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The Alchemy of Capital: Industrial Waste and the Chemicalization of United States Agriculture

Author
Romero, Adam M.

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The Alchemy of Capital:

Industrial Waste and the Chemicalization of United States Agriculture

By Adam M. Romero

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Committee in charge:

Professor Nathan F. Sayre, Chair
Professor Richard A. Walker
Professor Robin L. Einhorn
Professor Garrison Sposito

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Adam M. Romero

Abstract

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Along with mechanization and scientific plant breeding, modern forms of industrial agriculture are premised on the use of synthetic chemicals to sustain yield, irrigate fields, decrease erosion, and provide defense against pests and disease. Chemicalized agriculture has its origins in the late 19th and early 20th centuries as the presence of industrially produced chemicals became available on domestic and international markets, as crop production specialized, and as scientists, farmers, and policy makers turned to chemicals to "fix" fertility, pest, and labor issues. While the use of agricultural chemicals has created the conditions for astonishing yields, their generalized use has also resulted in the pollution and degradation of ecosystems, harmful effects on consumers and farm workers, and large greenhouse gas emissions.

This dissertation investigates the relationships between the late 19th and early 20th century US mining, chemical, and petroleum refining industries, their waste byproducts, and the promotion and naturalization of economic poisons in US agriculture. Specifically, I explore the transition from the ad hoc use of economic poisons on US farms to the use of economic poisons as an agricultural necessity by focusing on the complex and multidirectional links between industrial and chemical waste and the use of a rapidly industrializing and specializing agriculture as an efficacious and profitable outlet for industrial byproducts. Drawing from fourteen archives across the US, I use the history of mining and smelting companies, chemical and petrochemical manufacturers, marketers and dealers, industrial R&D, governmental institutions, university scientists and extension agents, capital investment, environmental regulation, the military, along with politics of an inchoate toxicological science, to narrate the political economic thresholds of industrial waste's transmutation and US agriculture's chemicalization. In other words, I relay the historical and political economic origins of economic poisons in US agriculture from the mid 1860s to the end of WWII through the lens of industrial waste.

"Go forward, Faustus, in that famous art
Wherein all Nature's treasure is contain'd:
Be thou on earth as Jove is in the sky,
Lord and Commander of these elements."

C. Marlowe, *The Tragical History of Doctor Faustus*, 1616

To all who have mixed their labor with the soil, and to all who ever will

Acknowledgments

My debts of gratitude are too numerous and too great to be captured in a few paragraphs. However, I would like to acknowledge my dissertation committee and the graduate students that made this adventure possible. The Martin Institute (Geraldine F. Martin, President), the Chemical Heritage Foundation, along with UC Berkeley's Bancroft Library Fellowship and the UC Office of the President's Dissertation Year Fellowship provided funding for the project. I also want to thank all the librarians and archivists that I encountered over the last few years. Lastly, I want to thank my partner, Shannon Cram, who taught me to love the written word. Words cannot express my affection.

Preface:
When I Grow Up I Want To Tell Stories

"The 'control of nature' is phrase conceived in arrogance, born of the Neanderthal age of biology and philosophy when it was supposed that nature exists for the convenience of man. The concepts and practices of applied entomology for the most part date from that Stone Age of science. It is our alarming misfortune that so primitive a science has armed itself with the most modern and terrible weapons, and that in turning them against the insects it has also turned them against the earth."

Rachael Carson, *Silent Spring*, 1962[1]

In 1980, George Lakoff and Mark Johnson published their seminal book *Metaphors We Live By* in which they argued that "human thought processes are largely metaphorical."[2] More than simply rhetorical flourish, as Aristotle suggested, metaphors shape everyday thought and practice. "If we are right in suggesting that our [ordinary] conceptual system is largely metaphorical" they wrote, "then the way we think, what we experience, and what we do everyday is very much a matter of metaphor." Metaphors are incredibly powerful are shape how we think, act, imagine, and relate to the world. Metaphors tell stories.

What Lakoff and Johnson suggested, and what has been confirmed in countless cognitive science and neuro-linguistic studies since is that the subtlest incantation of metaphor can have tremendous influence on how we conceptualize and act to solve social problems. The most prominent recent example of this is a 2011 PLOS One study titled "Metaphors We Think By: The Role of Metaphor in Reasoning," where the authors examined the role of metaphor on how people think about crime.[3] Comparing crime-as-virus and crime-as-beast metaphors (both malevolent forces of nature outside human agency) they demonstrated how metaphor actively shapes how and literally where we think about crime (using fMRI). Many other studies, in kindred spirit with Donna Haraway's *Situated Knowledges*, have shown similar outcomes for the role of metaphor on how science is performed, communicated, and understood.[4] (Besides the military, the other group that is really interested in this area of research is the upper echelon running political campaigns).

To be involved in debates with environmental and agricultural thinkers today, as I am, is to be awash in a sea of economic metaphors. I am told that the market via prices efficiently and apolitically allocates scare resources. I am told that environmental destruction, pollution,

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[1] Carson, R. *Silent Spring*. New York: Houghton Mifflin 1962. 297.
[2] Lakoff, G, and M Johnson. *Metaphors We Live By*. Chicago, Il: University of Chicago Press, 1980. 3-5.
[3] Thibodeau, P H, and L Boroditsky. "Metaphors We Think With: The Role of Metaphor in Reasoning." *PLoS One* 6, no. 2 (2011): e16782.
[4] Haraway, D. "Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective." *Feminist Studies* 14, no. 3 (1988): 575-99.

and contamination are externalities that result from market failure. I am told that our persistence as a species depends on us internalizing these externalities. When this impossible singularity occurs, markets will realign in a new equilibrium of sustainability. But this is not necessarily the case, as internalizing externalities is not by definition a societal good. Efficiency and sustainability, as demonstrated by the likes of William Stanley Jevons more than 100 years ago, are not synonymous.[5] Or as Richard Norgaard, our former colleague and one of the founders of ecological economics liked to put it, "there are an endless number of ways to efficiently destroy the world."[6]

All metaphors are wrong. Some metaphors are useful. But the conceptual and discursive metaphors that dominate how we think about nature, waste, and pollution are garbage. For example, in framing environmental pollution or bodily contamination as an externality – that is as an aberration and something not intrinsic to the nature of the capitalism – we privilege the market as the solution and constrain how we imagine and practice social change. It is from this conceptual framing that we also choose – because their lives are worth less – to contaminate of the poorest among us.

And yet, these metaphors have spread across academia and society writ-large. Take the ecological sciences, for example, where the economic metaphors of ecosystem services and natural capital (which start from the assumption of internalizing externalities) have become the dominant way to think about nature, so much so that many ecologists now perform bad science in their name. This is utilitarian anthropocentrism at its worst; it would even make St. Augustine blush.[7]

"While we cannot dispense with metaphors in thinking about nature," the evolutionary biologist Richard Lewontin wrote, "there is a great risk of confusing the metaphor with the thing of real interest. We cease to see the world as if it were like a machine and take it to be a machine. The result is that the properties we ascribe to our object of interest and the questions we ask about it reinforce the original metaphorical image and we miss the aspects of the system that do not fit the metaphorical approximation."[8] Or as the pioneer cyberneticians Arturo Rosenblueth and Norbert Weiner put it, "the price of metaphor is eternal vigilance."[9]

Unfortunately though, we have not kept watch and the fire of metaphorical vigilance has gone unattended. Externality, efficiency, and market failure now rule the roost. And remember that in this view externalities are reciprocal, meaning there are no victims or perpetrators of pollution and contamination. Instead, there are only individual parties with equal property rights open to bargaining in a system that conflates economic and social welfare.

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[5] Jevons, W S. *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines*. New York: MacMillan And Co., Limited, 1906 (1865).

[6] This is something he would often say in his lectures about the economics of sustainability.

[7] Glacken, G J. "Reflections on the Man-Nature Theme as a Subject for Study." 1966.

[8] Lewontin, R. *The Triple Helix: Gene, Organism, and Environment*. Cambridge, MA: Harvard University Press, 1998. 3.

[9] Quoted in: Lewontin, *Triple Helix*, 1998.

What is the optimal – the most efficient – amount of pollution in your bloodstream? How many new widgets is your child's of your partner's life worth? Do we want to live society where this is the only way to think about pollution and contamination? I sure don't. That is why today I invite you to help me keep the fire going. Come gather round as I throw on some kindling and together we can talk new metaphors and new stories, ones that honor diversity, complexity, impossibility, ambiguity, unknowability, non-human agency, and perhaps most importantly, the substantive conditions of freedom.

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Introduction

"This is Nyodene D. A whole new generation of toxic waste. What we call state of the art."

D. DeLillo, *White Noise*, 1984[1]

Along with mechanization and scientific plant breeding, modern forms of industrial agriculture are premised on the use of synthetic chemicals to sustain yield, irrigate fields, decrease erosion, and provide defense against pests and disease. Chemicalized agriculture has its origins in the late 19th and early 20th centuries as the presence of industrially produced chemicals became available on domestic and international markets, as crop production specialized, and as scientists, farmers, and policy makers turned to chemicals to "fix" fertility, pest, and labor issues. While the use of agricultural chemicals has created the conditions for astonishing yields, their generalized use has also resulted in the pollution and degradation of ecosystems, harmful effects on consumers and farm workers, and large greenhouse gas emissions.

This year, United States farmers will consume about one hundred billion pounds of pesticides to combat pests and ward off yield loss.[2] Yet toxic chemicals have never been necessary for the US to produce sufficient food. Our real problem, like Rachael Carson pointed out over 50 years ago, has always been one of *overproduction* – too much, not too little.[3] Vast numbers of people do go hungry every day, but as Amartya Sen, Michael Watts, William Cochrane, and Mike Davis, among others, have elegantly shown, in market-based agricultural systems, the poor go hungry because they are poor, not because of absolute scarcities.[4] And yet, discourses of famine, hunger, continue to justify the use of pesticides and its infrastructure of war. If not for sufficient food production, then why and how have pesticides become integral to US agriculture? In what follows, I begin to answer that question.

As a result of good intentioned market-based approaches to agrarian reform over the last twenty-five years, the US food system is now bifurcating into one for the wealthy and one for the poor.[5] I applaud the intention, but the agricultural system's change cannot be

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[1] Delillo, D. *White Noise*. New York: Penguin Books, 1985. 138-39

[2] This is my crude estimate that accounts for inert ingredients in pesticide mixes. EPA data only lists active ingredients. See Chapter 3.

[3] Carson, R. *Silent Spring*. New York: Houghton Mifflin 1962.

[4] Sen, A. *Poverty and Famines: An Essay on Entitlement and Deprivation*. Oxford, UK: Oxford University Press, 1983; Watts, M. *Silent Violence: Food, Famine, and Peasantry in Northern Nigeria*. Berkeley, CA: University of California Press, 1983; Cochrane, W W. *The Curse of Agricultural Abundance: A Sustainable Solution*. Lincoln, NE: University of Nebraska Press, 2003; Davis, M. *Late Victorian Holocausts: El Niño Famines and the Making of the Third World*. New York: Verso, 2002.

[5] Guthman, J. *Agrarian Dreams: The Paradox of Organic Farming in California*. Berkeley, CA: University of California Press, 2004; Guthman, J. *Weighing In: Obesity, Food Justice, and the Limits of Capitalism*. Berkeley, CA: University of California Press, 2011.

piecemeal and it cannot rely on price as the system attractor. An entirely new United States agricultural system is needed: one that cleaves the production of food and fiber from the production of surplus value, one that begins by respecting the people that mix their labor with the soil, one that replenishes human health by replenishing the soil. We, unlike Faustus, still have a chance to repent; it is "never too late."[6] Our salvation, however, lies not in conjuring new technologies or new regulatory frameworks, but in better sermons and better stories, and "[b]y what voice other than the orator's is history."[7] To this end I offer the following critical history of US agriculture, a history in which scarcity, the underlying assumption of economics and environmental policy, does not operate.

This dissertation investigates the relationships between the late 19th and early 20th century US mining, chemical, and petroleum refining industries, their waste byproducts, and the promotion and naturalization of economic poisons in US agriculture.[8] Specifically, I explore the transition from the ad hoc use of economic poisons on US farms to the use of economic poisons as an agricultural necessity by focusing on the complex and multidirectional links between industrial and chemical waste and the use of a rapidly industrializing and specializing agriculture as an efficacious and profitable outlet for industrial byproducts. Drawing from fourteen archives across the US, I use the history of mining and smelting companies, chemical and petrochemical manufacturers, marketers and dealers, industrial R&D, governmental institutions, university scientists and extension agents, capital investment, environmental regulation, the military, along with politics of an inchoate toxicological science, to narrate the political economic thresholds of industrial waste's transmutation and US agriculture's chemicalization. In other words, I relay the historical and political economic origins of economic poisons in US agriculture from the mid 1860s to the end of WWII through the lens of industrial waste.

I tell the story of a critical agroecological state-change in the United States – a state-change in which toxic chemicals became necessary for industrial agricultural production. By tracing the biogeochemical fate and transport of industrial waste I demonstrate how pre-WWII agriculture served as a profitable sink for industry's toxic byproducts. Throughout the chapters that follow, I position industrial agriculture as a key site of productive consumption – that is, as a metabolic process where commodities are consumed. As such, this shifts my analysis away from the farm and points it toward the linkages between larger developments in industry and aggregate changes in agriculture. Even so, I maintain the primacy of agriculture's basis in natural processes. Agriculture's fundamental basis in nature means that it holds a unique place as a consumer of other industries' commodities.

[6] Said the good angel to Faustus. Marlowe, C. *The Tragical History of Doctor Faustus*. 1616. 26.

[7] "Historia vero testis temporum…" Cicero quoted and translated in: Guldi, J, and D Armitage. *The History Manifesto*. Cambridge, UK: Cambridge University Press, 2014.

[8] Economic entomologists used the term "economic poison" until the mid 1930s. As such, I use the term interchangeably with pesticide throughout the dissertation. I like the term economic poison because it better captures the political economic nature of pesticides.

The four chapters that follow were written as stand-alone essays. As such, they contain their own unique arguments in reference to specific sets of literature. Thus, the style of each chapter varies and certain empirical information may be repeated between chapters.[9] Nevertheless, across the chapters that follow, I make the following claims:

- Agroindustrial consumption can serve as a site of waste's transmutation whereby the burden of point source waste disposal is transformed into widely distributed inputs and non-point source pollution.
- Chemicalization is a distinct, critical, and often ignored process of industrialization. Understanding the chemicalization of industry is important for understanding the nature industrial waste and its role in the chemicalization of agriculture.
- Industrial agriculture has a unique relationship (among industries) to toxic waste because of its basis in natural processes.

While the above arguments are more explicit in some chapters and more implicit in others, together they serve as the theoretical starting point for each of the chemical histories that follow.

Chapter 1 intervenes directly in contemporary debates surrounding waste geographies and new materialities. The first part of the chapter introduces the history and materiality of arsenic as industrial waste product, situating this history within the 19th century smelting and refining industries and emerging US chemical and agrochemical industries. The second part of the chapter uses this history to engage debates on the nature of waste and value, debates that have completely ignored industrial waste. In this chapter I introduce the place-holder *dark value* as a way to conceptualize the nature of capitalist waste. By returning to first principles – the capitalist labor process and the temporal and spatial nature of value – I argue that dark value must be part any theorization of the nature of nature and the nature of waste under capitalism.

In Chapter 2, through the narrative of a late nineteenth century creation story, I argue that industrial pest control has been imbued with the practices, discourse, materials, and ethics of modern chemical warfare since its inception. I do this to show that the origins of industrial chemical agriculture both on and off the field have a much longer history than most people realize. Industrial agriculture's much-discussed chemical dependency has a long and diverse past that extends well back into the nineteenth century. In the late 1880s, faced with pest-induced collapse, Los Angeles citrus growers and scientists of the USDA and UC Agricultural Extension "fixed" the citrus pest problem by developing and utilizing the cyanide gas chamber. Cyanide fumigation quickly became the toxic cornerstone of the citrus industry, enabling its intensification and expansion as the pest infection became systemic. By the turn the century, furnished with an economic poison made cheap and weapons-grade

[9] This also means that citations start anew each chapter.

due to changes in the world gold mining industry, growers, scientists, and government officials transformed cyanide fumigation into a necessary agricultural input and amalgamated industrially organized agriculture to accelerating and endless chemical warfare. These suddenly necessary agricultural practices signaled a state change in world-ecology and agroindustrial organization, thus, the discovery of effective industrial control for citrus pests was not only a pivotal moment in the history of Southern California but it was also an event that has had world-historical implications. Chapter 2 begins with a preface that situates the above argument in the context of industrial and consumer waste recycling and the 19th century Philadelphia chemical industry.

Chapter 3 begins with the premise that pesticides have never been necessary for the United States to produce sufficient food. I argue that pesticide use has been critical to the production of other goods and services – goods and services that are not critical to the survival of the population but to the survival of a particular form of political economy. Focusing on the interwar period, this chapter explores the *ecosystem services* that industrial agriculture provides to capital, arguing that the rapid adoption of pesticides in American agriculture in the interwar years proceeded on two distinct yet intimately related fronts: 1) as a temporary fix for overproduction in the chemical industry and 2) as a sink for industrial, often highly toxic, wastes. I tell the first history of the Crop Protection Institute to frame my narrative and to make my case. Founded in 1920 under the aegis of the National Research Council, the Crop Protection Institute was a non-governmental organization tasked with linking private industry to public science by bringing together expertise and facilities of state, university, and extension scientists in the emerging fields of crop protection with the toxic materials and capital of a rapidly developing post WWI US chemical industry.[10] Through the industrial, scientific, and political networks of the Crop Protection Institute, chemical manufacturers, agricultural producers, and crop protection scientists collaborated to facilitate new agricultural outlets for primary chemical products and new methods to transmute the growing masses of inorganic and organic industrial wastes from costs of production into valuable and effective pest control products. By helping standardize agricultural toxicology and geographically homogenize crop protection research and pesticide use and through the establishment and naturalization of private-public agro-industrial research networks, the Crop Protection Institute helped shift crop protection to the forefront of capital investment and industrial R&D, laying the techno-social infrastructure necessary for the generalization of industrially produced chemicals across American agriculture following WWII.

Chapter 4 traces two stories of agriculture that merge in late autumn of 1944 on a lettuce field in California's Salinas Valley. On that field, two transmuted industrial waste products from California's rudimentary petroleum economy were at once injected into the soil and into agricultural production, spurring a radical transformation of crop rotation and

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[10] O'Kane, W C. "The Crop Protection Institute: A Get-Together Movement on the Part of Three Great Groups, the Intelligent Grower, the Scientist, and the Businessman," Crop Protection Institute, Washington DC. 1920.

recasting the organizational possibilities of industrial agriculture. Taken together, these two stories tell a tale of capital and chemistry overcoming an ecological contradiction of agroindustrialization. This chapter considers an earlier history of petroleum-based agrochemicals – one that is often left untold – situating their development in the interwar years and within the context of California's emerging petroleum complex. I argue that, in the late 1920s, agriculture began its transformation into a new and immensely productive agricultural regime organized around the oil industry and its waste byproducts. The petrochemicals and subterranean chemical warfare that were developed during this time became industrial agriculture's chemical salvation, providing both the soil disinfection power and the soil nutrition that made the massive yield increases in agricultural production following WWII possible. This chapter begins an excavation of the origins of petroleum chemicals, positioning both the chemicals used in agro-industrialization and the subsoil itself as critical sites of historical inquiry.

In taking agriculture's consumptive role seriously, this dissertation opens a novel window into the industrialization of agriculture and the chemicalized nature of everyday life. In arguing that waste is fundamental to the expanded reproduction of capital, the dissertation's findings have important implications for US environmental and agricultural policy and the political economic theorizations of waste, pollution, and agroindustrialization. Thus, in the conclusion I draw key points of the chemical histories together to highlight role of materiality and scale in industrial waste's production and reutilization and in the chemicalization of agriculture.

Chapter 1

Capital's Demon:
Arsenic, Industrial Sorting, and a Theory of Dark Value

"'Sorting isn't work?' Oedipa said. 'Tell them down at the post office. You'll find yourself in a mailbag headed for Fairbanks, Alaska, without even a FRAGILE sticker going for you.'

