated and precision manufacturing along with new advances in chemistry, point toward a future in which humanity’s relationship to material stuff will undergo another momentous shift. Add to this the current geographic reconfiguration of chemical production and the global push for green technology and you have a brave new world of material possibilities. What does this mean, though, for those of us who will confront this new commodity production with our bodies and our genomes, for those of us who will live and die as repositories of twenty-first-century chemical hubris (Crooks 2016)?

Prior to 2007, it seemed unthinkable that there could be a chemical renaissance in the United States. Peak domestic oil had supposedly occurred in the early 1970s, and by the mid-1980s, the industry that made chemicals from oil or natural gas found itself chasing the “cheapest stuffs” across the globe. Now the United States is awash in oil and gas and this production is outpacing chemical plant construction (Crooks 2013, 2015; Stacey and Crooks 2016). New oil discoveries make it clear that we are not running out anytime soon (U.S. Geological Survey 2016). Industrial chemicals are made from far more than petroleum, though. They are also made from metals, minerals, gases, salts, and organic materials like corn. Some are available here, some are not. Even when available, environmental and health laws can make them expensive to produce, so other countries often supply U.S. demand. Nevertheless, the chemical world order is changing (Quinn 2013; CNBC 2016; Knapp 2016; Reuters 2017).

The sources and availability of the “cheapest stuffs” are only half of the story, however. The other half—chemistry’s ability to make wonderful things that “transcend sensuousness”—is the far more magical part of the equation (Marx 1976, 163). John Teeple, a prominent chemical engineer during World War I, coined the term *chemicalization* to describe the movement of industrially produced chemicals into commodity production. Chemicals, by his account, proceeded into industry on four fronts: (1) to modify natural products, (2) to save time or lower costs, (3) to create new synthetic products, and (4) to utilize the wastes of other industries (Haynes 1945). Just like Teeple, we stand to witness the coming of a new age of industry’s chemicalization. This time, though, it will not occur alongside late nineteenth- and twentieth-century technologies like the conveyor belt, electrification, and scientific management. Instead, it will emerge in combination with the second machine age, artificial intelligence, nanofabrication, 3D printing, and the rise of biologically mediated, high-precision, “green” chemical production (McCoy 2004; Chandler 2005; Ritter 2010; Jacoby 2013; Brynnjolfsson and McAfee 2014; Davenport 2014; Smith and Anderson 2014; Dow Chemical Company 2015; FT 2015). Possibilities are again seen as limitless, but will we know better this time?

Maybe the material spoils of the commodity frontier will instead placate us, as they always seem to do. I can envision how robotic personal assistants, self-driving cars, and the iPhone 10 might supersede care for our floodplain neighbors. I can imagine how novel and personalized medical cures for dying loved ones might trump our concern for those that staff the pharmaceutical supply chain (Marriage 2016). I can depressingly foresee how our desires for the most enchanting objects could distract us from the perils of climate change and the plight of those who will suffer from their proximity to a twenty-first-century chemical industry. I worry that so much of our chemical future has already been written, that my body, your body, and the bodies of future generations unknown, are already stamped with the imprint of a chemicalized twentieth-century capitalism (Stemmler and Lammel 2009; Skinner, Manikkam, and Guerrero-Bosanga 2011).

I hope that with the knowledge we already have it will be possible to produce and consume industrially produced chemicals without harm. I know others say that it is possible to reap the benefits of a “chemistic society” without suffering any ill effects; that it is possible to internalize all of the externalities; that it is possible to design our way out of the problem (Rosin and Eastman 1952, 166; Ayres 1994; Geiser 2015; Schmidt 2016). Unlike these modern prophets, though, my “chemivision” is cloudy. For now, I see no direct path within capitalism—a system that will always put profits over people—that points toward a chemical future without harm. I truly hope I am wrong.