'It's mental work,' Koteks said, 'But not work in the thermodynamic sense.' He went on to tell of how the Nefastis machine contained an honest-to-God Maxwell's demon. All you had to do was stare at the photo of Clerk Maxwell, and concentrate on which cylinder, right of left, you wanted the demon to raise the temperature in. The air would expand and push a piston. The familiar Society for the Propagation of Christian Knowledge photo, showing Maxwell in right profile, seemed to work best."

T. Pynchon, *The Crying of Lot 49*, 1965[1]

"One of the most shameful, the most dirty, and the worst paid kinds of labour, and one on which women and young girls are by preference employed, is the sorting of rags."

Marx, *Capital: A Critique of Political Economy*, 1867[2]

The wealth of societies in which the capitalist mode of production prevails appears as an immense collection of wastes. The individual waste appears as the material mirror of its elementary form, the commodity. Our investigation therefore begins with the analysis of waste, the commodity's chiral other.

The Industrial Revolution was a revolution in the scale of waste. By the mid 19th century, as factory owners divided labor into increasingly specialized tasks, as capital begat capital and machine begat machine, the production of wastes gained economies and ecologies of geographic scale. Let's begin with an example:

Scene: Cornwall, England, ca. 1870 – Copper and Tin Works Outside Town (See Figures 1 and 2)

[1] Pynchon, T. *The Crying of Lot 49*. New York: The Penguin Press, 2012 (1965). 86.
[2] Marx, K. *Capital: A Critique of Political Economy* Vol. I, New York: Penguin Classics, 1990 (1867). 592.

Figure 1 – A typical Cornwall scene in the mid 1870s. Camborne looking northeast toward Redruth.[3]

Figure 2 – Typical scene in present day Cornwall. Towanroath Engine House at Wheal Coates Mine, looking south toward Porthtowan.[4]

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[3] Trust, Cornwall Heritage. "Industry in Cornwall: A Brief History from the Industrial Revolution to the Present Day..." http://www.cornwallheritagetrust.org/page_history_industrial_revolution.php.

[4] Mail, Daily. "Tin Cornish Tin Mine Which Has Joined the Taj Mahal, Sydney Opera House and the Northern Lights in the Top Sights in the World to See before You Die." http://www.dailymail.co.uk/news/article-2173124/Taj-Mahal-Sydney-Harbour-tin-mines-Cornwall-Remote-coastal-structures-make-CNNs-global-27-places-die-list.html#ixzz3VskqM8XS.

Setting: You have tagged along with a factory inspector (because you were inspired by reading Marx to become a factory inspector) sent to survey the working conditions of the Cornish mining industry, which at the time accounted for more than half of the entire world's copper, lead, and tin refining capacity. In the process of touring a copper smelter, the owner of the mine takes you and the inspector to a closed off area of the factory. You pause at some large doors. You begin to ask what is behind the doors, but before you can say anything, the owner has already pushed the doors open, revealing mountains of white semi-crystalized powder. You now stare blankly at the piles that he has just revealed, not sure of what to make of it.

"What is it?" you whisper to yourself, barely audible.

The startled inspector gathers himself and replies. It is "a quantity of white arsenic probably sufficient to destroy every living animal upon the face of the earth."[5]

The mine owner responds, "and this is just one month's output of our arsenical waste. Every factory around here produces this, some more."

"But where does it all go?" you ask the factory owner.

Beaming with pride the owner responds, "This here is 'Cornish white,' the highest quality arsenic you will ever see. It puts that cheap Mexican crap to shame. Where does it go? It goes into everything."[6]

It truly did.[7] Besides the environment, of course, in Victorian Britain arsenic went into food, into medicine, into beauty products, and into wallpaper. It went into beer, into candy, and into glass. It went into dyes, pigments, and animal and human poisons of all sorts (ex. ratsbane). Judging from its ubiquity, it was as if this toxic waste product was indispensible.

In the early 1800s, for the first time, arsenic's bio-chemo-active nature – once only a use-value for aristocrats in need of speeding up the arrival of their inheritances or for dispatching political rivals – was democratized. Industrial arsenic became of the people; it saw no class divisions. By the late 1830s, industrial arsenic production-as-waste crossed a waste-value threshold. By mid-century, across southwest England and Wales, the toxic waste of the nonferrous industrial mining industry, the dark products of human labor, had

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[5] British Factory Inspector Report for 1872 quoted in: Arlidge, J T. *The Hygiene, Diseases, and Mortality of Occupations*. London: Percival & Co., 1892. 284

[6] Earl, B. "Arsenic Winning and Refining Methods in the West of England." *Journal of the Trevithick Society* 10 (1983): 9-29; Earl, B. *The Cornish Arsenic Industry*. Cornwall, UK: Penhellick Publications, 1996.

[7] Bartrip, P W. "How Green Was My Valence? Environmental Arsenic Poisoning and the Victorian Domestic Ideal." *English History Review* 109, no. 433 (1994): 891-913; Whorton, J. *The Arsenic Century: How Victorian Britain Was Poisoned at Home, Work, and Play*. Oxford, UK: Oxford University Press, 2010.

become a new source of nature's "free gifts."[8] At the dawn of the Victorian Age, arsenical waste had become a means of production.

Toward Materialist New Materialities

"What happens to politics – and indeed to the "political" as a category – if we begin to take this *stuff* seriously?"

Braun and Whatmore, *The Stuff of Politics: An Introduction*, 2010[9]

Among geographers, waste scholarship has exploded over the last decade.[10] From e-waste to food waste to wastelands, this scholarship has begun to pry apart the complex nature of waste under capitalism. Generally focused on consumer waste and consumer or municipal waste management, this research has accompanied calls among human geographers and the social sciences for greater engagement with materiality, often couched as "new materiality" scholarship. This scholarship, however, has failed to live up to its promise. "Waste," as Gregson and Crane (2010) wrote,

"is intrinsically, profoundly, a matter of materiality and yet… much of what is most readily identified as waste research remains staunchly immaterial. Just as societies have sought to distance

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[8] Marx, K. *Capital: Volume III*. New York: Penguin Books, 1981. 745. "Natural elements entering as agents into production, and which cost nothing, no matter what role they play in production, do not enter as components of capital, but as a free gift of Nature to capital, that is, as a free gift of Nature's productive power to labour, which, however, appears as the productiveness of capital, as all other productivity under the capitalist mode of production."

[9] Braun, B, and S J Whatmore. "The Stuff of Politics: An Introduction." In *Political Matter: Technoscience, Democracy, and Public Life*, edited by B Braun and S J Whatmore, ix-xl. Minneapolis, MN: University of Minnesota Press, 2010. Emphasis in original.

[10] For example: O'Brien, M. "Rubbish Values: Reflections on the Political Economy of Waste." *Science as Culture* 8, no. 3 (1999): 269-95; Strasser, S. *Waste and Want: A Social History of Trash*. New York: Henry Holt and Company, 1999; Gregson, N, A Metcalfe, and L Crewe. "Identity, Mobility and the Throwaway Society." *Environment and Planning D: Society and Space.* 25, no. 4 (2007): 682-700; Bulkeley, H, and M Watson. "Modes of Governing Municipal Waste." *Environment and Planning A* 39, no. 11 (2007): 2733-53; Gille, Z. "Actor Networks, Mode of Production, and Waste Regimes: Reassembling the Macro-Social." *Environment and Planning A* 42 (2010): 1049-64; Gregson, N, M Crang, F Ahamed, N Akhter, and R Ferdous. "Following Things of Rubbish Value: End-of-Life Ships,'Chock-Chocky' Furniture and the Bangladeshi Middle Class Consumer." *Geoforum* 41, no. 6 (2010): 846-54; Gidwani, V, and R N Reddy. "The Afterlives of "Waste": Notes from India for a Minor History of Surplus Capital." *Antipode* 43, no. 5 (2011): 1625-58; Lewpanksy, J, and C Mather. "From Beginnings to Endings to Boundaries and Edges: Rethinking Circulation and Exchange through Electronic Waste." *Area* 43, no. 3 (2011): 242-49; Davies, A R. "Geography and the Matter of Waste Mobilities." *Transactions of the Institute of British Geographers* 37, no. 2 (2012): 191-96; Moore, S A. "Garbage Matters: Concepts in New Geographies of Waste." *Progress in Human Geography* 36, no. 6 (2012): 780-99; Dillon, L. "Race, Waste, and Space: Brownfield Redevelopment and Environmental Justice at the Hunters Point Shipyard." *Antipode* 46, no. 5 (2013): 1205-21; Herod, A. "Waste, Commodity Fetishism, And the Ongoiness of Economic Life." *Area* 45, no. 3 (2013): 376-82; Herod, A, G Pickren, Al Rainnie, and S M Champ. "Global Destruction Networks, Labour, and Waste." *Journal of Economic Geography* 14, no. 2 (2013): 421-41; Hawkins, G, and E Potter. "Waste Matter: Potatoes, Thing-Power and Biosociality." *Cultural Studies Review* 12, no. 1 (2013): 104-15; Pickren, G. "Geographies of E-Waste: Towards a Political Ecology Approach to E-Waste and Digital Technologies." *Geography Compass* 8, no. 2 (2014): 111-24.

themselves from and hide their wastes for fear of contamination, so academia has been shy of the *stuff* of waste." (emphasis in original).[11]

Thus, I follow on recent calls to turn toward the "metal and chemical waste of industrial production" to begin a more material engagement with the scholastically ignored category of industrial waste.[12]

This chapter contends that geographers have failed to devote attention to the geographical nature of industrial waste under capitalism. Unlike historians, economists, and industrial ecologists, who have long-established (although still limited) engagement in researching the chemical industry and industrial waste, geographers have a more reticent relationship with the deployment of chemicals, chemical production, and industrial byproducts, as research agendas.[13] Despite repeated calls more than a decade ago, following the cultural turn, for the rematerialization of geography, this chapter demonstrates how human geographers could benefit from greater engagement with the biogeochemical materiality of commodity production – "the stuff of politics."[14]

As Gregson and Crane concluded in their much-cited editorial, it is not just that "materiality matters to the development of waste scholarship but that a focus on industrial waste matters to the development of work on materiality."[15] This chapter signals a much broader agenda in geographical research that takes fuller head of material attributes of commodity production and consumption and challenges human geographers in particular to engage further with the materiality of the materials and processes they study. In doing so, it opens a broad arena of industrial production and consumption for geographic scholarship at a critical time when the ontological politics of stuff has extensive implications for the persistence of *Homo sapiens*.

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[11] Gregson, N, and M Crang. "Materiality and Waste: Inorganic Vitality in a Networked World." *Environment and planning A*. 42, no. 5 (2010): 1026-32

[12] Gregson and Crane, "Materiality and Waste," 2010. This collection of scholarship is calling for a reorientation of geography and social science toward the biophysical world as necessary for understanding the social and political life of people, places, and things. They are claiming that scholarship on the materiality of waste still remains immaterial. That of course brings up many possible explanations, one being that human geographers, for the most part, are not trained in the natural or physical sciences. Whether this is case or not, it does seem apparent that any large move toward the "rematerializaion" of human geography, in a serious manner, would have to involve not just novel scholarship, but new approaches to education and training.

[13] Colten, C E. "Creating a Toxic Landscape: Chemical Waste Disposal Policy and Practice, 1900-1960." *Environmental History* 18, no. 1 (1994): 85-116; Tarr, J. "Industrial Waste Disposal in the United States as an Historical Problem." *Ambix* 49, no. 1 (2002): 4-20; Rosen, C M. "'Knowing' Industrial Pollution: Nuisance Law and the Power of Tradition in a Time of Rapid Change." *Environmental History* 8, no. 4 (2003): 565-97; Quivik, F L. "The Historical Significance of Tailings and Slag: Industrial Waste as Cultural Resource." *The Journal of the Society for Industrial Archeology* 33, no. 2 (2007): 35-52; Desrochers, P. "Does the Invisible Hand Have a Green Thumb? Incentives, Linkages, and the Creation of Wealth out of Industrial Waste in Victorian England." *The Geographic Journal* 175, no. 1 (2009): 3-16; Cooper, T. "Peter Lund Simmonds and the Political Ecology of Waste Utilization in Victorian Britain." *Technology and Culture* 52, no. 1 (2011): 22-44. There are still calls within history for more engagement with industrial waste. For example: Tarr (2002) argues that "we must also understand how those materials came to be, why those particular substances, and not others, were mobilized and transformed, what their uses are, and how the particular physical characteristics of those compounds limit their use, reuse, and safe discard." Tarr P. 1051

[14] Gregson and Crane, "Materiality and Waste," 2010; Kirsh, S. "Cultural Geography I: Materialist Turns." *Progress in Human Geography* 37, no. 3 (2013): 433-41; Jennings, Ivor. *Party Politics*. Vol. 3: Cambridge University Press, 1962. 1.

[15] Gregson and Crane, "Materiality and Waste," 2010. 1031.

Current political economic scholarship tends to read industrial waste through lenses of market and production efficiency, and it is through these polarized glasses that scholars across diverse fields have categorized the waste products of socioecological metabolism as "externalities."[16] But, by doing so, these scholars conceptually relegate waste – the commodity's chiral other – to a lesser or minor history.[17] Instead, if one insists that the production, utilization, and circulation of anthropogenically sorted waste are *fundamental* to the expansion and maintenance of capitalism, terms such as externality lose their theoretical purchase, and the acts of commodity production and consumption can be reimagined as sites of waste's transmutation.[18] Thus, reconceptualizing the nature of waste is critical for understanding not only the productive role of waste in commodity production and everyday life, but also the nature of capitalism. This chapter considers waste reutilization, as Marx insisted, as one of two fundamental scaling functions of post-1850s capitalist organization.[19]

Tacking on Gille's observation that "industrial and, in general, production wastes are rarely accessible to fieldwork methods," I utilize an historical case-study approach to remedy this methodological limitation and provide an empirically grounded discussion on the materiality of industrial waste.[20] Through a history of waste arsenic from the early 1800s to WWII, this chapter introduces the conceptual place-holder *dark value* and highlights the dark value produced in the labor process whose spatial and temporal paths to realization diverge greatly from value that capital can see. By returning to first principles – the capitalist labor process and the temporal and spatial nature of value – this chapter argues that dark value must be part of any theorization of the nature of nature and the nature of waste under capitalism.

The first part of the chapter introduces the history and materiality of arsenic as industrial waste product, situating this history within the 19th century smelting and refining industries and an emergent chemical and agrochemical industry. I build on Gille's (2010) concept of waste regime, where "waste itself–its production, its consumption, and its circulation, and metamorphosis is constitutive of society," and Larkin's take on infrastructures, or the built environments

"that facilitate the flow of goods, people, or ideas and allow for their exchange over space. As physical forms they shape the nature of a network, the speed and direction of its movement, its

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[16] Coase, R H. "The Problem of Social Cost." *Journal of Law & Economics* 3 (1960): 1-44; Ayres, R U, and A V Kneese. "Production, Consumption, and Externalities." *The American Economic Review* 59, no. 3 (1969): 282-97; Benton, T. "Marxism and Natural Limits: An Ecological Critique and Reconstruction." *New Left Review* 178 (1989): 51-86; Horton, S. "Value, Waste and the Built Environment: A Marxian Analysis." *Capitalism Nature Socialism* 8, no. 2 (1997): 127-39; Baumgärtner, S, and J Arons. "Necessity and Inefficiency in the Generation of Waste." *Journal of Industrial Ecology* 7, no. 2 (2003): 113-23; Soper, K. "Waste Matters." *Capitalism Nature Socialism* 14, no. 2 (2003): 129-34; Moore, J. "Cheap Food & Bad Climate: From Surplus Value to Negative-Value in the Capitalist World-Ecology." (2014).

[17] Gidwani and Reddy. "The Afterlives of "Waste," 2011.

[18] Marx, *Capital, Vol. I*, 1990.

[19] Marx, K. *Capital: Volume III*. New York: Penguin Books, 1981.

[20] Gille, "Actor Networks, Mode of Production, " 2010.

temporalities, and its vulnerability to breakdown. They comprise the architecture for circulation, literally providing the undergirding of modern societies, and they generate the ambient environment of everyday life… Their peculiar ontology lies in the facts they are things and also relations between things."[21]

I utilize the concepts of waste regime and infrastructure to conceptualize the industrial networks of arsenical waste as well as the social and cultural shifts – humanity's changing relation to nature – that were co-constitutive of and a necessary given for these new networks of waste reutilization to function.

The second part of the chapter uses this history to engage current geographical debates on waste and value, debates that have completely ignored the role of industrial waste and the opaqueness and incomprehensibility of industrial productive consumption (the consumption of things to make other things).[22] Since industrial waste, i.e. waste that occurs in the production of commodities, accounts for the vast majority of waste produced worldwide, it seems only fitting to stop ignoring it in debates on the nature of the "ongoingness" and expansion of capitalist value. In this section I introduce the concept of "dark value" as a way to theorize waste under capitalism. By dark value, I mean materials that have the imprint, or shadow, of value production without necessarily having value. I do so to show that contra to Moore's (2012) contention (following Žižek), industrial waste is not necessarily a parallax object – "[the most radical object] that which objects, that which disturbs the smooth running of things," particularly when viewed from a standpoint of the chemical industry (an industry that prides itself on literally lubricating the gears of modern industry).[23] Instead, we must also think of industrial waste as a vast collection of materials that bear the imprint of labor in pursuit of value. In this chapter, by calling for more engagement with the geography of industrial waste, I am simultaneously calling for a deeper engagement with nature of capitalist value.

The chemical technosciences, particularly when expressed in their industrial form, have always been capital's philosopher's stone, transmuting valueless waste byproducts of commodity production (and productive consumption) into new elements of production and consumption.[24] What that means is that in order to fully embrace industrial waste and its

[21] Gille, "Actor Networks, Mode of Production, " 2010; Larkin, B. "The Politics and Poetics of Infrastructure." *Annual Review of Anthropology* 42 (2013): 327-43.

[22] Strasser, S. *Waste and Want: A Social History of Trash*. New York: Henry Holt and Company, 1999; Bulkeley, H, and M Watson. "Modes of Governing Municipal Waste." *Environment and Planning A* 39, no. 11 (2007): 2733-53; Gregson, N, A Metcalfe, and L Crewe. "Identity, Mobility and the Throwaway Society." *Environment and Planning D: Society and Space.* 25, no. 4 (2007): 682-700;

[23] Moore, S A. "Garbage Matters: Concepts in New Geographies of Waste." *Progress in Human Geography* 36, no. 6 (2012): 780-99. Žižek, S. *The Parallax View*. Cambridge, MA: The MIT Press, 2006. 17. I am also not sure that Žižek meant exactly what Moore describes.

[24] Marx, K. *Capital: Volume III*. New York: Penguin Books, 1981 (1894); Haynes, W. *This Chemical Age: The Miracle of Man-Made Materials*. London, UK: Secker and Warburg, 1946; Haynes, W. *Chemical Economics*. New York: D. Van Nostrand Company, Inc., 1933; Haber, L F. *The Chemical Industry During the Nineteenth Century: A Study of the Economic Aspects of Applied Chemistry in Europe and North America*. Oxford, UK: Oxford University Press, 1958; Leslie, E. *Synthetic Worlds: Nature, Art, and the Chemical*

material politics under capitalism, one must embrace chemicals and the chemical industry writ large. By doing so, its profound history can be brought to bear on questions of waste and value. The reproduction of capital is premised on processes of substitution, replacement, simulation, opposition, and transformation, and often the materials of these processes are coaxed from the waste piles and waste streams of industrial production.

Chemistry and Capital

"So-called waste products play an important role in almost every industry… the most striking example of the use of waste products is provided by the chemical industry. Not only does this make use of its own waste products by finding new applications for them, but it also employs those of a great many other industries and coverts coal-tar, for example, which was previously almost useless, into aniline dyes, alizarin *and* most recently into medicines."

Marx, *Capital, Volume III*, ca. 1875.

Chemistry and capital have long haunted the state-boundary thresholds that abound the waste-value dialectic. Chemistry and capital have resurrected the dregs of industrial production with new life: transforming the blackness of coal tar into vibrant colors, air and water gas into fertilizer, and petroleum into makeup, medicine, and plastic. Chemistry and capital has allowed us to create simulants and substitutes that are in many cases, "more real than the real thing."[25] Chemistry and capital have created a parallel world of fakes and substitutes, of commodities that specialize in being isomers of affect. Chemistry and capital have produced "wonders akin to the stuff of dreams.[26]" The (post-15th century) alchemist's pursuit of making gold made from lead has been realized in the ability of capital and chemistry to turn waste into its antithesis: value.[27]

The rarely discussed chemical revolution trailed the industrial revolution because it fed on the byproducts of industry, meaning that capitalism had to develop to the point that waste was being produced at large enough scales that entirely new industries could become based on waste piles and waste streams.[28] As well, scientific knowledge had to advance to the point that the scale of waste piles and waste streams could be imagined as raw materials for the production of commodities. This historical lag is clearly seen in the development of the organic chemical industries in the 1850s and 1860s.[29] Coal-tar, a major waste product of the first industrial revolution had to be physically produced in large enough amounts in

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Industry. London: Reaktion Books Ltd., 2005.

[25] Leslie, *Synthetic Worlds,* 2005. 16-17. Benjamin, W. *The Work of Art in the Age of Mechanical Reproduction and Other Writings on Media*. Cambridge, MA: Belknap Press of Harvard University, 2008 (1933).

[26] Leslie, *Synthetic Worlds,* 2005. 17.

[27] Principe, L M. *The Secrets of Alchemy*. Chicago, Il: University of Chicago Press, 2013.

[28] Marx, *Capital Vol. III*, 1981.

[29] Haber, *Chemical Industry During the Nineteenth Century,* 1958.

constrained geographic locations that scientists could begin to chemically probe coal-tar's corporeality (See Chapter 3).

The bidirectional movement of matter across the waste-value dialectic is a fundamental tendency of capitalism, an economic system that raids everything for value, even the wastebaskets of industry.[30] This movement that on one hand throws waste outside the value sphere can bring waste back into circulation and make it amenable to value production in times of (socioscalar) opportunity, only to throw it out again.[31] To fully appreciate the role of industrial waste under capitalism, however, a clear distinction must be made between the concepts of mechanization and chemicalization. I do this not to discount the role of machines and managerial technologies on shaping capital's industrial form, but instead to highlight the important role the chemical technosciences, including fields like metallurgy, physics, and engineering, have had on the production and reutilization of industrial waste. [32] The distinction between chemicalization and mechanization in industrial development is more important in the chemical industries than other arenas of manufacture, like textiles, the object of so much scholarly scrutiny.

The ontology of large-scale *chemical reaction* creates distinct waste problems for firms and industries, problems that arise due to elemental rearrangement and not simply mechanical transformation.[33] This distinction points to the fact that the production and utilization of industrial waste is not just a question of efficiency in the use of raw materials, but also critically, a question of the material nature of the waste and the labor process that created it, often expressed in the apolitical language of chemical reaction yields. The distinction matters because it allows us to see that as a property of the social nature of collective human labor, "[t]he economy in the refuse of production achieved by re-use should be distinguished from economy in the creation of waste."[34] The distinction between chemical and mechanization, of course, requires a much more extended discussion, but the following example highlights why conceptualizing differences between chemicalization and mechanization matter, particularly for the ontological politics of industrial waste.[35]

You fell a tree on your land to turn into furniture. Using machines, you cut, reshape, and craft some beautiful furniture, perhaps for the porch. The waste produced in this process – sawdust and small pieces of wood – are for the most part materially the same as

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[30] Marx, *Capital Vol. III*, 1981.
[31] Marx, *Capital Vol. 1*, 1990. 754.
[32] Howe, H E, and J V Antwerpen. "Utilization of Industrial Wastes." *Industrial & Engineering Chemistry* 31, no. 11 (1939): 1323-230. Metallurgy is a topic that at least one new materialist scholar has sought to take the material seriously without actually taking the material seriously. See: Barry, A. "Materialist Politics: Metallurgy." In *Political Matter: Technoscience, Democracy, and Public Life*, edited by B Braun and S J Whatmore. Minneapolis, MN: University of Minnesota Press, 2010;
[33] Haynes, W. *Chemical Economics*. New York: D. Van Nostrand Company, Inc., 1933.
[34] Marx, 1981, *Capital Vol. III*, X.
[35] John Teeple, a prominent chemical engineer during WWI and the post war period, coined the term chemicalization. It has proceeded socio-historically (and usually chronologically) on three related fronts: to modify materials (like tanning/dyeing), to save time or lower costs (bleaching and substitutes for natural products), and to create new synthetic products (like dyes, plastics, and pesticides), materially derived from the wastes of other industrial processes. Chemicalization and mechanization have differing effects on labor (See Chapter 4). Haynes, W. *The American Chemical Industry*. Vol. 5, New York: Van Nostrand, 1955.

the wood they came from, just smaller. You can reuse the wood waste as kindling for your fire or to make some paper, but you'll decide later. But now, let's say you want to make some wood alcohol to act as your solvent for an old paint you found in the garage. You cut down another tree, but this time, you put it in a reaction vessel attached to a distillation apparatus, suck out the oxygen, and subject it to immense heat in a process known as pyrolysis, or destructive distillation (essentially the same as making charcoal).[36] Giving it the time needed to undergo thermochemical reactions, you collect the gases driven off through pyrolysis to process and make your methanol (wood alcohol – CH_3OH). However, chemical rearrangement of the wood's materiality not only yielded methanol but hundreds if not thousands of other chemicals – wastes – at various reaction yield percentages. The nature of the waste is qualitatively different because of chemical transformation.[37] This is why often both the products and the wastes of industrial chemical synthesis, including mineral processing, are novel in scale, scope, and composition.[38]

The Origins of Industrial Arsenic

"Arsenic is mined from deep mines, for it is a material that Nature hides from us, teaching us to leave it alone as harmful, but this does not cause the arrogant miners to leave it."

Biringuccio, *The Pirotechnia*, 1540[39]

In the early 1840s, under a policy called *Harmony*, the British military productively consumed vast quantities of white arsenic (arsenic trioxide – As_2O_3) in a campaign to exterminate Australian aboriginals in the Manning River Valley, a fertile river valley midway between what is now Brisbane and Sydney.[40] Lacing gifts of food and drinking water sources with the tasteless, odorless poison, British soldiers executed chemical warfare against starving aboriginals who, deprived of traditional food sources, had been killing the livestock of settlers. *Harmony* was perhaps the largest deployment of chemical weapons since ancient times.[41] The British use of white arsenic was only possible, however, because of the rapid industrialization of the copper, lead, and tin mines of the British southwestern mining and

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36 Bunbury, H M. *The Destructive Distillation of Wood*. New York: Van Nostrand Company, 1926.

37 Haynes, W. *Chemical Economics*. New York: D. Van Nostrand Company, Inc., 1933.

38 Leslie, E. *Synthetic Worlds: Nature, Art, and the Chemical Industry*. London: Reaktion Books Ltd., 2005.

39 Biringuccio, V. *The Pirotechnia*. Translated by C S Smith and M T Gnudi. New York: The American Institute of Mining and Metallurgical Engineers, 1942 (1540). 105.

40 Barta, T. "After the Holocaust: Consciousness of Genocide in Australia." *Australian Journal of Politics & History* 31, no. 1 (1985): 154-61; Marr, N. "Aboriginal History of the Great Lakes District, Australia." www.greatlakes.nsw.gov.au/commprof/aborigin.htm, 1995; Tatz, C. "Genocide in Australia." In *Centuries of Genocide: Essays and Eyewitness Accounts*, edited by S Totten and W S Parsons. New York: Routledge, 2013; Barta, T. "Discourses of Genocide in Germany and Australia: A Linked History." *Aboriginal History* 25, no. 1 (2001): 37-57.

41 Kokatnur, V R. "Chemical Warfare in Ancient India." *Journal of Chemical Education* 25, no. 5 (1948): 268; Mayor, Adrienne. *Greek Fire, Poison Arrows, and Scorpion Bombs: Biological & Chemical Warfare in the Ancient World*. Penguin, 2008.

smelting complex in the first few decades of the 19th century. *Harmony* was thus not only an attempt at chemically mediated genocide, in its prodigious use of white arsenic, it also signaled the coming of a new age, the age of arsenic.

Arsenic (As), the name chemists have given to element 33 on the periodic table, is derived from the Greek word *arsenicum,* which was derived from the Arabic name (*al-zarnīḵ)* for the marvelous yellow pigment that Arabian colorists made from the yellow mineral arsenic trisulfide (As_2S_3) (a brilliant and incredibly toxic yellow).[42] Arsenic is ubiquitous. It is the 20th most abundant element of the earth's crust, the 14th most in seawater, and the 12th most abundant in your body.[43] In pure form, it is a slightly toxic brittle mettaloid, but in its contemporary biogeochemical iteration it is usually expressed in relationship with other elements like copper (Cu), lead (Pb), tin (Sn), and sulfur (S).[44] Although arsenic dominant mineral deposits exist, arsenic is found mostly as a small component of more than 250 minerals.

Arsenic has been known since ancient times for its bioactivity. It has been used as "medicine" since at least the time of Hippocrates (400 BCE). BCE Chinese civilizations also valued it for its "curative" properties.[45] Arsenic's use as medicine was likely encouraged from the fact that because the hair (keratin) and skin are physiographical fates of biological detoxification, sublethal arsenic intoxication often causes the skin and hair to appear shiny and lustrous.[46] But this phenotypical-toxicological-aesthetic expression is just a mask of arsenic's toxicity, a property of arsenic that has shaped human history and human evolution.[47]

Arsenic is the king of all poisons. Arsenic in drinking water has poisoned humans across diverse world regions from time immemorial. And because arsenic is a waste product of copper ore processing, arsenic has also been one of the most influential occupational and environmental poisons, at least since the Bronze Age.[48] Arsenic's industrial history, however,

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[42] Most etymologies trace arsenic's origin to the Greek word, *arsenikon*, meaning virile potent, but this is incorrect. Arsenic trisulfide was used extensively by pre Common Era Egyptian and Chinese civilizations. The incredibly toxic, lustrous yellows made from Arsenic trisulfide would briefly regain popularity among European artists in the first couple decades of the 19th century as King's Yellow. Ball, P. *Bright Earth: Art and the Invention of Color*. Chicago, IL: University of Chicago Press, 2001; *New Oxford American Dictionary*. Apple Inc., 2014.

[43] Frankenberger, W T, ed. *The Environmental Chemistry of Arsenic*. New York: Marcel Decker, Inc., 2002.

[44] A metalloid is an element (e.g., germanium or silicon) whose properties are intermediate between those of metals and solid nonmetals. They are electrical semiconductors, which is why arsenic was used in the first experimental and commercial semiconductors; Frankenberger, *Environmental Chemistry of Arsenic*, 2002; Mandal, B K, and K T Suzuki. "Arsenic Round the World: A Review." *Talanta* 58, no. 1 (2002): 201-35.

[45] Matschullat, J. "Arsenic in the Geosphere—a Review." *Science of the Total Environment* 249, no. 1 (2000): 297-312.

[46] The hair is a main exit route of metabolic arsenic detoxification in humans and other animals. Le, X C. "Arsenic Speciation in the Environment and Humans." In *The Environmental Chemistry of Arsenic*, edited by W T Frankenberger, 95-116. New York: Marcel Dekker, Inc., 2002. Arsenic is still added to makeup, particularly cheap lipsticks. Hepp, N M, W R Mindak, J W Gasper, C B Thompson, and J N Barrows. "Survey of Cosmetics for Arsenic, Cadmium, Chromium, Cobalt, Lead, Mercury, and Nickel Content." *Journal of Cosmetic Science* 65, no. May/June (2014): 125-45.

[47] Schlebusch, C M, L M Gattepaille, K Engström, M Vahter, M Jakobsson, and K Broberg. "Human Adaptation to Arsenic-Rich Environments." *Molecular Biology and Evolution* (2015): msv046.

[48] Bronze is the general name for alloys of copper and other metals, predominantly tin. Arsenic has also been added in small quantities in bronze alloys since at least 3000 BCE.

didn't begin until the early 19th century when arsenical smelting waste accumulated at such a scale that people began to take notice.

Until the 18th century, the Prussians, the French, and the Swiss dominated European mining and smelting.[49] Germany, for instance, has a long history of excellence in mining and refining techniques. For example, it was a German from Saxony who wrote *De Re Metallica*, which he addressed to a German aristotechnocratic audience.[50] However, beginning in the late 1600s, as British colonial ambitions reached heightened scale and scope, material and social networks began linking the mines and smelters of southwest England and Wales with colonial and capitalist aspirations across the world. Metals like copper enabled a vast political economy of empire: copper paid for slaves on the African coasts; giant copper kettles distilled the products of slave labor and the plantation system into sweetness and power; copper-lined ship bottoms decreased the build up of marine life, speeding up the flows of people and products and the metabolisms of a rapidly changing world; and copper flowed to new industrial centers like London, Manchester, and Bombay, where labor combined it with tin or other metals to make machines, art, and coins.[51]

By the mid 1600s, Britain's forests had been denuded of their trees. Enterprises involved in processing ore into finished product had to shift to a new power source for their roasting ovens.[52] The use of coal as a source of smelter heat, however, increased impurities in the finished product and decreased its quality. By the mid 1700s, miners developed refractory and early blast-oven technology, in which a bellows-driven combustion of coal and the waste stream with its impurities never touch the ore directly, instead heating an element that reverberates heat to the ore.[53] The generalization of these technologies across southwest England and Wales firmly established coal as the smelter fuel. In the late 18th century, the spread of the Welsh copper smelting process, which used ore pre-processing together with multiple furnaces in sequential stages to make possible the use of low-grade coal, led to a higher purity product in less time. The generalization of the Welsh process fundamentally transformed the copper smelting industry by speeding up the processing time and by increasing the purity of the final product, significantly reducing the cost of smelting per unit of copper.[54] This helped a rapidly developing smelting industry to achieve the economies of scale and scope it needed to compete on the growing world stage. An increase in smelting productivity also demands an increase in the availability of feedstocks, and miners went deeper in search of more ore.

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[49] Smelting is the collection of mechanical and chemical processes needed to turn ore into finished metals of high purity.

[50] Agricola, G. *De Re Metallica*. Translated by H Hoover and L H Hoover. New York: Dover Publications, 1950 (1556).

[51] Mintz, S W. *Sweetness and Power*. New York: Penguin Books, 1986.Harris, J R. "Copper and Shipping in the Eighteenth Century." *The Economic History Review* 19, no. 3 (1966): 550-68.

[52] Lynch, M. *Mining in World History*. London: Reakton Books, 2002.

[53] Dennis, W H. *A Hundred Years of Metallurgy*. Chicago, Il: Aldine Publishing Company, 1964.

[54] Because of its pretreatment steps, the Welsh process was able to handle a variety of ore types and qualities and produce a copper of very high quality. Hofman, H O. *Metallurgy of Copper*. New York: McGraw-Hill Book Company, Inc., 1914.

Technology does not determine history, but as a social extension of human metabolism, it has a starring role.[55] In 1710, Huey Vor installed the second Newcomen engine built in Britain (the first was at a coal mine) at his Cornish tin mine, doing so in the hopes of pumping out the ground water that was impeding labor's progress deeper into the earth's bowels.[56] The Newcomen engine, although a prodigious consumer of coal, spread across the Cornwall, Devon, and Swansea non-ferrous mining industries in the half century that followed. Throughout the mid 1700s, miners ventured deeper and deeper in search of valuable minerals to feed the world's growing appetite for copper, lead, and tin.

In the summer of 1777, James Watt arrived in Truro, the heart of Cornwall mining district.[57] He was on his way to install one of his Watt engines at the Wheal Busy mine, a few miles south of Truro. In 1778, Watt returned to Cornwall, where he supervised the erection of an engine at a mine at Tregurtha Downs, perched on the cliffs overlooking the Celtic Sea. In the early 1780s, Cornwall's mining industry, financed through Watt's partner novel credit arrangement – where Bolton provided Watt engines upfront at no cost, instead, receiving annual payments based on the annual amount of coal saved – erected Watt after Watt engine across Cornwall and eventually Devon and Swansea (CDS).[58] By 1784, only one Newcomen engine was still active in Cornwall.

As the mines got deeper and deeper, the miners became increasingly, as one visitor to the southwest put it, "slaves" to the Watt engine machine.[59] Because of the depth and rudimentary elevator technology, miners began spending multiple days underground. Machine power coupled to mining's unique labor requirements that Agricola highlighted two centuries prior (ex. no light, long hours underground, toxic fumes), the CDS non-ferrous mining and smelting industries quickly became an example of J. S. Mill's observation that machines increased labor's daily toil instead of reducing it.[60]

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[55] Marx, *Capital Vol.1*, 1990. Mumford, L. *Technics and Civilization*. Chicago: University of Chicago Press, 2010 (1934); Smith, M "Technological Determinism in American Culture." In *Does Technology Drive History? The Dilemma of Technological Determinism*, edited by M Smith and L Marx, 1-36. Cambridge, MA: MIT Press, 1994.

[56] Jones, H. *Steam Engines: An International History*. London: Ernest Benn Limited, 1973. 20-21; Lynch, *Mining in World History*, 2002.

[57] Jones, *Steam Engines*, 1973. 34-35.

[58] Lynch, *History of World Mining*, 2002. I have decided to call the mining and smelting industries of Cornwall, Devon, and Swansea,the CDS complex. Although certain activities agglomerated in certain geographic areas – coal mining in Swansea, copper ore mining on Cornwall, copper smelting in Swansea, arsenic smelting in Cornwall and Devon – I argue that they must be viewed together as pieces of a larger industrial complex. A detailed discussion of the economic and industrial geography of the CDS complex is fascinating but it is also beyond the scope of the argument. By 1800, the CDS was a highly integrated agglomeration and the most productive non-ferrous mining and smelting region in the world.

[59] Clarke, E. *A Tour through the South of England, Wales, and Part of Ireland, Made During the Summer of 1791*. London: Minerva Press, 1793; Also see: Marx, *Capital Vol.1, 1990*. Chapter 15; Engels, F. *Condition of the Working Class in England*. Oxford, UK: Oxford University Press, 2009 (1845).