MODES OF POTENTIALITY

Suzana Sawyer, University of California–Davis

Sink into the Crude Laced Surfaces

A bewildering sensorial profusion gives witness as an entourage of lawyers and scientific experts accompany the judge and examine alleged contamination around oil installations in the Ecuadorian Amazon. Over five years, legal teams representing forest dwellers and the Chevron Corporation complete fifty-four judicial inspections before a provincial court judge assessing the oil wells, separation facilities, pumping stations, pipelines, and waste pits associated with petroleum's so-called development. The judicial inspections consist of multiple parts: surveying the technology used, advancing legal arguments, recording testimony by local residents, and extracting soil and water samples at alleged contaminated sites. So unfolds the litigation in a lawsuit against the second largest U.S. oil company by marginalized Amazonian *campesinos* and *indígenas*—not in the confines of a wood-paneled courtroom, but largely in the humid, oil-stenched, and rain-drenched field of oil operations. Guarded under chains of custody, extracted water and soil samples, the prophets or deniers of toxic contamination, are sent to laboratories for chemical analysis. Based on those analyses, Chevron argues that former oil operations pose no threat to human health; crude still present in the environment is not toxic or of concern. Predictably, the plaintiffs' lawyers argue the reverse: Crude evident in soil and water samples poses a grave threat to human and ecological well-being. The hundreds of pages of raw data on which these assessments are made, although not identical, by and large overlap. Both arguments, however, cohere, albeit in different registers.

Seep into the Chemistry of Crude

Crude oil is a brew of hundreds of hydrocarbon compounds—molecules made of carbon and hydrogen atoms. Some are quite small and easily identifiable; others are large and intricate. All change temporally and spatially. Most profoundly, however, the vast majority of these hundreds have never been studied, let alone significantly analyzed toxicologically. Because of crude oil's dizzying and transforming complexity, hydrocarbon contamination over the latter half of the twentieth century had largely been measured by a gross assessment of total petroleum hydrocarbons (TPH); in the United States, individual states established varying regulations for what constituted permissible levels, ranging from 5,000 ppm to 100 ppm, with the average hovering around 1,000 ppm. Being a gross assessment, TPH levels do not conclusively or precisely indicate the presence or absence of known toxic elements. Given the overall lack of knowledge around the chemistry of crude yet the absolute knowledge that a small set of hydrocarbon compounds are clearly toxic, however, state regulators were confident that TPH measures above a certain level posed a problem.

At the turn of the twenty-first century, however, the fossil fuel industry (with Chevron scientists playing not insignificant roles) established a working group (THP Criteria Working Group, TPHCWG) to thoroughly and systematically rethink how to decipher the chemistry of crude and assess contamination. After seven years of study and the production of five extensive volumes analyzing different aspects of the complex chemical structure of hydrocarbons, the working group devised a new analytic for assessing contamination. Rather than determine the presence of crude oil via TPH, scientists broke down the brew of hydrocarbon molecules into fractions, or equivalent carbon groupings, that reflected

their atomic weight. These equivalent carbon fractions purportedly expressed the molecular function and fate of grouped hydrocarbon compounds. In line with the conventions of toxicological knowledge, aromatic hydrocarbon—those composed of a six-carbon benzene ring—were of most concern, and, more precisely, aromatics that contained one to four benzene rings. These aromatic fractions (EC = > C6–C8, > C8–C10, > C10–C12, > C12–C16, > C16–C21, and > C21–C35) correspond to understandings finally settled, after decades of fraught debate embattled by industry, that a cluster of hydrocarbons are detrimental to health: These include benzene, toluene, ethylbenzene, xylene (BTEX, the source of warnings on gasoline pumps) and seventeen polycyclic aromatic hydrocarbons (PAHs).

As for aromatic hydrocarbons containing more than four benzene rings—those captured in TPH measures—they were of no concern. Laboratory assays declared they were inert, thus once embedded in the environment, they posed no threat to human and nonhuman life. To the oil and gas industry and Chevron's significant benefit, BTEX and light PHAs are volatile and rendered nonexistent over time—a few hours, days, or weeks, depending on the matrix in which they are embedded. The upshot is that because hydrocarbon compounds shift, mutate, disperse, and reconfigure over time, those compounds clearly deemed by industry and now U.S. regulatory science hazardous to health and ecologies disappear over time, precisely as molecularly heavier hydrocarbon compounds sink and nestle into sediment and soil particles, become absorbed by plants, coagulate and float on the surface of heavier sludge and water molecules, or ossify and harden crisp only to seep under the equatorial sun. (For an expanded version of this story, see Sawyer 2015.)

Dwell in Chemical Philosophies

The Ecuadorian lawsuit against Chevron is mind-spinning complex, now spanning over two decades, three continents, and two legal systems. Untangling that complexity is the focus of my current book project. Here, my aim is to pause and dwell for a moment on chemical philosophies.