[60] "It is questionable if all the mechanical inventions yet made have lightened the day's toil of any human being. They have enabled a greater population to live the same life of drudgery and imprisonment, and an increased number of manufacturers and others to make fortunes." Mill, J S. *Principles of Political Economy*. 7th ed. London: Longmans, Green and Co., (1909) 1848. Book 4, Chapter 6

"With hardly room to move their bodies," the visitor wrote, "in sulpherous air, wet to the skin, and buried in the solid rock, these poor devils live and work for a pittance barely sufficient to keep them alive; pecking out the hard ore by the glimmering of a small candle, whose scattered rays will hardly penetrate the thick darkness of the place."[61]

By 1800, the pieces were in place for the coming British dominance in industrial copper, lead, and tin, and despite (or because of) ferocious competition and cut-throat cartelization of the copper, lead, and tin industries, the southwest mining and smelting complex had attained a unrivaled degree of industrial productivity.[62] At the turn of the century, in Cornwall alone, 55 Watt engines burning Welsh coal were active. The CDS complex also had an infrastructure of extensive and well-established trade networks, state-of-the-art smelting, ore extraction, and pumping technology, a vast industrial reserve army, and new ways to organize and discipline collective mining labor.[63]

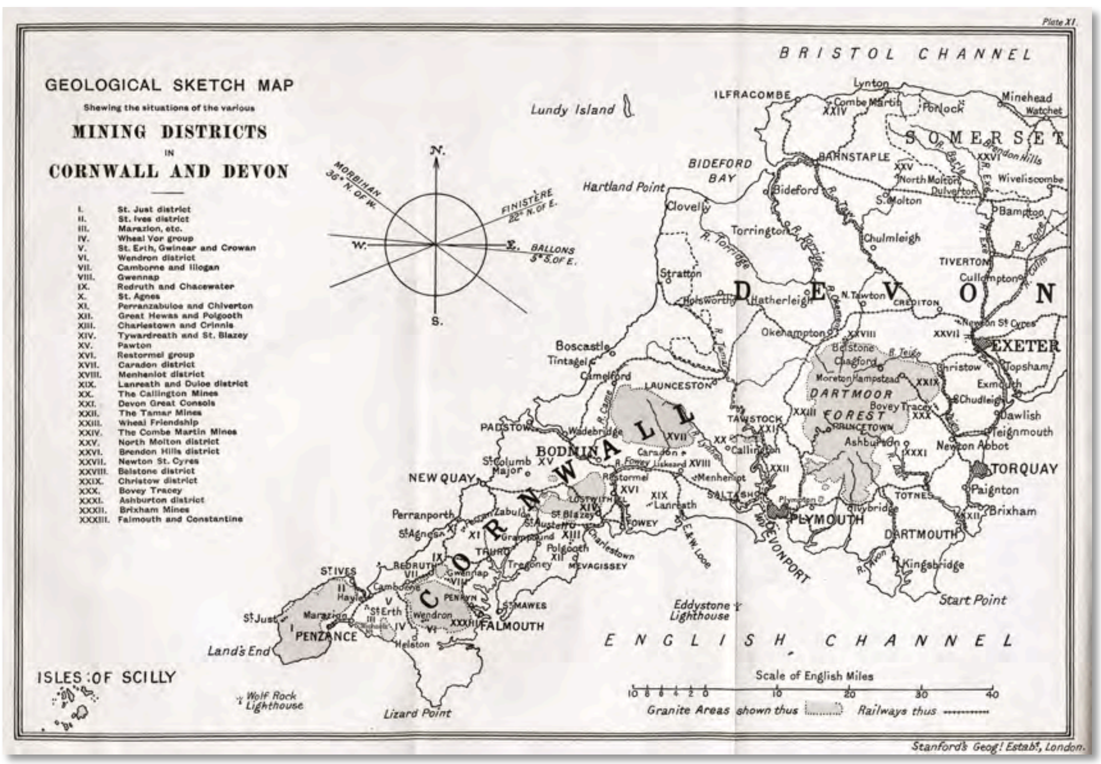

Figure 3 - Geological Map of Cornwall and Devon Mining Districts[64]

[61] Clarke, *A Tour through the South of England*, 1793. 93.

[62] Tredinnick, R. *A Review of Cornish Copper Mining Enterprise, with a Description of the Most Important Dividend and Progressive Copper and Tin Mines of Cornwall and Devon, and Detailed Account of the Buller and Bassest District*. 2nd ed. London: Thompson and Vincent, 1858; Francis, G G. *The Smelting in the Copper in the Swansea District of South Wales, from the Time of Elizabeth to the Present Day*. 2nd ed. London: Henry Southern & Co., 1881; Robert, "Development and Decline," 1969.

[63] For example, by 1861, more than 16,000 Irish immigrants had flooded into the Welsh mining complex following the potato famine at a rate nearing Irish immigration to the US. Robert, "Development and Decline," 1969

[64] Collins, J H. *Observations on the West of England's Mining Region: Being an Account of the Mineral Deposits and Economic Geology of the*

In 1800, Watt's patent on the double-acting steam engine expired. A few years later, Richard Trevithick, a Cornish mining engineer redesigned Watt's engine to run at much higher pressures, a technological development that led to smaller, more powerful, and more efficient engines, as well as the ability to go deeper.[65] By 1810, the CDS mining and smelting complex dominated non-ferrous world trade (See Figure 3). Combing state of the art technology, mediocre ore, and the exploitation of labor, mining and smelting companies across the CDS region produced and refined more copper, tin, and lead than any other mining district around the world.[66] In 1819, for example, the mines of Cornwall produced 7,214 tons of copper or 84% of all copper produced in Britain.

Just a few years later, however, the eventual demise of CDS mines appeared on the western horizon. Sometime in the early 1820s, the first ship loaded with foreign ore sailed up the Bristol Channel destined for a port in Swansea or Cornwall.[67] By the mid 1820s, the scene was commonplace, as ships with ores from Germany, Sweden, and Norway arrived at ports near CDS smelters heavily loaded with concentrated metallic ores. In the 1830s and 1840s, ships loaded with ores from Chile, Cuba, Spain, Mexico, Australia, and the United States arrived at the same ports. Ships journeying from Portugal, Spain, Northern Rhodesia and the Belgian Congo subsequently joined these ships. Despite the costs involved in transportation and because of the amount of capital needed to build smelters, as well as the CDS's technological sophistication and cheap coal access, the southwestern industrial smelter agglomeration remained the most lucrative option for foreign miners wishing to have their ores processed.[68] In addition, London was the center of finance and the main avenue of metallic exchange traffic.

By the early 19th century, the mines of Cornwall, Devon, and Swansea had been subjected to over 100 years of capital-intensive exploitation; high quality ores hadn't been available for about as long. The ores of the coastal southwest had never been of the quality found in other countries, yet between the turn of the century and about 1830, the mining and smelting operations of CDS complex combined cheap coal, state-of-the-art refining technology, and endless streams of wasted life to dominate the global production of copper, lead, and tin. The free gifts of new colonial and capitalist territories, however, were far

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Region, an Forming Vol. Xiv of the Transactions of The Royal Geological Society of Cornwall. Plymouth, UK: William Brendon & Son, Limited, 1912.

[65] By 1810, he had also invented a steam-powered rock drill.

[66] Dines, H G. *The Metalliferous Mining Region of South-West England*. Memoirs of the Geological Survey of Great Britain. Vol. 1, London: Her Majesty's Stationary Office, 1956 Dennis, *Hundred Years of Metallurgy*, 1964; Barton, D. *A History of Copper Mining in Cornwall and Devon*. Truro, UK: D. Bradford Barton Ltd., 1968; Robert, R O. "The Development and Decline of the Non-Ferrous Metal Smelting Industries in South Wales." In *Industrial South Wales, 1750-1914*, 264. London: Frank Cass and Company Limited, 1969; Day, J. "Copper, Zinc, and Brass Production." In *The Industrial Revolution in Metals*, edited by J Day and R F Tylecote, 131-99. London: The Institute of Metals, 1991.

[67] Tredinnick, R. *A Review of Cornish Copper Mining*, 1858; Francis, G G. *Copper in the Swansea*, 1881; Robert, "Development and Decline," 1969; Lynch, History of World Mining, 2002.

[68] Such as the Welsh process, with its pretreatment, allowed smelters to refine any type of copper ore. Redgrave's Report in *Reports of Inspectors of Factories*, October 1852, outlines the productive advantages of Cornwall mine, especially in terms of energy use per unit of output. Duplicated in Marx, Capital, Vol. III, 1991. 193.

richer and more extensive than anything the British mining industry had ever seen. High quality ores, combined with lower labor costs (i.e. slavery), and the transportation of European goods to the colonial world helped to offset the costs of transportation. It also made the smelting of low quality British ores less lucrative per unit of smelting capacity.

In 1850, British copper production hit an all time, reaching 150,000 tons.[69] That year, the share of foreign ores consumed also hit an all time high. About two-thirds of the 150,000 tons of copper that British smelters produced in 1850 arrived on ships as ore from mines from Europe and across the oceans.[70] By mid-century, local ores could no longer compete, and ore production by the CDS region's non-ferrous mines rapidly declined. The smelters and refiners, however, continued to expand their processing capacity to accommodate more foreign ores, increasing production until the early 1870s.[71] By the late 1870s, developments outside England shifted the capitalist playing field. As a result, by the early 1880s the CDS smelting industry was nearing its end.

Since the late 16th century, miners have repeatedly subjected the lithosphere of southwest Britain to ever-larger capital investments and more intrusive and more efficient production technologies.[72] Between the late 1700s and the 1850s, smelters developed from small open pit roasting operations into high technology, high throughput, high finance operations. Throughout the 1870s and 1880s, CDS smelters were the most productive in the world. But these mid-century smelters, some with flues reaching 175 feet or more into the air, were the most advanced and the largest smelters would ever get in the CDS mining region.[73] Smelting's future was destined for a new industrial geography.

In the late 1880s and 1890s, across the American west, US mining companies erected the world's largest and most technologically sophisticated smelters to treat the copper ores that had been pouring from the American west to CDS smelters since the late 1870s.[74] In 1890, copper production from CDS smelters fell to the lowest since 1800. However, despite the rapid decline of the mining and smelting complex since the 1850s, many mines and smelters remained profitable.[75] They did so by turning to the toxic wastes of past production processes that had accumulated nearby. Arsenical waste piles, some more than 300 years old were plundered for their anthropogenic ores. If approached correctly, what was once a troublesome waste of past and current industrial metabolism had the potential to be turned into a valuable commodity.

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[69] 154,299 tons. Tredinnick, *A Review of Cornish Copper*, 1858.

[70] Checkland, S G. *The Mines of Tharsis: Roman, French and British Enterprise in Spain*. London: George Allen & Unwin Ltd., 1967.

[71] Robert, "Development and Decline," 1969

[72] The mines of South West England and Wales, particularly Cornwall, have long been known for their rich ores. The Romans relied on them as a source of copper to make their armor.

[73] Robert, "Development and Decline," 1969

[74] Richter. "The Copper-Mining Industry in the United States, 1845-1925." *The Quarterly Journal of Economics* 41, no. 2 (1927): 236-91.

[75] Earl, B. "Arsenic Winning," 1983; Earl, *Cornish Arsenic Industry*, 1996; Rothwell, R P, ed. *The Mineral Industry: Its Statistics, Technology, and Trade in the United States and Other Countries to the End of 1897*. Vol. 6. New York: The Scientific Press, 1898.

Arsenic at the Waste-Value Threshold

"Every advance in Chemistry not only multiplies the number of useful materials and the useful applications of those already known, thus extending with the growth of capital its sphere of investment. It teaches at the same time how to throw the excrements of the processes of production and consumption back again into the circle of the process of reproduction, and thus, without any previous outlay of capital, creates new matter for capital."

Marx, *Capital: A Critique of Political Economy*, 1867[76]

Arsenic-as-waste's industrial production is solely a function of the desire for other more valuable metals. Since arsenic is an impurity that poisons the quality of copper and other metals, it must be separated in the smelting process, the collection of operations that transforms raw ore into high metal content finished product.[77] Thus, metal bearing ores containing arsenic are roasted as a normal part of the smelting process. In the roaster furnace arsenic sublimates from red-hot ore and combines with oxygen in a distinctive blue flame to form various arsenic oxides, the trioxide (As_2O_3) the most commonly formed.[78] Upon exit from the roasting oven, arsenic oxides rapidly cool, condensing into a heavy white cloud of poisonous dust that readily succumbs to the pull of gravity. Because of their material properties, arsenic oxides tend to deposit near ore roasting operations in geographical gradients of downwind concentration.

Before 1800, the Germans, from the metallic mines of Saxony, fulfilled the industrial world's limited demand for arsenic. In the late 1700s, most arsenic was consumed as arsenic trisulfide (As_2S_3) in the manufacture of yellow pigments like King's Yellow.[79] Arsenic trisulfide was a waste product from the roasting of arsenical cobalt ores for the manufacture of zaffre, a cobalt blue pigment used in pottery glazes.[80] As such, it was produced in limited quantities. In the early 1800s, the growing presence of white arsenic-as-waste from British mines led to chemical exploration and industrial experimentation. Glass manufactures realized that arsenic trioxide in small quantities could be used to clarify and decolorize glass. White arsenic and its derivatives also moved into everyday life as the active ingredient in medicines, tonics, and lustrous green pigments. By 1820, demand for the deadly white powder had increased considerably.[81]

In 1817, Dr. Richard Edwards, with financial backing by the Williams, Gregory, and Company partnership, constructed the first dedicated arsenic works in England.[82] Built in

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[76] Marx, Capital, Vol.1, 1990, 745.
[77] Arsenic's content is about 1% in concentrated copper ore. Hofman, *Metallurgy of Copper*, 1914.
[78] The sulfur oxides created in the waste stream can remain aloft for great distances, eventually returning to the land as sulfurous dusts or acid rain.
[79] Earl, "Arsenic Winning," 1983.
[80] Earl, *Cornish Arsenic Industry*, 1996; Ball, *Bright Earth*, 2001.
[81] Whorton, *The Arsenic Century,* 2010. X.
[82] Earl, *Cornish Arsenic Industry*, 1996.

Perrenwell on the west coast of Cornwall, across the Bristol Channel from Swansea, it immediately began producing a highly refined white arsenic product. The plant found its raw materials in the piles of crude arsenical wastes that had collected at nearby operations. Because they needed a steady supply of feedstock for the plant, the partners expanded their sourcing through informal partnerships with local miners and by encouraging them to build recovery flues onto their roasting ovens to collect and concentrate the arsenic oxides in the waste streams.

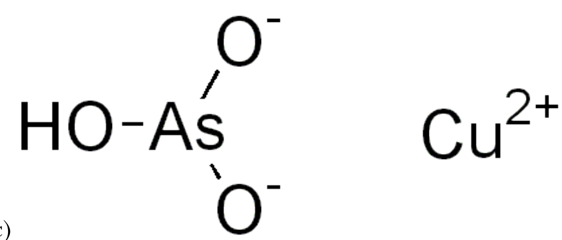
In 1820s, more and more white arsenic flowed from west coast of Cornwall to the capitalist world and arsenic's use values, once reserved for the aristocracy and upper classes, suddenly became accessible to even the poorest. In the 1820s, arsenic trioxide was increasingly consumed in the manufacture of glass, medicines, and the green wallpapers that plastered the walls of high society.[83] These consumptive outlets together served a greater and greater dissipative function for the point-source toxic waste of the nonferrous mining industries of Cornwall, Devon, and Swansea. Throughout the 1820s, arsenic increasingly made the newspapers in the small print below headlines like "Profligate Seduction and Suicide" and the "Melancholy of Poison."[84] In the 1830s, the king of all poisons extended its dominion further into the productive and final consumption of all sorts of commodities. Arsenic colored the expanding imitation flower trade and candy manufactures began adding it to candy and other foodstuffs to enhance their color. The refined product also began appearing behind the counter at druggist's stores across England and at dye and print works across Europe.

[83] Whorton, *The Arsenic Century,* 2010. X.

[84] TST. "Melancholy Effects of Poison." *The Sunday Times* March 30, 1823; TST. "Profligate Seduction and Suicide." *The Sunday Times* December 26, 1824.

a)

b)



c)

Figure 4 – a) Mid 19th century wallpaper by William Morris made with Scheele's green b) green dress made with arsenical pigments, ca. 1860 and c) chemical composition of Scheele's green [85]

In 1835, Henry Conn and Company opened the second arsenic works near Truro in central Cornwall. This plant's primary feedstock, like the Perrnewell plant, was the wastes of previous mining and smelting processes rapidly growing across the industrial countryside. The presence of a second company seeking raw materials spurred competition, resulting in higher prices for crude arsenical wastes. Many roasting operations responded to the market signal by installing recovery flues to concentrate their arsenical waste so they could sell it to arsenic refiners. For some mining operations, the burden of toxic arsenical waste became the blessing of profit. In the 1840s, a third Cornwall based arsenic plant came online, and

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[85] Ferrebee, W. "Poison Walls." https://ferrebeekeeper.wordpress.com/tag/scheeles/.; Wikipedia. "Scheele's Green Chemical Structure." http://en.wikipedia.org/wiki/Scheele's_Green#/media/File:Scheele%27s_Green.png. Jankowski, N, and A Mathews. "Toxic Dyes and Mercury-Laced Hats: Exhibit Looks at the Dark Side of Fashion." http://www.theglobeandmail.com/life/fashion-and-beauty/fashion/toxic-dyes-and-mercury-laced-hats-exhibit-looks-at-the-dark-side-of-fashion/article19115689/.

more arsenic-as-waste flowed from these plants into new forms of dissipative consumption.[86]

Arsenic found new uses in the manufacture of lead shot, arsenical soaps for the taxidermy industry, new colors for French enamels, fireworks, and as the agent of death for mice, sheep pests, and Australian aboriginals.[87] By the late 1850s, the three plants in Cornwall, accompanied by three recently built plants in Swansea, accounted for the vast majority of global arsenic production and the industrial and consumer demand for the white arsenic had grown considerably. Higher prices, like the discovery of a new continent, instigated a quest for the industrially sorted deposits of arsenical waste that dotted the CDS region's wet and windy landscapes.

Mid 19th century arsenic plant work was one of the most toxic occupations of the time. But in addition to being utterly horrible places to work, these arsenic plants were technologically rudimentary.[88] Because the arsenic industry is an industry whose feedstock is the waste of another, the arsenic industry only became possible in the 19th century. As such, it lacked the long history of scientific development and capital investment of industries like copper and lead. Only the wide and rising consumption of white arsenic across manufacture and the rapid decline in the quality and profitability of British ores in the 1850s led mining syndicates finally to first consider the construction of their own arsenical works.

In the early 1860s, mining companies unleashed new rounds of investment, especially in Cornwall, constructing large arsenic refining plants with more efficient purpose-designed ovens, finally bringing economies of industrial scale to white arsenic's manufacture.[89] The newly built plants could achieve a much higher purity of white arsenic at a much faster rate than all previous methods. These modern plants produced the first "Cornish white," the high purity (>98%) white arsenic that quickly became the standard bearer of quality (and price) the world over. By the late 1870s, the arsenic works of the CDS districts were producing more than 5,000 tons of white arsenic per year, more than 80% of world production.[90] By the 1880s, valuable arsenic wastes had become the main source of profit for the skeleton remains of the once magnificent CDS mining complex.[91]

At its peak in the early 1890s, 85 arsenic plants were active in the CDS region, producing over 8,000 tons of white arsenic per year from the wastes of past production.[92] By the turn of the century, the industry was in tatters, and all but the most profitable arsenic works had been shuttered. The horrors of WWI briefly revived the Cornish arsenic industry.

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[86] Bartrip, P W. "How Green," 1994; Earl, *Cornish Arsenic Industry*, 1996; Whorton, *The Arsenic Century,* 2010. X,

[87] TST. "Sheep Dipping, and Sheep Killing, with Corrosive Sublimate of Arsenic." *The Sunday Times*, September 12, 1858.

[88] Earl, *Cornish Arsenic Industry*, 1996.

[89] Earl, "Arsenic Winning," 1983; Earl, *Cornish Arsenic Industry*, 1996. These new rounds of investment also unleashed a new scale of human an environmental arsenic poisoning.

[90] Hunt, R. *Mineral Statistics of the United Kingdom of Great Britain and Ireland for the Year 1879*. Geological Survey of Great Britain. London: Longmans, Green, & Co. for Her Majesty's Stationary Office, 1880.

[91] Arsenic "was considered of so little value it was thrown on the waste dump for many years, now the chief source of profit." Rothwell, *The Mineral Industry*, 1898.

[92] Barton, D. *A History of Tin Mining and Smelting in Cornwall*. Cornwall, UK: D. Bradford Barton Ltd., 1967.

Arsenical wastes, produced from the last 300 years of copper, lead, and ore processing and smelting, glowed again with potential value. The first major industrial war brought a new generation of prospectors to the CDS region, identifying waste deposits, assaying their quality, and staking claims to meet wartime needs. However, even though the demand for white arsenic exploded after the war, by 1925, Cornwall's tired mines could not compete on the world stage and they had all closed for good.

The Red Metal in the American West

"Amalgamated Copper… has from its birth to present writing been responsible for more hell than any other trust or financial thing since the world began. Because of it people have sustained incalculable losses and have suffered untold miseries."

Lawson, *Frenzied Finance: The Crime of Amalgamated*, 1905[93]

Since arsenic-as-waste's production is governed by the economies of scale operating on the primary mineral, massive copper smelters with the most capacity also produce the most arsenical waste. By the late 1870s, on the European continent, in Sweden and Germany in particular, smelting had moved on from the 1860s designs of CDS engineers.[94] As Swedish and German companies sunk more and more capital into smelter construction, plants got bigger and their capacity increased. Massive capacity, however, also assumes an industrial geography of feedstocks capable of supplying the smelter's appetite. This made the siting of smelters a difficult question. The last thing a company wanted was to have idle or inefficient capacity (a reason why the British smelters rapidly turned to foreign ores in the 1830s).[95] In the 1700s, British mining companies began "managing" this issue of the copper, lead, and tin industries through cartelization and rudimentary vertical integration. By owning key steps an industry that takes raw ore from the bowels of the earth, concentrates it, moves it to smelters, and transforms it into a finished product, companies could regulate the source of their material life blood.

In the last quarter century of the 19th century, across the American West, US mining companies brought vast ore deposits and new ore processing and smelting technologies in line with high finance, the railroad, waves of immigrant labor, and vertical integration to create the largest and most productive copper industry in the world.[96] With a bonanza of smelter construction throughout the 1880s and 1890s, the flow of American ores to the ports of Cornwall in Swansea dried up. Because arsenic-as-waste is mainly a byproduct of

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[93] Lawson, T W. *Frenzied Finance: The Crime of Amalgamated* New York: The Ridgway-Thayer Company, 1905. 3.
[94] Dennis, *Hundred Years of Metallurgy*, 1964.
[95] Suboptimal and overcapacity continues to be plague of the smelting and chemical industries.
[96] Richter, " Copper-Mining Industry," 1927; Rickard, T A. *A History of American Mining*. New York: McGraw-Hill Book Company, Inc., 1932.

copper ore smelting, the American arsenic industry, like the British industry that came before it, only makes sense by understanding the American copper industry.

Historians usually label 1845 as the beginning of the American copper industry.[97] That year investors formed the Pittsburg and Boston Mining Company formed to exploit copper deposits on the southern shores of Lake Superior, an area now colloquially referred to as the UP (Upper Peninsula of Michigan).[98] Miners first applied rudimentarily milling and concentration methods on site, and then loaded the concentrated ores onto (copper-bottom) ships bound for the British southwest. Small-scale copper mining sputtered in many eastern states in the 1850s, but by 1865, 78% of US copper ores (equivalent to about 7,200 tons of finished copper) came from the shores of Michigan. "Lake copper" continued to be the dominant source of American copper until the early 1880s. In the 1850s, small ore refiners opened in Baltimore and New Jersey.

In the late 1850s, several silver mines opened in the 29,640-square-mile (76,800 km^2) slice of present-day southern Arizona and New Mexico known as the Gadsden Purchase, bought from Mexico in 1854.[99] But silver production never took off at these mines. Instead, miners turned to rich copper ores that they had discovered in the process of mining for silver. After rudimentary on-site milling and concentration, these mining company shipped their ores overland to Yuma or Galveston and then on to Wales or Cornwall. In the 1860s, California miners began exploiting copper deposits of the Sierra Nevada foothills (Copperopolis!). Shipped via the Golden Gate and Cape Horn, these ores also found their way to the furnaces of British smelters.[100]

It was the discovery of large copper deposits (that went unnoticed by gold and silver prospectors in the 1860s) in Montana and Arizona in the 1870s that enticed American mining companies to build their own smelters.[101] Captains of the US copper mining companies argued that instead of being held hostage by the ore buyers of the CDS complex, they could produce finished copper cheaper than CDS smelters and profit handsomely at both ends of the red metal industry.

In 1879, at their mine near Butte, Montana, the Colorado Smelting and Refining Company erected the first commercial copper smelter in the American West.[102] Two years later, in 1881, the plant came online just as the Utah Northern railroad reached Butte from

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[97] Paine, F W. "Copper." In *Political and Commercial Geology and the World's Mineral Resources*, edited by J E Spurr, 223-60. New York: McGraw Hill Book Company Inc., 1920.

[98] Richter, " Copper-Mining Industry," 1927.

[99] Raymer, R G. "Early Copper Mining in Arizona." *Pacific Historical Review* 4, no. 2 (1935): 123-30.

[100] Some of the ore was also processed by American smelters at Baltimore and New Jersey. The first US smelters were built in 1848 but their capacity impact on world copper production was minimal. American ore smelting industries began in 1848 at Boston, followed by Pittsburg, Cleveland, Baltimore, and Detroit. American smelting companies collectively introduced new blast furnaces, water jacket furnaces, Bessemer converters, pyritic smelting, giant refractory furnaces, and electro-refining technologies.

[101] "In every Gulch where gold placer mines are found, gold bearing quartz veins are also found, many of which contain silver, copper, antimony, arsenic, and manganese, and are rich but refractory." Browne, J R, and J W Taylor. *Reports Upon the Mineral Resources of the United States*. US Government Printing Office, 1867. 504.

[102] Rickard, *History of American Mining*, 1932.

Salt Lake City. The smelter produced highly concentrated copper matte and regulus, which was then shipped to the Argo Works in Denver for final processing.[103] Two other significant events happened in 1881.[104] The first was the commencement of large-scale copper mining in Southern Arizona at the Globe Mine and the Copper Queen Mine; mines eventually linked with the Southern Pacific and the rapidly expanding US rail and port network in 1898.[105] The second was the purchase of the Anaconda mine northwest of Butte, MT by the partners' Daly, Haggin, Tevis, and Hearst. A small silver mine at the time, the partners paid $30,000 for the claim. However, in the process of expanding the mine deeper in search of more silver ore, miners cut across seam after seam of rich copper ore.

In 1882, the Anaconda mining company turned its focus from silver to copper and loads of incredibly rich copper ores began flowing from the mountains of Montana westward across the Pacific slope to the shores of Puget Sound and the Golden Gate and then on to Swansea. By 1884, the Anaconda mining company had shipped more than 37,000 tons of concentrated copper ore (at 45% copper) to CDS smelters.[106] For the owners of Anaconda, the situation was untenable. That is why in 1883, the Anaconda mining company began construction of their own smelter complex in the Deer Lodge Valley, not far from their mine. By the fall of 1884, the smelter was consuming 500 tons of ore per day, converting 12% copper ore into 64% matte.[107] That same year the Parrot Silver and Copper Company built the first commercial electrical converters in the world at their Butte mine. Conversion is the last step in refining that takes matte copper and refines it to >99% copper. In 1885, for the first time, American exports of finished copper to Britain surpassed the exports of ore. By 1887, the Anaconda mine was the largest producer of copper in the US and by 1890, US copper production was seven times 1870 levels. American ore exports to CDS smelters had all but ceased.[108]

Throughout the 1880s and 1890s, US mining companies erected state-of-the-art Cyclopean scale smelting complexes in Montana, Arizona, Utah and Washington State.[109] In the 1880s and 1890s, copper facilitated industrial growth and electrification, which in turn, increased the demand for copper. During this period the copper industry was also the subject of increasingly vicious financial battles, red in tooth and claw. Companies grew

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[103] Matte is a highly concentrated product that contains 60-70% copper by weight that comes from sulfide ores. Regulus refers to copper in a high purity metallic state but not fully finished.
[104] Weed, W H. "Copper Deposits of the United States." In *The Copper Mines of World*, 253-367. New York: Hill Publishing Company, 1908.
[105] Richter, "Copper-Mining Industry," 1927. It makes sense for many reasons that the exploitation of copper from the West trailed that of precious metals like gold and silver. Copper is not a precious like gold and silver. Copper is foremost an industrial metal; its utilization is almost exclusively for productive purposes. The copper industry thus requires the development of an infrastructure of mines, labor networks, smelters, and transportation along with the increased demand for copper from new electrical technologies, including electrochemical ore separation, which was first applied to copper finishing in Montana in the 1880s; Raymer, "Mining in Arizona," 1935.
[106] Rickard, *History of American Mining*, 1932.
[107] Which was then shipped to Swansea, Baltimore, Denver, or New Jersey for finishing.
[108] Rothwell, *The Mineral Industry*, 1898.
[109] Richter, " Copper-Mining Industry," 1927; Dennis, *Hundred Years of Metallurgy*, 1964.

larger and more vertically integrated, mines and smelters repeatedly changed hands, red metal production soared, and all the time labor suffered.[110] In the 1890s, American mining engineers introduced two new technologies to the smelter industry, technologies that enabled a qualitative shift in copper smelting capacity and efficiency, in turn, enabling the expansion of copper mining via the ability to profitably treat low quality ores formerly considered unprofitable.

The first major technological development, the Bessemer process, is known much more for its effects on the steel industry.[111] However, the process's refinement and commercial introduction by US mining engineers in the 1890s did as much for the US copper industry as it did for the steel industry. By using powerful engines to force oxygen into red-hot ores to speed up the removal of impurities, the Bessemer process allowed smelters to decrease the amount of labor, fuel, and time per unit of copper produced.[112] In the early 1890s, western mining engineers coupled the Bessemer process together with late 19th century industrial gigantism, hydroelectric power, and the newly developed American technique of electrolytic refining.[113] Electrolytic conversion is the last process involved in ore smelting, and it uses electrical currents to dissolve pure copper from impure slabs of matte and deposit it pure copper seeds, creating incredibly pure copper in a fraction of time. With the application electrochemistry to metallurgy, chemists and engineers turned a smelting process that once took days into one that that took only a few hours. These major American developments in metallurgy foretold of the dominant American position in the world copper industry in the near future. "The years from 1895 to 1901, inclusive, were in certain respects among the most spectacular that the American Copper industry has ever known."[114]

In the spring of 1902, Anaconda finished construction of their new smelter in the Deer Lodge Valley of Montana.[115] This new machine, powered by wood and hydraulic head, consisted of 48 six-hearth MacDougall roasting furnaces, five blast furnaces with 72-ton water jackets, 14 matte furnaces, and eight electrolytic converters. It was largest and most technologically advanced smelter in the world. It also quickly became the world's largest point source of arsenic trioxide. By 1903, the smelter was releasing more than 29,000 pounds per day of crude arsenical waste downwind into the surrounding forest.[116] The production of copper ore and finished copper soared across the American west and farmers,

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[110] Pettengill, R B. "The United States Copper Industry and the Tariff." *The Quarterly Journal of Economics* (1931): 141-57; Schmitz, C. "The Rise of Big Business in the World Copper Industry 1870-1930." *The Economic History Review* 39, no. 3 (1986): 392-410; Underwood, K D. "Mining Wars: Corporate Expansion and Labor Violence in the Western Desert 1876-1920." University of Nevada, Las Vegas, 2009.
[111] Dennis, *Hundred Years of Metallurgy*, 1964.
[112] Hofman, *Metallurgy of Copper*, 1914.
[113] Richter, " Copper-Mining Industry," 1927.
[114] Richter, " Copper-Mining Industry," 1927.
[115] Richter, " Copper-Mining Industry," 1927.
[116] Ingallis, W R, ed. *The Mineral Industry: Its Statistics, Technology, and Trade During 1905*. Vol. 14. New York: The Engineering and Mining Journal, 1906. X

forests, and livestock immediately suffered the consequences of US smelters' new economies of scale.[117]

In the early 1910s, US mining companies opened massive copper mines in the Southwest at Santa Rita, NM, Douglas, AZ, and in Alaska at Kennecott (See Figure 5).[118] The enormous scale of these new mines demanded massive amounts of upfront capital, financing necessary to build a profitable mine at the economies of scale for ores with overall copper recovery rates of ~1%.[119] By the outbreak of WWI, the handful of smelters across the US west – Montana, Arizona, Utah, Colorado, and Washington – produced 60% of the world's copper. By 1917, the US, like CDS complex before it, had become the industrial core of copper smelting. 30% of US copper production came from ores imported from Mexico, Canada, Japan, and Chile.[120] In 1918, US copper output peaked for the first time at 954,000 tons (See Figure 6).

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[117] Haywood, J K. "Injury to Vegetation and Animal Life by Smelter Fumes." *Journal of the American Chemical Society* 29, no. 7 (1907): 998-1009; MacMillan, Donald. *Smoke Wars: Anaconda Copper, Montana Air Pollution, and the Courts, 1890-1924*. Helena, MT: Montana Historical Society, 2000.

[118] Raymer, "Mining in Arizona," 1935.

[119] Hofman, *Metallurgy of Copper*, 1914.

[120] Paine, "Copper," 1920; Bureau of the Census. *Historical Statistics of the United States 1789-1945, a Supplement to the Statistical Abstract of the United States*. Washington, DC: US Department of Commerce, 1949.

Figure 5 – Santa Rita copper mine (aka Chino mine), looking southwest toward the "Kneeling Nun" geologic formation, ca. 2003. [121]

In the face of low copper prices after WWI, copper mining and smelting companies went through further rounds of consolidation and companies such as ASARCO reached further abroad into places like Mexico.[122] In the early 1920s, US mining and chemical engineers introduced the flotation method of copper dressing, a form of pre-treatment utilizing the waste byproducts of the post war oil boom (See Chapter 4) to again decrease the turnover time of copper smelting.[123] By 1929, the maelstrom of merger and acquisition upon merger and acquisition had coalesced into four large US companies that controlled more than half of the world's copper production. The smelters of Anaconda, ASARCO, Kennecott Copper, and Phelps Dodge, produced all but a small portion of US copper. In 1929, US copper production surpassed the one million ton mark, hitting an all time high.[124] However,

[121] Wikipedia. "Chino Copper Mine." http://en.wikipedia.org/wiki/Chino_Mine#/media/File:Chino_copper_mine.jpg.
[122] Heikes, V C. "Arsenic." In *The Mineral Industry: Its Statistics, Technology and Trade During 1924*, edited by A B Butts and G A Roush, 63-70. New York: The McGraw Hill Book Company, Inc., 1925.
[123] Dennis, *Hundred Years of Metallurgy*, 1964.
[124] Survey, United States Geological. "Historical Statistics for Mineral and Material Commodities in the United States." Department of the Interior, http://minerals.usgs.gov/minerals/pubs/historical-statistics.

because arsenic is a waste product of copper smelting, the Cyclopean smelters of the four copper companies also produced more than half of the world's white arsenic wastes.

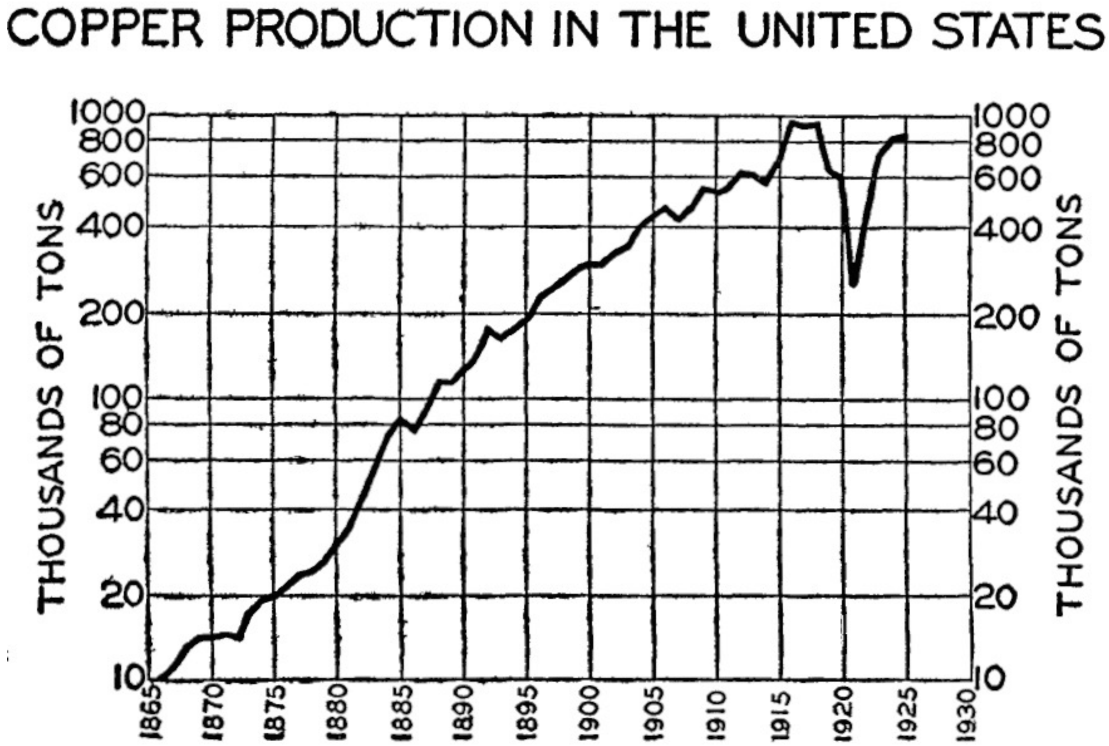

Figure 6 – United States copper production (in thousands of tons) from 1865 to 1925.[125]

The history, politics, and environmental effects of arsenic production in the US would turn out very different by far than that of the CDS region. This means that in addition to the US copper industry, the history of arsenic production and consumption in the US has to also be understood in the context of the early 20th century conservation movement, the politics of pure food, and the development of industrial agriculture (See Chapter 3).[126] As Nriagu has noted, "80% of all of the arsenic produced by human kind was used in environmentally dissipative manners, as herbicides, insecticides, desiccants, feed additives, wood treatments, chemical warfare agents, and drugs."[127] In the early 20th century, US agriculture bestowed upon the king of all human poisons a new duty as the agent of non-human mass death (See

[125] Richter, " Copper-Mining Industry," 1927.
[126] Wiley, H W. *The History of a Crime against the Food Law: The Amazing Story of the National Food and Drugs Law Intended to Protect the Health of the People, Perverted to Protect the Adulteration of Foods and Drugs*. Washington, DC: Harvey W. Wiley, M.D., 1929; Whorton, *Before Silent Spring*, 1974.
[127] Nriagu, J O. "Arsenic Poisoning through the Ages." In *Environmental Chemistry of Arsenic*, edited by W T Frankenberger, 1-16. New York: Marcel Dekker, Inc., 2002.

Chapter 2). The profitable use of arsenic in pest control, however, was only possible because arsenic was a cheap industrial waste product of the copper industry.[128]

The American Arsenic Industry

"It is an uncanny thought that this poison [arsenic] is everywhere about us, ready to gain unsuspected entrance to our bodies from the food we eat, the water we drink and the air we breathe."

K. Vogel, *The Significance of Arsenic in the Excretions*, 1928[129]

In 1901 the Puget Sound Reduction Company (ASARCO) launched the American arsenic industry.[130] Using a design based on Saxony technology (and likely engineers from Wales or Germany), they erected the first US arsenic plant in Everett, WA, just north of Seattle. Refining waste ores originally from California, Washington, British Columbia, and Japan, the plant made about 300 tons of white arsenic the first year, a small portion of the roughly 3,000 tons of arsenical compounds consumed by US industries in 1901. Plagued with low arsenic prices, lack of direct access to ores, and rudimentary technology, over the next few years, the plant produced an average of about 600 tons per year running at less than full capacity.

In 1905, the Anaconda Mining Company began construction of an arsenic plant adjacent to their immense Washoe smelter.[131] The impetus for its construction, however, was not economical, but political (See chapter 3). Downwind vegetative destruction is a characteristic of all smelters, but the scale of downwind forest destruction from Anaconda's newest and largest smelter was orders of magnitude greater than any smelter before it. In 1903, shortly after it fired up its ovens, farmers and foresters who suffered from the smelter's toxic excretions appealed to state and federal officials. The Roosevelt administration, backed by a growing conservation movement, pressured the company into installing its first waste recovery flues and taller effluent stacks. The mining engineer A. Fay observed at the time that "smelter companies only make it [arsenic] to prevent its escape to the atmosphere."[132]

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[128] Nriagu, J O, and J M Azcue. "Food Contamination with Arsenic in the Environment." In *Food Contamination from Environmental Sources*, edited by J O Nriagu and M S Simmons. Advances in Environmental Science and Technology. New York: John Wiley and Sonds, 1990.

[129] Vogel, K. "The Significance of Arsenic in the Excretions." *The American Journal of the Medical Sciences* 176, no. 2 (1928): 215-24.

[130] Rothwell, R P, and J Struthers. *The Mineral Industry: Its Statistics, Technology, and Trade in the United States and Other Countries to the End of 1901*. New York: The Engineering and Mining Journal, 1902.

[131] Ingallis, W R, ed. *The Mineral Industry: Its Statistics, Technology, and Trade During 1905*. Vol. 14. New York: The Engineering and Mining Journal, 1906.