The chemist's calling to dissolve and constitute bodies into and from their constituent parts harks back to the alchemist. In the eighteenth century, though, Antoine Lavoisier, the revered father of modern chemistry, instantiated the practice as chemistry's defining project: to decompose and recompose natural bodies into “all the substances which we cannot decompose; all that obtains from the final result by chemical analysis” (Lavoisier 1787, 17). The new chemical nomenclature that Lavoisier and colleagues established determined that a compound's name was a listing of its components, a “faithful mirror” (*miroir fidèle*) of the actual composition of material form (Lavoisier 1787, 14). The logic was one of identity; A compound equaled its constitutive elements. With the chemical equation—that is, water = hydrogen + oxygen—chemistry was able to describe, classify, catalog, and analyze a chemical compound by its constituent elements, and elements by virtue of their behavior in a compound. The equation signaled an “equality” between the body examined and elements obtained (Lavoisier 1789, 140).

By the mid-nineteenth century, John Dalton's theorizing of the atom displaced Lavoisier's compositional paradigm. Rather than the nature and proportion of constituent elements, what defined a compound was the structural arrangement of atoms and their determined valencies, or bonding affinities, in a molecule and between molecules. Although atomic and molecular formulae exceeded what a list of linked elements could achieve in accounting for the nature of chemical compounds (where now chemical properties and bonds depended on the charge, energy levels, and spin of electrons), the logic of equivalence remained.

At the turn of the twentieth century, chemist-philosopher Pierre Maurice Duhem lamented that molecular architecture and atomic structure, the dominant paradigm for analyzing chemical worlds, was incapable of capturing or “providing an exhaustive explanation of chemical transformation” (Bensaude-Vincent and Simon 2008, 126). As philosophers of chemistry, Bensaude-Vincent and Simon (2008) noted, the “enigma of chemical composition” escaped structural and equivalent logics (127). Of concern was the quandary of the “mixt,” that product of the coming together of parts that in turn disappear in the process of forming a genuinely new entity. Either there is the mixt and the properties of its constituents are lost, or there are the decomposed constituent properties and the mixt is lost. There is never both, though, and they are not the same. Duhem worried that chemical nomenclature and structural atomism were analytical models that led chemists to “imagine that the reactants were actually present in the compounds formed by their reaction” (Bensaude-Vincent and Simon 2008, 196). He wrote, “The chemical formula in no way expresses what really persists in the compound but rather that which is potentially there, that which can be extracted by the appropriate reactions” (Duhem [1902] 2002, 151; Needham 2002, xvii). The distinction between the mixt and the mixture is instructive. The mixture is the combining of entities that retain their qualities (as if, in H_2O , hydrogen and oxygen are present as hydrogen and oxygen), whereas the mixt is the combining of entities that when combined no longer exist (i.e., hydrogen and oxygen combine to form H_2O , but subsequent to combining they are not present; they are only there in potentiality, not actuality). The question, posed long ago by Aristotle, was, “what is the mode of existence of the elements that enter into a mixt?” (Bensaude-Vincent and Simon 2008, 195).

Since Lavoisier decomposed water in 1785, chemistry has been conscious that the capacity to evince elements and their properties is relative to the analytical techniques at hand. This antiessentialist stance takes elements not as invariable building blocks of nature but as vital tools “bound to laboratory operations” (Bensaude-Vincent and Simon 2008, 202). The chemical formula—that is, C_6H_6 (benzene) or an equivalent-carbon fraction—does not signal a molecule’s intrinsic structure, but rather serves as rigging for deciphering behavior and properties from experimental techniques that compel and register molecular agency. Thus, the light equivalent-carbon fractions known to be volatile and toxic and for which Chevron tested ($> C_6-C_8$, $> C_8-C_{10}$, etc.) reflect less the fundamental nature of these molecules than how chemists evince them, “in particular the use they can put [them] to, and what useful performances they can get out of [them]” (Bensaude-Vincent and Simon 2008, 206). In the irreducible multiplicity of chemistry’s world, a world “populated by individuals with a range of capacities to put themselves in relation with one another,” the work is to understand how the entities at stake “exist not only in the mode of actuality but also in the complementary mode of potentiality” (Bensaude-Vincent and Simon 2008, 209). That those heavier equivalent-carbon fractions are thought to be inert and benign (the basis for why industry claims that they pose no danger) reflects less the essence of these molecules and more the lack of relevant techniques at hand needed to obtain signification. Said differently, rather than determining what these compounds are, assumptions about inertia more clearly reflect the inability to capture the modes of potentiality that inhere. In the presence of the vast unknowns of hydrocarbons’ dazzling complexity, a reliance on THP sustains the recognition that yet to be registered capacities suffuse the mixt.

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