[132] Fay, A H. ed. *The Mineral Industry, Its Technology and Trade During 1910*. Vol. 19, New York: McGraw-Hill Book Company, 1911. X.

In 1906, Anaconda finished the most sophisticated arsenic plant in the world. By combining CDS arsenical smelting methods with American capitalism, Anaconda built a plant capable of producing a white arsenic product that surpassed 'Cornish White' in its purity.[133] But low prices and cheap foreign imports kept the plant idle most of year despite the production of increasing amounts of concentrated arsenical waste by the adjacent smelter. In 1909, the US Smelting Company completed an arsenic plant at Salt Lake City to treat the arsenical wastes of their lead and copper smelters that had accumulated since the plant was erected decade earlier. In 1910, at a cost of over $1 million, the Boston and Montana Milling Company completed most advanced arsenic recovery system in the world at their smelter in Great Falls, Montana.[134]

Together these four US plants were producing about 1,500 tons of white arsenic per year (~28% of US consumption), still only a fraction of the toxic waste collectively produced in their roasting operations. Anaconda's world-class Washoe smelter, for instance, was producing 11 million tons of crude white arsenic wastes per year, more than enough for the entire world's consumption many times over.[135] The arsenic market did not operate on the basis of scarcity.[136] As a waste of copper production, the arsenic market operated from a basis of overabundance, or surplus. As such, one of the strategies employed by Anaconda and other companies was to price their incredibly pure white arsenic at the cost of transportation. Trying to rid themselves of their accumulating toxic waste, these companies essentially gave their arsenic away for free to those who would pay to have it shipped.

By 1910, US consumption of arsenic had reached more than 5,000 tons per year. Between 1900 and 1914, also known as the golden age of the American farm, agricultural use overtook non-agricultural use as the largest share of annual white arsenic consumption. By this time, western apple growers had developed capital-intensive export-oriented apple industries in coastal central California and eastern Washington, industries that were increasingly reliant on lead arsenate for codling moth control.[137] As a result, arsenical demand in the early 1910s, particularly on the west coast, increased considerably.

The outbreak of WWI caused white arsenic demand and prices to soar. Higher wartime demand for white arsenic was a function of the increased use of arsenic in the manufacture of lead shot, as a substitute for antimony oxide (Sb_2O_3) in glass manufacture, and its secret incorporation into chemical weapons. But importantly, demand also came from the expanded use of pesticides by farmers during the war. With food prices high, more

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[133] Ingallis, W R, ed. *The Mineral Industry : Its Statistics, Technology, and Trade During 1909*. Vol. 18. New York: The Engineering and Mining Journal, 1910.

[134] Of, C, ed. *The Mineral Industry : Its Statistics, Technology, and Trade During 1912*. Vol. 21. New York: McGraw-Hill Book Company Inc., 1913; LeCain, T. "The Limits of "Eco-Efficiency": Arsenic Pollution and the Cottrell Electrical Precipitator in the U.S. Copper Smelting Industry." *Environmental History* 5, no. 3 (2000): 336-51.

[135] Of, *The Mineral Industry:* Vol. 21, 1913.

[136] LAT. "Wide Use of Arsenic: Is Principally Employed in Glass Making and in Insecticides, as Well as Paints and Medicines." *Los Angeles Times*, May 10, 1914.

Haynes, *Chemical Economics*, 1933;

[137] Woodworth, C W. "Codling Moth Control in California." *Journal of Economic Entomology* 3, no. 6 (1910): 470-73.

farmers could afford the pesticides and fertilizers they needed to maximize their yields and realize their share of the war's spoils. By 1916, as the war slogged on, soaring prices for white arsenic had enticed mining companies to capture more of their wastes. Across the American West, mining companies introduced new flue scrubbing technologies.[138] US arsenic refining plants and arsenical insecticide plants finally ran at full capacity.[139]

Since 1914, the European war had caused the refining of primary metals like copper to increase, but it wasn't until 1917 that the production of refined arsenic began to catch up. In 1917, the Anaconda Mining Company enlarged it arsenic plant at Great Falls, Montana to treat more "accumulated flue dusts."[140] By 1917, strong demand along with a constrained supply had driven the price of white arsenic to five times pre-war prices. European imports had fallen dramatically, Mexican imports had increased slightly, and the US was now producing more than 80% of its domestic consumption.

In the spring of 1917, the Food Administration (FA) Division of the War Industries brought arsenic under its control.[141] It banned all exports and it began regulating its price and uses. Arsenic was a critical ingredient for the production of food, plus it was necessary for the secret production of arsenical chemical weapons, some of which like Lewisite – code-name-methyl – were prepared in large quantities.[142] The FA's estimate of wartime demand of 12,000 tons was 2,500 tons higher than current US production plus Mexican imports. In 1917, four US companies at seven plants produced over 6,000 tons of white arsenic. The war came to an abrupt and unexpected end in the fall of 1918 (See Chapter 3). Even so, in 1919, US demand for white arsenic remained at 12,000 tons. In the early 1920s commodity prices collapsed and US farmers confronted agricultural depression. White arsenic production and price also fell sharply. But unlike US agriculture in general, the production and consumption of refined arsenic would quickly recover (See Figure 7).

In 1922, Anaconda opened a new smelter and new arsenic plant at Tacoma, WA, and the US Smelting, Refining, and Milling Company, the largest domestic producer of refined white arsenic, added further value to their wastes by manufacturing calcium arsenate [$Ca_3(AsO_4)_2$] insecticide at their Midvale, UT arsenic plant.[143] This created a more direct route from mine to farm. In 1923, the US produced over 14,000 tons of white arsenic and consumed more than 24,000 tons, two-thirds of it in the industrial production of food and

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[138] LeCain, "Limits of "Eco-Efficiency,'" 2000.

[139] Roush, G A, ed. *The Mineral Industry: Its Statistics, Technology, and Trade During 1915*. Vol. 24. New York: McGraw-Hill Book Company Inc., 1916. LeCain, "Limits of "Eco-Efficiency,'" 2000.

[140] Roush, G A, and A B Butts, eds. *The Mineral Industry: Its Statistics, Technology, and Trade During 1918*. Vol. 27. New York: McGraw-Hill Book Company Inc., 1919.

[141] Baruch, B M. *American Industry in the War: A Report of the War Industries Board*. New York: Prentice-Hall, Inc., 1921.

[142] Vilensky, J A. *Dew of Death: The Story of Lewisite, America's World War I Weapon of Mass Destruction*. Bloomington, IN: Indiana University Press, 2005.

[143] Davis, J J. "The Value of Crude Arsenious Oxide in Poison Bait for Cutworms and Grasshoppers." *Journal of Economic Entomology* 12, no. 2 (1919): 200-03; Roush, G A, and A B Butts, eds. *The Mineral Industry: Its Statistics, Technology, and Trade During 1921*. Vol. 30. New York: McGraw-Hill Book Company Inc., 1922; LAT. "Arsenic in 1924." *Los Angeles Times*, June 5, 1925.

fiber. Three companies at five plants controlled the US arsenic market. The American Smelting and Mining Company (ASARCO) operated arsenic plants in Denver, CO, Tacoma, WA, and Perth Amboy, NJ. The Anaconda Mining Company operated a plant at their Washoe, MT, smelter, and the US Smelting, Refining, and Milling Company did so as well at their plant in Midvale, UT.

In the mid 1920s, railroads began substituting the use-value of arsenic' herbicidal bioactivity for the human labor needed to clear weeds in and around railroad tracks.[144] Armed with sodium arsenite ($NaAsO_2$) or crude arsenical wastes, what once required teams of men, now required but one man with a pressurized liquid sprayer. Throughout the 1920s, in an increasingly total war against the "insect menace," agriculture demanded more and more toxic arsenical compounds.[145] Scientists and other opportunistic inventors flooded the US patent office with submissions for new arsenical concoctions and new machines to efficiently spread arsenic's toxicity across large acreages.[146] In 1926, US mining and chemical companies began exporting both white arsenic and arsenical insecticides in significant quantities to places like the West Indies and South America, especially the cotton fields of Peru.[147]

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[144] McDonnell, C C. "Recent Progress in Insecticides and Fungicides." *Industrial & Engineering Chemistry* 16, no. 10 (1924): 1007-12; Tyler, P M, and C N Gerry. "Arsenic." In *Minerals Resources of the United States*, 319-27. Washington DC: US Bureau of Mines, Geological Survey, 1931/32; Essig, E O. "Farm Machinery in Relation to Insect Pest Control." *Journal of Economic Entomology* 26, no. 4 (1933): 864-68.

[145] Howard, L O. *The Insect Menace*. New York: D. Appleton-Century Company, 1933.

[146] Tyler, P M, and C N Gerry. "Arsenic." In *Minerals Resources of the United States*, 319-27. Washington DC: US Bureau of Mines, Geological Survey, 1931/32. For example: Howard, H. "Brown-Colored Insecticide for Use on Tobacco Plants." *Patent #1,580,200*, United States Patent Office. USA: Grasselli Chemical Company, 1926. The Grasselli Chemical Company was one of the largest producers of arsenical insecticides and innovations like the one describe in the patent helped arsenic spread to tobacco crops, leading to a rapid increase of the arsenic content of cigarettes. (Dow bought the Grasselli chemical company in the barrage of chemical mergers and acquisitions following the crash of 1929). The arsenic content in cigarettes peaked in the mid 1940s along with the peak of arsenic insecticide use by the tobacco industry. "The Toxic Elements in Your Future and in Your Past." *Smithsonian*, 1972, 62-69.

[147] Ambruster, H W. "Arsenic." In *The Mineral Industry: Its Statistics, Technology and Trade During 1926*, edited by A B Butts and G A Roush, 54-65. New York: The McGraw Hill Book Company, Inc., 1927.
Roark, "Statistics for 1928," 1929; Wolcott, G N. "The Status of Economic Entomology in Peru." *Bulletin of Entomological Research* 20, no. 02 (1929): 225-31.

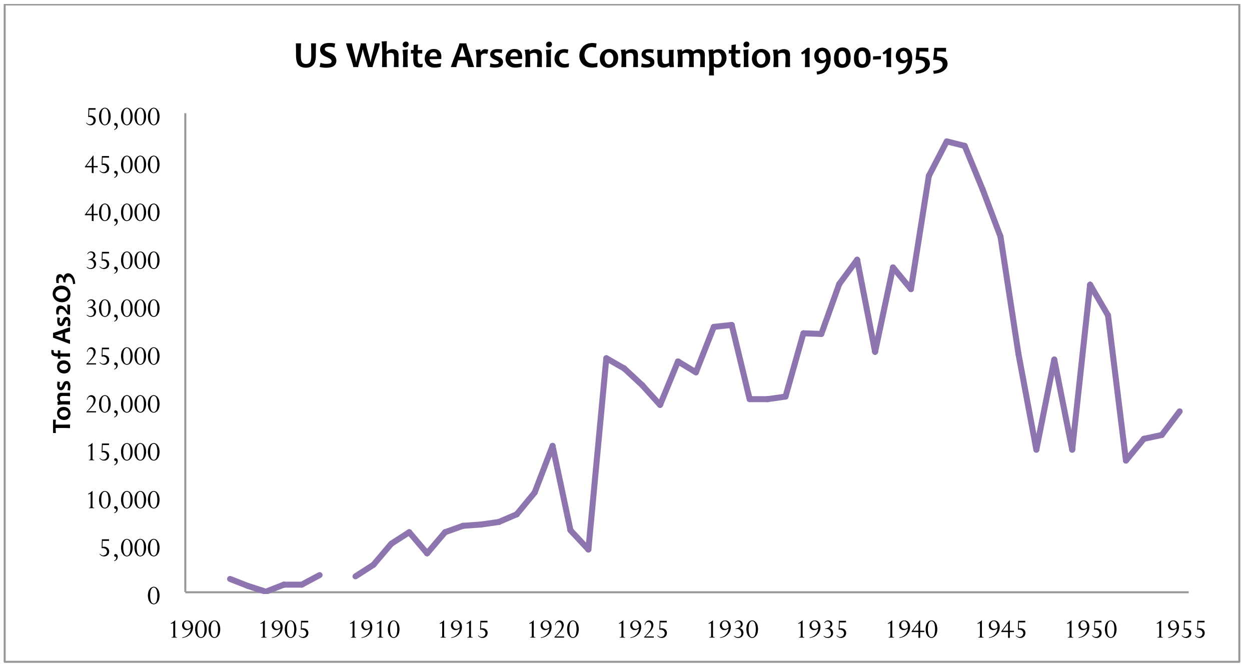

Figure 7 – White arsenic (As_2O_3) consumption in the United States in short tons of As_2O_3.[148]

By the late 1920s, the pome-fruit growing regions of the West – Central California, Eastern Washington, the Hood River Valley of Oregon – consistently consumed enormous amounts of arsenic to produce high quality fruit for US and foreign export markets.[149] Agricultural consumption east of the Rockies, however, was less consistent.[150] Unlike the west coast fruit industries that saw lead arsenate as just another industrial input and where private spraying outfits did most spraying, in the mid 1920s, Northeastern and Midwestern farmers applied their own arsenicals and then only in response to (real and/or perceived) outbreaks.[151] In these growing regions, arsenical insecticide consumption had yet to fully naturalize as a general agroindustrial input. In the US South, less than 20% of cotton farmers used arsenicals on a regular basis.[152] However, when insect outbreaks did occur, southern famers snapped up arsenicals seemingly at no matter the price.[153] As more than one observer

[148] Data compiled from *The Mineral Industry, Its Statistics and Trade* Vols. 8-40 and the *Mineral Resources of the United States* (Minerals Yearbook) 1931-1952.

[149] Roark, "Statistics for 1928," 1929

[150] Anonymous. "Minutes of the Conference of Plant Pathologists, Entomologists, and Manufacturers of Insecticides and Fungicides at the National Academy of Sciences, Washington, Dc, September 28." In *Institutions: Association Individuals*, edited by National Research Council. Washington DC: Archive of the National Academy of Sciences, 1920.

[151] Whorton, *Before Silent Spring*, 1974.

[152] Coad, B R. "Killing Boll Weevils with Poison Dust." In *Yearbook for 1920*, 241-52. Washington, DC: USDA, 1921; Helms, D. "Technological Methods for Boll Weevil Control." *Agricultural History* 53, no. 1 (1979): 286-99.

[153] For example, in 1911, an outbreak of the cotton weevil (*Alabama argillacea)* in Mississippi Delta region caused a sudden increase in the demand for arsenicals. Many US factories began running day and night to meet the demand, and over a two-week period, 800,000 pounds of arsenicals shipped from New Orleans up Mississippi to the Yazoo Delta of Mississippi. The Paris green, London purple, and lead arsenate consumed did nothing to stop the outbreak of the weevil. Hunter, W D. "The Outbreak of Alabama Argillacea in 1911." *Journal of Economic Entomology* 5, no. 2 (1912): 123-31.

noted at the time, the general expansion of pest control in cotton could provide "a potential outlet for practically all the arsenic now produced in the United States."[154] The commercial crop duster was introduced to the South in 1925 and by 1929 planes loaded with toxic dusts coated millions of cotton acres with up to 40 pounds of calcium arsenate per acre (See Chapter 3).

Despite arsenic selling at a price near the cost of transportation, 1929 was a good year for the arsenic industry. The US produced more than 16,000 tons of white arsenic and consumed more than 27,000 tons.[155] All stocks on hand were consumed to manufacture more arsenical insecticides. Mining companies began selling large amounts of crude arsenical waste directly to railroad companies for use as herbicides. By 1930, the US and Mexico combined produced two-thirds of global white arsenic output, meaning that more than half of all white arsenic produced in the world made its way to the farms and fields of the US.[156] Although US arsenic consumption dropped following the stock market crashes of late 1929, it quickly weathered the Great Depression. Its use continued to climb in the 1930s. In the mid 1930s, the US government via New Deal programs like the Civilian Conservation Corp, began spreading arsenic baits across the Dust Bowl west to combat the grasshoppers and locusts outbreaks that were adding insult to injury. In the mid 1930s, Sweden began exporting large quantities of white arsenic to the US from their Boliden smelter, although this quickly tapered off in the run up to WWII. In the early 1940s, US production and consumption of white arsenic peaked at more than 30,000 and 47,000 tons respectively. During WWII, more than half of all the refined arsenic produced across the world was consumed as an economic poison on US farms, and US agriculture was more productive than ever.[157]

The King of Economic Poisons

"The enormous use of arsenical insecticides makes fruits and vegetable a potent source of poisoning. Cotton has been shown to be contaminated by the calcium arsenate used to combat the boll weevil."

Dr. A. F. Kraetzer, *Raynaud's Disease Associated with Chronic Arsenical Retention*, 1930[158]

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[154] Bowles, O. "Arsenic." In *The Mineral Industry: Its Statistics, Technology and Trade During 1929*, edited by A B Butts and G A Roush, 36-42. New York: The McGraw Hill Book Company, Inc., 1930.

[155] More than 90% of all US produced arsenic has come from copper ores. Renick, A. "Arsenic." In *Minerals Resources of the United States*, 162-66. Washington DC: US Bureau of Mines, Geological Survey, 1951.

[156] Three plants, as a byproduct of copper produced arsenic in Mexico. The two largest exporters to the US were the American Metal Co. plant in at Durango and the American Smelting and Refining Co. plant in San Luis Potosi. The American Metal Co. shipped white arsenic from Durango via rail to Laredo, TX. ASARCO shipped their white arsenic by from the port of Tampico or to various Southern ports.

[157] Cochrane, W W. *The Development of American Agriculture*. Minneapolis, MN: University of Minnesota Press, 1993.

[158] Kraetzer, A F. "Raynaud's Disease Associated with Chronic Arsenical Retention: Report of Case Cured by Sodium Thiosulphate." *Journal of the American Medical Association* 94, no. 14 (1930): 1035-37.

In the early 1860s, as pioneers pushed further west of the Mississippi, the Colorado potato beetle (*Leptinotarsa decemlineata)* began an inverse trek eastward. By the mid 1860s, the beetle had spread from Colorado to states like Missouri and Wisconsin via the logistics networks built to supply new settlements. And like the pioneers on the western frontier, the beetle found new territory ripe for colonization. Mythology suggests that a Missouri farmer first successfully "controlled" the Colorado beetle in 1867 when he threw some leftover paint on his infested potato plants. Evidence suggests Paris green was used as insecticide in Colorado as early as 1862, but the first official documentation of the use of Paris green was in 1868 in the Journal of American Agriculture.[159] Edwin Reynolds, a Wisconsin farmer reported the results of an application of a paste he made from Paris green and wood ashes to his potato plants.[160] By 1875, despite growing concern over the phytotoxicity of Paris green, many progressive farmers, from Minnesota to Missouri to Massachusetts, had begun experimenting with it to protect their potato vines from the voracious appetite and fecundity of the plump, striped beetle.

Paris green, a copper and arsenic based compound (named for Dr. Paris and not the French city), was a brilliant emerald derivative of Scheele's green used across the color industries since the 1850s (See Figure 8).[161] By the 1860s, the use of green arsenical pigments like Paris green imported from England was common in the US to paint shutters and house trim, even in frontier settlements. In 1875, 500 tons of Paris green, imported from dye and pigments works of England, sold in New York's chemical markets. While it is impossible to determine how much of this went to pest control, we can conclude that the demand for Paris green by farmers was responsible for an increase in imports and sales of the toxic pigment. In the mid 1870s, a cheap industrial waste product called London purple joined Paris green in New York chemical markets.

[159] Whorton, J. "Insecticide Residue of Foods as a Public Health Problem: 1865-1938." Thesis, University of Wisconsin, 1969.
[160] He mixed Paris green with ash to make a paste an applied it to foliage to combat the potato beetle. The editors dismissed the technique as "unsafe advice" not necessarily because it was poisonous, but because it was likely to kill the potato vines. Journal of American Agriculture, 1868, (vo. 27, p. 321) quoted in, Whorton, "Insecticide Residue, 1969.
[161] Ball, *Bright Earth,* 2001.

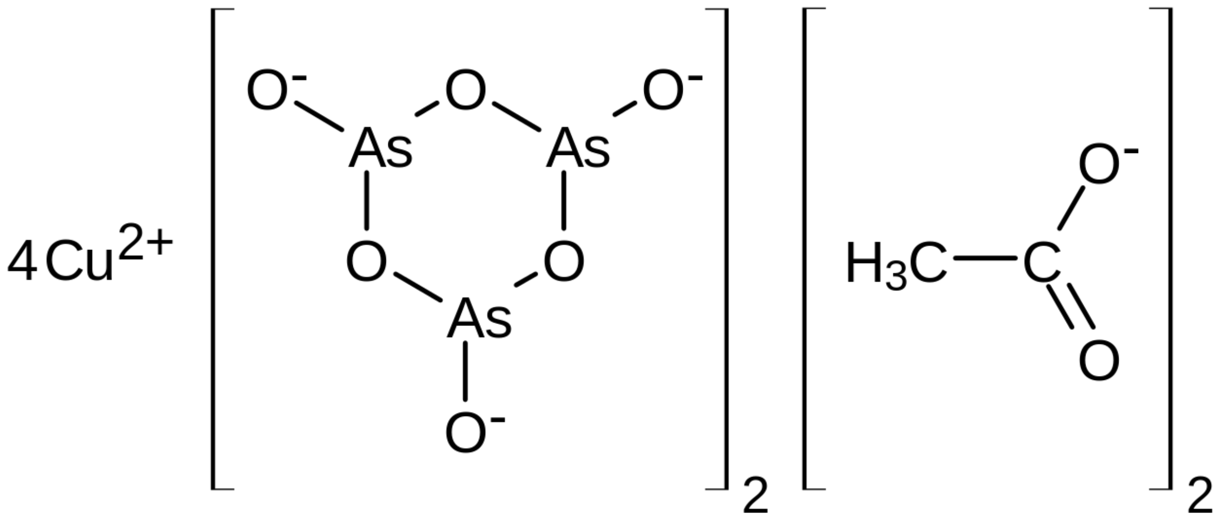

Figure 8 – Chemical structure of Paris green (copper (II) acetate triarsenite).[162]

London purple, a mixture of calcium arsenate ($Ca_3(AsO_4)_2$), calcium arsenite ($CaHAs_3O_3$), aniline ($C_6H_5NH_2$), and organic matter, was a waste product of the coal-tar based fabric dye industry.[163] London purple was normally dumped into the ocean and other waterways near British dyeworks, but with the discovery of Paris green's agricultural worth, British dye companies saw a new profitable sink for their waste in the US and they began shipping their wastes west across the Atlantic.[164] The physical properties of London purple made it easier to apply than Paris green.[165] This, together with its cheapness, helped London purple make significant inroads to the Eastern US insecticide market in the 1870s and 1880s. However, London purple's inconsistent chemical composition and its readily apparent phytotoxicity limited widespread acceptance.

During the 1880s, Paris green's spread across US agriculture was limited. Progressive farmers and agricultural scientists had tried it on many other crops besides potatoes, but phytotoxicity limited its spread. In the 1880s, a dominant concern of economic entomologists was the spread of the ravenous European Gypsy moth (*Lymantria dispar)* in northeastern forests.[166] The moth was imported to Boston in 1869 in the hopes of spawning an American "silk" industry, however, this scheme quickly collapsed and the moth

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[162] Wikipedia. "Paris Green Chemical Structure." http://en.wikipedia.org/wiki/Paris_Green#/media/File:Schweinfurter_Grün.svg.

[163] Cook, A J. "Insecticides." In *Bulletin No. 58*, University of Michigan Agricultural Experiment Station. Ann Arbor, MI, 1890; Haywood, J K. "The Composition and Analysis of London Purple." *Journal of the American Chemical Society* 22, no. 12 (1900): 800-09; Browne, C A. "Chronological Table of Some Leading Events in the History of Industrial Chemistry in America from the Earliest Colonial Settlements until the Outbreak of the World War." *Industrial and Engineering Chemistry* 18, no. 9 (1926): 884-93.

[164] TMG. "The Cotton Worm in the South." *The Manchester Guardian*, August 9, 1880.

[165] Riley, C V. "Insecticides: Summer and Spring Washes and Remedies against Pests." *Los Angeles Times*, May 3, 1887.

[166] McWilliams, J E. *American Pests: Losing the War on Insects from Colonial Times to DDT*. New York: Columbia University Press, 2008.

rapidly spread. Throughout the 1880s, economic entomologists repeatedly foretold of the complete collapse of northeastern forests unless they chemically intervened.

In 1892, F. C. Moulton developed (hydrogen) lead arsenate ($PbHAsO_4$) as an alternative to Paris green and London purple in the hope of annihilating the gypsy moth in Northeastern forests (See Figure 9).[167] Lead arsenate dusts were not immediately soluble and thus could be sprayed on the delicate foliage of shade and forest trees.[168] Although used on forests, it was on the farm where lead arsenate market growth took place. By the turn of the century, the use of arsenicals in agriculture, particularly lead arsenate, was growing, but it was still only used by an extremely small percent of progressive US farmers.

In farming regions east of the Rocky Mountains, economic poisons had not yet become a common industry practice. Many farmers were hesitant to spray their food with poison, while others resisted their use indirectly by opposing the industrialization of US agriculture that was well underway.[169] Many farmers had observed first-hand or heard second-hand stories of crop damage caused by sprays or non-human mass die-offs caused by pesticide runoff off.[170] Many agricultural scientists were arsenical propagandists, but many others questioned the benefit of their use.[171] The situation, however, was vastly different on the west coast, where intensive export driven commercial agriculture was the point of growing food.[172]

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[167] Howard, L O. *A History of Applied Entomology (Somewhat Anecdotal)*. Washington, DC: The Smithsonian Institution, 1930.

[168] Riley, C V. "Our Shade Trees and Their Insect Defoliators." In *Bulletin No. 10*. Washington, DC: United States Department of Agriculture, Division of Entomology, 1887.

[169] Smith, J B. "Cultivation and Susceptibility to Insect Attack." *Journal of Economic Entomology* 1, no. 1 (1908): 15-17; Symons, T B. "Should State Departments Conduct Public Sprayers?" *Journal of Economic Entomology* 1, no. 2 (1908): 106-10.

[170] For example: NYT. "Millions of Fish and Fowl Dying, Results of the Use of Paris Green." *New York Times*, August 9, 1878.

[171] SFC. "Scientific Scraps." *San Francisco Chronicle*, January 18, 1880; Whorton, *Before Silent Spring*, 1974, pp. 24-26

[172] Moses, H V. "" The Orange-Grower Is Not a Farmer": G. Harold Powell, Riverside Orchardists, and the Coming of Industrial Agriculture, 1893-1930." *California History* 74, no. 1 (1995): 22-37; Walker, R. *The Conquest of Bread: 150 Years of Agribusiness in California*. The New Press, 2004.

Figure 9 – Farmer size container of (hydrogen) lead arsenate, manufactured by the Grasselli Chemical Company, 1909. By 1914, the Grasselli Chemical Company of Cleveland, OH, was the largest producer of lead arsenate in the US.[173]

Turn of the century California is best remembered for the citrus empire of Southern California. By 1900, the citrus industry was the pinnacle of agroindustrial progress, truly factories in the field (See Chapter 2). Growers (not farmers) had turned the Los Angeles Basin into the world largest exporter of citrus and marketer of sunshine. The citrus industry, however, is only one example of the dramatic agroindustrial changes that came to the fertile valleys of California during the 1880s and 1890s. By the 1890s, California's general shift to input intensive specialty crops was well underway.[174] For instance, in the late 1890s, growers began turning the coastal valleys of Monterey Bay into a major pome-fruit growing region. As the industry developed, the codling moth, the proverbial worm in the apple, first introduced to the eastern US sometime in the late 1700s, integrated its life history with

[173] Virginia Tech Cooperative Extension. "Arsenicals and Their History of Application." http://vtpp.ext.vt.edu/museum-of-pest-management/the-application-technology-wing/chemistry-2/lead-arsenate-story/arsenicals-and-their-history-of-application.
[174] Henderson, G. *California and the Fictions of Capital*. Oxford: Oxford University Press, 1999; Olmstead, A L, and P W Rhode. "The Evolution of California Agriculture 1850-2000." In *California Agriculture: Dimensions and Issues*, edited by J Siebert. Berkeley, CA: Information Series, Giannini Foundation of Agricultural Economics, UC Berkeley, 2003; Walker, *The Conquest of Bread*, 2004.

the industrial apple tree. In other words, with the rise of intensive apple industry in California, the codling moth began to cause extensive commercial damage.

Pájaro Valley apple growers first used lead arsenate to combat the codling moth in 1902.[175] Right away though, growers noticed that spraying resulted in extensive foliage injury. First thinking it was caused by impurities, growers tried switching brands, but all available brands caused significant foliage injury. In 1905, growers finally appealed to C.W. Woodworth, Professor of Entomology and head of UC Agricultural Extension, for a remedy to the situation. In the spring of 1906, Woodworth sent two Berkeley researchers, W. H. Volck and E. E. Luther, under the supervision of the UC Berkeley Professor of Chemistry E. DeOng, south to Watsonville to appraise the situation and come up with a diagnosis and a possible solution.[176]

Unlike the orchards of the East Coast and Midwest, where lead arsenate was used with limited foliage injury, apple trees in the coastal valleys of Pájaro and Salinas were subject to different climatic regimes. California had a Mediterranean climate, meaning that there were no summer rains, rains that washed lead arsenate off the tree foliage. What the central coast did have for large parts of the growing season, especially during the height of the arsenical spraying season in May and June, was nightly fogs, which unlike rain wet the lead arsenate dust without washing it off the foliage. Volck and Luther quickly determined that the lead arsenate dusts were reacting with water in nighttime fogs, dissolving into them to become phytotoxic.

During the fall and winter of 1906/07, working between the DeOng chemistry laboratory at UC Berkeley and a UC Agricultural Extension laboratory in Watsonville, Volck and Luther discovered two things that dramatically increased the consumption of lead arsenate by agriculture. The first was the successful development of a non-soluble lead arsenate known as “basic” lead arsenate that could be used successfully in foggy coastal valleys of California. As the central coast’s apple trees sat dormant following the 1906 season, Luther and Volck worked furiously to develop a lead arsenate that would resist the dense coastal fogs. Formulating over 400 lead arsenate compounds and mixtures, they brought the resources of the state together with the commercially oriented agrochemical expertise of the University of California. By the early spring of 1907, they decided that the compound $[Pb_5OH(AsO_4)_3]$ had the necessary properties.[177] Following bud break, they returned to Watsonville to conduct field tests. Their basic lead arsenate proved extremely effective in combatting the codling moth and did not cause foliage injury. Not only was the product extremely pure, it was cheaper to make than all other lead arsenates on the market.

[175] Woodworth, "Codling Moth," 1910.

[176] Woodworth, "Codling Moth," 1910; Essig, E O. *A History of Entomology*. New York: Hafner Publishing Company, 1931; Chevron. "A Brief Chronological History of the Ortho Division, Chevron Spray Company." In *California Spray Chemical Company*, Chevron Chemical Company, 29. Concord, CA: Chevron Corporate Archive, 1965.

[177] Volck, W H. "The Significance of Lead Arsenate Composition." *Science* (1911): 866-70.

That was because the second major development occurred in the commercial synthesis of lead arsenate. In the production of lead arsenate compounds for their experiments, Luther and Volck figured out they could replace the expensive lead acetate catalyst with cheap lead oxide and acetic acid (vinegar) in lead arsenate synthesis, decreasing the cost of production. This switch also dramatically increased reaction yields and reaction velocity, increasing productivity and making lead arsenate's production cheaper per unit. In the process of searching for an insoluble lead arsenate, Luther and Volck developed a commercial method of making cheap high purity lead arsenate. In 1907, Luther and Volck dispatched patent applications for both discoveries to the US patent office.[178]

In early 1908, Volck and Luther resigned their positions at the University of California and spun off the Berkeley based California Spray Chemical Company to manufacture and sell basic and acid lead arsenate under the Ortho brand. By the end of the year, the two entrepreneurs had built a plant in Watsonville on Riverside Drive near Walker Street to manufacture both types of lead arsenates as well as lime-sulfur, a commonly used dormant spray among the stone fruit growers of the Santa Clara, San Joaquin, and Sacramento Valleys. In 1909, Luther and Volck incorporated their company in California as the California Spray Chemical Company, in the process bringing on the grower-shippers' Siliman and Rodgers as well as the Bean Spray Pump Company as major investors.[179] Because their process of making lead arsenate was so much more efficient, they also began licensing their patents to manufactures of lead arsenate in the US and Europe.[180]

Between the discovery of basic lead arsenate in 1907 and the end of the 1910 apple-growing season, basic lead arsenate consumption rose dramatically among Pájaro Valley apple growers. By 1910, the apple industry had crossed a significant agroindustrial threshold and the use of lead arsenate had gone from ad hoc use to a necessary annual industry practice.[181] The close of the 1910 growing season also marked a significant milestone for Central Coast apple industry. During the harvest, as Watsonville boosters and townspeople put on "the greatest apple show ever," growers, pickers, and shippers were conducting the largest commercial export of apples ever (See Figure 10). The Watsonville train station had become the greatest shipping point for apples in the entire world and from late summer to early fall of 1910, 4,000 apple filled train cars (more than 60 train cars per day at the height of harvest) left the station bound for eastern markets.[182]

Earlier that year, private spraying companies armed with high-pressure sprayers used California Spray Chemical Company product to coat 95% of the apple orchards within 10

[178] Luther, E E, and W H Volck. "Process of Making Lead Arsenate." *Patent #892,603*, US Patent Office. USA, 1908; Luther, E E, and W H Volck. "Process of Making Arsenate of Lead." *Patent #903,389*, US Patent Office. USA, 1908; Luther, E E, and W H Volck. "Manufacture of Lead Arsenate." *Patent #929,962*, US Patent Office. USA, 1909.
[179] Woodworth, *Codling Moth Control*, 1910.
[180] Chevron. "A Brief Chronological History of the Ortho Division, Chevron Spray Company." In *California Spray Chemical Company*, Chevron Chemical Company, 29. Concord, CA: Chevron Corporate Archive, 1965.
[181] Essig, History of Entomology, 1931.
[182] Woodworth, *Codling Moth Control*, 1910.

miles of Watsonville with more than 60 tons (120,000 pounds) of basic lead arsenate. Even so, demand still exceeded supply. During the 1911 spray season, private spray companies in the Watsonville area consumed more than 100 tons (200,000 pounds) of basic lead arsenate as the active ingredient in codling moth abatement. In 1912, as a marketing scheme and a show of confidence, Luther offered growers one dollar for every worm they found in orchards sprayed with Ortho brand lead arsenate.[183]

Figure 10 – Apple label, ca. 1920.[184]

Only July 1, 1911, the first significant US insecticide regulation went into effect in California.[185] Championed by California agribusiness, the Insecticide Law was aimed at protecting California growers from ineffective and potentially destructive chemical concoctions that were being sold as economic poisons. The law stipulated that all products

[183] Chevron. "History of the Ortho Division," 1965.
[184] Vintage Ad Browser. "Food Advertisements of Miscellaneous Years." http://www.vintageadbrowser.com/.
[185] Gray, G P. "The Workings of the California Insecticide Law." *The Journal of Industrial and Engineering Chemistry* 6, no. 7 (1914): 590-94.

sold as economic poisons in California must have their composition registered with the State of California and further and that companies must affix a label of their true chemical composition on the product (ex. chemical form, place and company of manufacture, percent active ingredients and percent inert). The law gave UC Extension agents the power to regulate, test, and levy fines on incorrectly or falsely labeled insecticides. The law stimulated the development and expansion of the Analytical Laboratory at UC Berkeley.

The law benefitted California insecticide manufactures by stamping out the sale of low quality and fraudulent imports while also providing the basis of the legal infrastructure needed to rationalize the California insecticide industry. By 1912, California growers stood foremost among all users of insecticides and the production of insecticides in California was also rapidly growing.[186] In 1912, domestic production provided nearly all of the lead arsenate consumed in California. That year the California Spray Chemical Company also began shipping their high purity (and labeled) lead arsenates to apple and pear growers in eastern Washington, where they quickly displaced the lower quality arsenical insecticides that growers had been using.[187] During the 1916 growing season, California growers consumed over 360 tons (720,000 pounds) of lead arsenate to control the codling moth on deciduous fruit trees and the California Spray Chemical Company opened multiple sales branches in Oregon and Washington[188] In 1919, the California Spray Chemical Company consciously became a provider of "scientific pest control" and not simply a seller of agricultural chemicals. All of its salesmen would have to undergo scientific training before they could sell economic poisons to farmers.[189]

After WWI, arsenic consumption by southern cotton growers began to rival that of Western apple and pear growers. Although first discovered in 1906, it wasn't until wartime demands and the weather mediated explosion of the boll weevil across the South in the early spring of 1917 that cotton growers first embraced the toxic power of calcium arsenate. Encouraged by the USDA, state experiment scientists, and often politicians seeking to maintain state coffers, southern growers began turning to arsenic's toxic nature as the active ingredient in their war against cotton pests and yield loss (See Chapter 3). By 1919, across the South, a small number of progressive cotton growers used over three million pounds of calcium arsenate (1,500 tons) to protect their yields.

In the early 1920s, arsenic residues on fruit and vegetables became the subject of increased governmental and public scrutiny.[190] Since the outbreak of WWI, there had been a growing public discomfort with arsenic laden produce, especially among East Coast health

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[186] LAT, "Wide Use of Arsenic," 1914.
[187] Woodworth, CW. "The Insecticide Industries in California." *Journal of Economic Entomology* 5, no. 4 (1912): 358-64.
[188] Gray, George P. "The Consumption and Cost of Economic Poisons in California in 1916." *Industrial & Engineering Chemistry* 10, no. 4 (1918): 301-02.
[189] Chevron. " History of the Ortho Division," 1965.
[190] Lynch, W D, C C McDonnell, J K Haywood, and M B Waite. "Poisonous Metals on Sprayed Fruits and Vegetables." *Bulletin 127*. Washington, DC: USDA, 1922; Myers, C N, B Throne, F Gustafson, and J Kingsbury. "Significance and Danger of Spray Residue." *Industrial and Engineering Chemistry* 25, no. 6 (1933): 624-29; Reuter, M J. "The Arsenic Problem: Report of a Case of Arsenic Dermatitis from Wearing Apparel." *Archives of Dermatology and Syphilology* 31, no. 6 (1935): 811-18.

and pure food activists.[191] City inspectors in places like Boston had begun seizing and analyzing produce they deemed a public hazard and the USDA began studies into spraying practices and arsenic residues. The Bureau of Chemistry, via the Food and Drug Act of 1906, had the power to seize hazardous produce that crossed state lines, but they didn't.[192] Political battles raged over the power of the USDA and over residue tolerances.[193]

In April of 1925, Florida celery growers finally forced the Bureau of Chemistry's regulatory hand. Earlier that spring, the celery leaftier caterpillar (*Udea profundalis)* invaded the celery growing regions of Florida, and growers tried to stop its voracious feeding by repeatedly dousing their celery with (hydrogen) lead arsenate, many right up until the day harvest.[194] A Bureau of Chemistry inspector tested some of the celery and found that single celery stalks contained upwards of 9 mg of arsenic, 14 times the 1906 federal tolerance of 0.65 mg – that is the maximum amount of pesticide residues allowed on produce.

In the fall of 1925 Washington apples made international headlines, and not for their taste. Beginning in October, English newspapers reported people falling ill (whether rightly or not) from arsenic poisoning after consuming Washington grown apples.[195] Washington growers by this time were spraying hundreds of pounds of lead arsenate per acre on their apples trees, often late into the season, and the lack of summer rains meant that this news came at no surprise for many people. In 1926, the USDA began enforcing the tolerance originally set as part of the Pure Food and Drug Act of 1906. Bureau of Chemistry inspectors began seizing interstate fruit and vegetables deemed hazardous. By the late 1920s, despite fierce political skirmishes between the USDA, congress, and the deciduous fruit industry, western growers, packers, and shippers adapted their spraying and post-harvest practices to meet the new regulatory climate. Growers started allowing for more time between the last spray and day of harvest. Growers and shippers built (chemical) washing houses to clean their apples below the federal tolerance.[196] Regulation also stimulated investigation into arsenical substitutes, like the waste fluorides of the rapidly expanding American aluminum industry.[197]

By 1927, 19 companies operated 22 arsenical insecticide plants across the US where they manufactured 27 million pounds of calcium arsenate, 27 million pounds of lead arsenate, and 8.5 million pounds of Paris green.[198] Between 1919 and 1929, despite severe

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[191] Kallet, A, and F J Schlink. *100,000,000 Guinea Pigs: Dangers in Everyday Foods, Drugs, and Cosmetics*. New York: The Vanguard Press, 1933; Lamb, R. *The American Chamber of Horrors: The Truth About Food and Drugs*. New York: Farrar & Rinehart, 1936.
[192] Wiley, *Crime Against the Food Law*, 1929; Whorton, *Before Silent Spring*, 1974.
[193] Whorton, *Before Silent Spring*, 1974, pp. 95-248.
[194] Lamb, *American Chamber of Horrors,*1936. X.
[195] Whorton, *Before Silent Spring*, 1974.
[196] Robinson, R H. "New Solvents for the Removal of Arsenical Spray Residue." *Industrial and Engineering Chemistry* 21, no. 11 (1929): 1132-36; Fisher, D F. "Arsenical and Other Fruit Injuries of Apples Resulting from Washing Operations." In *Technical Bulletin*, 12. Washington, DC: USDA, 1931.
[197] Fleming, Walter E. "Fluorosilicates as Insecticides for the Japanese Beetle." *Journal of Economic Entomology* 20, no. 5 (1927): 685-91; Carter, R H, and R C Roark. "Composition of Fluorides and Fluorosilicates Sold as Insecticides." *Journal of Economic Entomology* 21, no. 5 (1928): 762-73;
[198] Roark, RC. "United States Insecticide Statistics for 1928." *Journal of Economic Entomology* 22, no. 4 (1929): 699-701.

agricultural depression (and also perhaps because of it), on farm use of lead arsenate more than doubled from 11.5 to 29 million pounds (5,750 to 14,500 tons), while calcium arsenate grew an order of magnitude from 3 to over 30 million pounds (1,500 to 15,000 tons). By the late 1920s, sodium arsenite and crude arsenical waste were rapidly gaining popularity as herbicides along right of ways and baits for grasshoppers.[199] This use helped diminish the trough of arsenical use following the 1929 stock market crash.[200]

In the 1930s, despite global economic malaise, arsenical consumption by US farmers continued to increase.[201] With every growing season that passed, more and more industrial waste flowed from the wastebaskets of industry to the fields and farms of the United States. In 1934, arsenical consumption hit an all time high in part due to large purchases by the USDA and the Bureau of Entomology in order to combat grasshoppers that had descended upon the dustbowl west.[202] Government purchases of arsenicals for grasshopper control continued to be significant until the early 1940s.[203] By the early 1940s, the American home had also become a steady market for arsenicals, particularly Paris green. At the outbreak of WWII, about one-third of all the Paris green sold in the US made its way to urban lawns and golf courses, where it was used to control grubs.[204]

In May of 1942, the US War Production board classified arsenic as Group 1 material, regulating its use and price.[205] Wartime demand made refined arsenic scarce and across the American west arsenic refineries began running day and night. In 1942, insecticide manufactures consumed over 30,000 tons of white arsenic to manufacture calcium arsenate (44.3%), lead arsenate (29.2%), sodium arsenite (21.9%), Paris green (3.7%), and London purple (0.8%).[206] In 1943, despite arsenic rationing, American farmers consumed even more. Domestic production and consumption of arsenic both peaked in the early 1940s (See Figure 11).[207] Agricultural use of lead arsenate and calcium arsenate peaked in 1944 at 45,000 tons (90 million pounds) and 40,000 tons (80 million pounds), respectively.[208] That

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[199] van Siclen, A P, and C N Gerry. "Arsenic." In *Minerals Resources of the United States*, 496-501. Washington DC: US Bureau of Mines, Geological Survey, 1935.

[200] Ambruster, H W. "Arsenic." In *The Mineral Industry: Its Statistics, Technology and Trade During 1937*, edited by G A Roush, 63-66. New York: The McGraw Hill Book Company, Inc., 1938.

[201] van Siclen and Gerry, "Arsenic." 1935.

[202] Roark, RC. "Insecticides and Fungicides." *Industrial & Engineering Chemistry* 27, no. 5 (1935): 530-32; Siverson, H S. "Arsenic Breakfasts Ready for 'Hoppers: Middle West Preparing for Grasshopper Swarms Predicted by Experts to Be Greatest in Many Years of Farm History." *The Washington Post*, May 16, 1937.

[203] Nighman, C E. "Arsenic." In *Minerals Resources of the United States*, 743-51. Washington DC: US Bureau of Mines, Geological Survey, 1944.

[204] In 1942, people tearing up their lawns to build victory gardens became concerned at the potential for plants to pick up lead arsenate used for lawn care. Studies showed that arsenic lingers in the soil for very long time and can accumulate in the tops of vegetable leaves and that the amount of arsenic in vegetation is directly related to the amount of arsenic in the soil. However, arsenic in vegetables was below current tolerances. McLean, H C, A L Weber, and J S Joffe. "Arsenic Content of Vegetables Grown in Soils Treated with Lead Arsenate." *Journal of Economic Entomology* 37, no. 2 (1944): 315-18.

[205] Nighman, "Arsenic." 1944.

[206] Nighman, "Arsenic." 1944.

[207] Nighman, "Arsenic." 1944.

[208] Alden, J C. "The Continuing Need for Inorganic Arsenical Pesticides." In *Arsenic: Industrial, Biomedical, Environmental Perspectives*, edited by W H Lederer and R J Fensterheim, 63-70. New York: Van Nostrand Reinhold, 1983; Alden, J C. "The Continuing

year, US farmers spread arsenicals on 83 different food crops and 41 different forage/row crops.[209] The eastern Washington apple crop alone used 7,500 tons (15,000,000 pounds) of lead arsenate at rates up to 400 pounds per acre over the spraying season.[210]

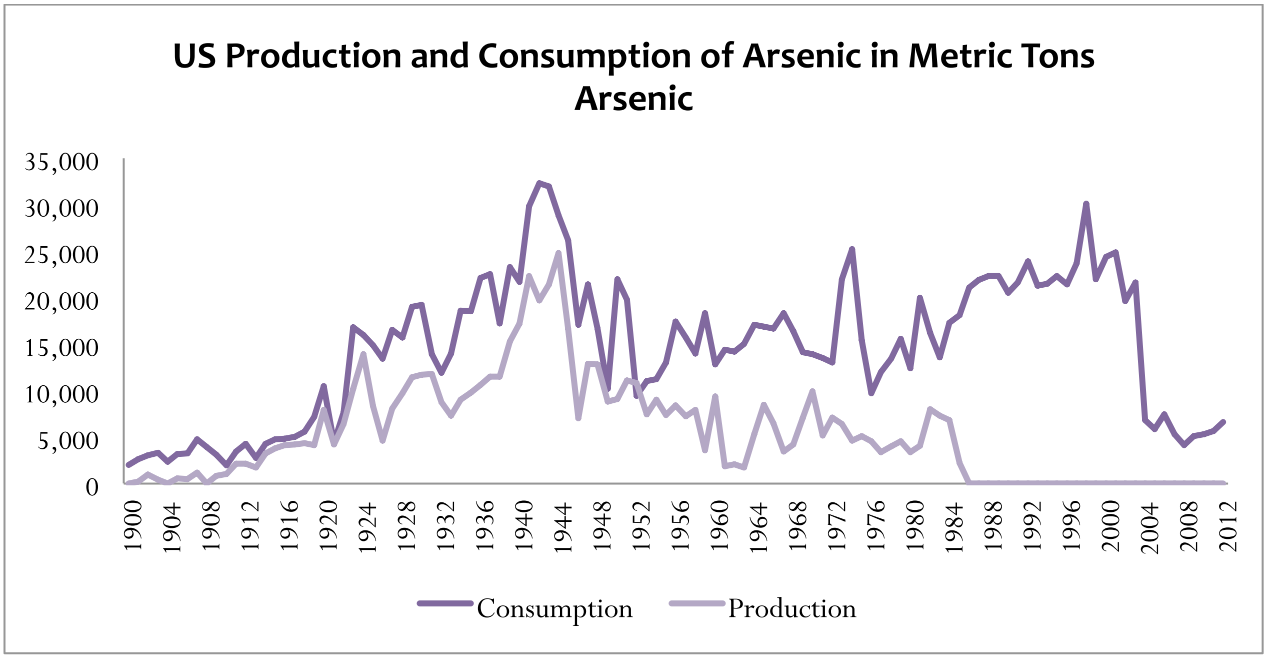

Figure 11 – Production and consumption of all arsenicals in the US normalized to arsenic content. The increase in arsenic consumption in the l980s was due to the use of arsenic as a wood preservative.[211]

After WWII, inorganic arsenicals quickly fell out of favor with farmers as new organic pesticides like DDT and 2,4-D took their place on market shelves. Organic arsenicals, however, gained in popularity, particularly among the poultry and cotton industries.[212] After WWII, organic arsenicals became a standard component of poultry feed to rid the industrial chicken of the parasites that rob the grower of his maximum chicken yield.[213] In the late 1950s, insecticide companies introduced organic arsenical herbicides and by the early 1980s, organic arsenicals like monosodium methyl arsenate (MMSA), disodium methyl

Need for Inorganic Arsenical Pesticides." In *Arsenic: Industrial, Biomedical, Environmental Perspectives*, edited by W H Lederer and R J Fensterheim, 63-70. New York: Van Nostrand Reinhold, 1983; Nriagu, J O, and J M Azcue. "Food Contamination with Arsenic in the Environment." In *Food Contamination from Environmental Sources*, edited by J O Nriagu and M S Simmons. Advances in Environmental Science and Technology. New York: John Wiley and Sons, 1990

[209] Nriagu, *Food Contamination*, 1990.

[210] Webster, R L. "Insecticide Situation in the Pacific Northwest." *Journal of Economic Entomology* 37, no. 6 (1944): 818-21.

[211] Data from: United States Geological Survey. "Historical Statistics for Mineral and Material Commodities in the United States." Department of the Interior, http://minerals.usgs.gov/minerals/pubs/historical-statistics/.

[212] Alden, J C. "The Continuing Need for Inorganic Arsenical Pesticides." In *Arsenic: Industrial, Biomedical, Environmental Perspectives*, edited by W H Lederer and R J Fensterheim, 63-70. New York: Van Nostrand Reinhold, 1983.

[213] In the 1930s USDA scientists discovered that the addition of organic arsenical acids like aminophenyl arsenic acid to feed stimulated the growth of chickens. WIilson, H F, and C E Holmes. "Little Danger in Eating Arsenic-Fed Chickens." *Journal of Economic Entomology* 29, no. 5 (1936): 1008-14.

arsenate (DSMA), arsenic acid (H_3AsO_4), and cacodylic acid [$(CH_3)_2AsO_2H$] were the most used herbicides by volume in US agriculture. [214] Each fall, as days grew short, US farmers coated about 15 million acres of cotton with organic arsenicals to defoliate (burn down) the cotton plant and make possible mechanical harvest.[215]

Industrial Sorting and a Theory of Dark Value

"The cost of production of white arsenic in the [copper] smelting plant is a matter of bookkeeping, in that the cost of crude arsenic up until the time it is collected from the smelter flues is, strictly speaking, an essential step in the [copper] smelting operation."

Roush and Butts, *The Mineral Industry, Its Statistics, Technology, and Trade During 1920*, 1921.[216]

There is no coherent theory of waste found in Marx's writing. One possible reason is that the categories of waste and wasting under capitalism are too broad to be couched under a single theoretical thread. Theorizing wastelands and wasted lives inclusively with household garbage and industrial waste is bound to be problematic.[217] Marxists scholars who have focused on waste have tended to view waste from a lens of efficiency or externality.[218] As Gregson and Crane observed, "Marxian attempts to explain and theorize the waste-society relationship tended to understand waste as inefficiency, lost opportunity cost, and as the profligate use of resources due to capitalism's inherent tendency toward overproduction, that is as the opposite of value."[219] Prominent Marxist scholars like David Harvey ignore the category of waste altogether and contemporary Marxist geographical waste scholarship focuses on consumer or municipal waste and completely ignores industrial waste.[220] But if

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[214] The US military used cacodylic acid during the Vietnam War. Comprising half of "Agent Blue," the US military used it to kill paddy rice. Westing, A H. "Agent Blue in Vietnam." *New York Times*, July 12, 1971.Cecil, P F. *Herbicidal Warfare: The Ranch Hand Project in Vietnam*. New York: Praeger, 1986; Stellman, J M, S D Stellman, R Christian, T Weber, and C Tomasallo. "The Extent and Patterns of Usage of Agent Orange and Other Herbicides in Vietnam." *Nature* 422, no. 6933 (2003): 681-87.

[215] Abernathy, J R. "Role of Arsenical Chemicals in Agriculture." In *Arsenic: Industrial, Biomedical, Environmental Perspectives*, edited by W H Lederer and R J Fensterheim, 57-62. New York: Van Nostrand Reinhold, 1983.

[216] Roush, G A, and A B Butts, eds. *The Mineral Industry: Its Statistics, Technology, and Trade During 1920*. Vol. 29. New York: McGraw-Hill Book Company Inc., 1921.

[217] Moore, S A. "Garbage Matters: Concepts in New Geographies of Waste." *Progress in Human Geography* 36, no. 6 (2012): 780-99.

[218] Benton, T. "Marxism and Natural Limits: An Ecological Critique and Reconstruction." *New Left Review* 178 (1989): 51-86; O'Connor, M. *Is Capitalism Sustainable?* New York: The Guilford Press, 1994; Horton, S. "Value, Waste and The Built Environment: A Marxian Analysis." *Capitalism Nature Socialism* 8, no. 2 (1997): 127-39; O'Connor, J. *Natural Causes: Essays in Ecological Marxism*. New York: The Guilford Press, 1998; Moore, J. "Cheap Food & Bad Climate: From Surplus Value to Negative-Value in the Capitalist World-Ecology." (2014).

[219] Gregson and Crane, "Materiality and Waste," 2010

[220] Harvey, David. *The Limits to Capital*. New York: Verso, 2007; Herod, A, G Pickren, Al Rainnie, and S M Champ. "Global Destruction Networks, Labour, and Waste." *Journal of Economic Geography* 14, no. 2 (2013): 421-41; Herod, A. "Waste, Commodity Fetishism, And the Ongoingness of Economic Life." *Area* 45, no. 3 (2013): 376-82; Pickren, G. "Geographies of E-Waste: Towards a Political Ecology Approach to E-Waste and Digital Technologies." *Geography Compass* 8, no. 2 (2014): 111-24.

industrial waste and industrial waste reutilization, as this chapter has argued, are critical to the never-ending reproduction and expansion of abstract value, then we must deal with the question of the value of industrial waste.

Waste "appears at first sight am extremely obvious, trivial thing. But its analysis brings out that it is a very strange thing, abounding in metaphysical subtleties and theological niceties…" Waste "production, its consumption, and its circulation, and metamorphosis is constitutive of society."[221] Capitalist waste, like the commodity, contains the mark of productive activity of a definite kind. Like the commodity it is also a social relation between people, not things. And if, as Marx argued, the value of "the total-labour-power of society" is manifested in the values of the heaping masses of world commodities, then the total labor-power of society is also manifested in dark value embodied in the masses of wastes from human labor's synthesis of value.

"Labour… as the creator" of waste "is a condition of human existence; it is independent of all forms of society, it is an eternal natural necessity which mediates the metabolism between [humanity] and nature, and therefore human life itself."[222] But under the capitalist mode of production, the material wastes of human labor have taken on a new social form and scale of production. They have become like the commodity, an expression of "congealed quantities of homogenous human labour" labor without regard to the form of expenditure, and yet also an expression of concrete action.[223] Industrial waste, as the chiral other of the commodity, is a product of concrete and abstract labor, yet unlike the commodity, it was never bestowed value and thus cannot be devalorized or devalued in any classical sense. But it did receive the imprint of value's synthesis, and this I call dark value.

Dark value, like value itself, is a unique property of the capitalist mode of production. Only with the generalization of capitalist social relations developed at large enough scales could the dark value form emerge from industrial and social metabolisms. Chronologically in the history of capitalism, economies of scale as a phenomenon arising from social labor came before inter and intra-firm waste reutilizing. Before you could have the waste at scales necessary to begin thinking about its reuse, generalized commodity production and the division of labor must have matured long enough to produce massive wastes and the state of scientific and industrial development had to have progressed enough to find new uses for and new apparatuses to aid the transformation of waste into value.[224] The history of arsenic-as-waste is a clear example of the role of scale and scientific development on the nature of capitalist waste. Waste as a critical raw material for modern capitalism means that the production of waste is necessary for the expanded reproduction of capitalist social relations.

[221] Gille, Z. "Actor Networks, Mode of Production, and Waste Regimes: Reassembling the Macro-Social." *Environment and Planning A* 42 (2010): 1049-64.
[222] Marx, K. *Capital: A Critique of Political Economy* Vol. II, New York: Penguin Classics, 1993. 133.
[223] Marx, K. *Capital: A Critique of Political Economy* Vol. I, New York: Penguin Classics, 1990 (1867). 135-136.
[224] Marx, K. *Capital: Volume III*. New York: Penguin Books, 1981. 172-174, 196; Haynes, *Chemical Economics*, 1931. Haber, *Chemical Industry During the Nineteenth Century,* 1958;

If labor is the father of material wealth, and the earth, its mother, then industrially sorted waste is their manic toddler.

Dark value, bestowed on capitalist waste via the labor process is what distinguishes valueless "free gifts" of nature from the valueless "free gifts" of capital. In other words, dark value denotes a special category of valueless raw material that has already been materially transformed by labor. Thinking of industrial waste through a lens of dark value allows one to conceptualize waste without resorting to the tautological theorizations of waste and value like Herod et al., for example, in which end-of-life commodities that go on to be reworked are the ones that still contain value and the end-of-life commodities that don't get used are the ones that don't.[225] It also brings to the theoretical fore the need to take the scale and scaling of waste and waste production seriously in thinking through the nature of capitalist value over the longue durée.

Arsenic and the Materiality of Industrial Waste

"All those things which labour merely separates from immediate connection with their environment, are subjects of labour spontaneously provided by Nature. Such are fish which we catch and take from their element, water, timber which we fell in the virgin forest, and ores which we extract from their veins. If, on the other hand, the subject of labour has, so to say, been filtered through previous labour, we call it raw material; such is ore already extracted and ready for washing. All raw material is the subject of labour, but not every subject of labour is raw material: it can only become so, after it has undergone some alteration by means of labour."

Marx, *Capital: A Critique of Political Economy*, 1867[226]

From an historical case study of arsenic-as-waste we learn two things about industrial waste geographies. The first is, of course, is that materiality matters. In the process of smelting copper, arsenic sublimes from ore and combines with atmospheric oxygen to form arsenic trioxide, an extremely toxic compound with very particular biogeochemical cycling. Oxidation, together with the massive scale of its production made arsenical waste both environmentally problematic and a potential useful raw material for a rapidly industrializing US agriculture (See Chapter 4). There are lots of wastes and lots of toxic compounds, but the immensity of arsenic-as-waste's production beginning in the late 1700s was qualitatively different.

By the turn of the 19th century, collective social forces – the industrial revolution in metals – had turned the wet southwest of England and Wales into the world's foremost producer of finished copper, lead, and tin. But this also made the wet southwest of England

[225] Herod et al., "Waste, Commodity Fetishism," 2013; Herod et al.,"Global Destruction Networks," 2013; Pickren, "Geographies of E-Waste," 2014.
[226] Marx, K. *Capital: A Critique of Political Economy* Volume I, New York: Penguin Classics, 1993 (1867).

and Wales the world's foremost producer of arsenical wastes. The biogeochemical nature of arsenic-as-waste meant that the arsenic waste stream collected nearby in ever expanding piles, waste piles that demanded larger and larger (environmental) sinks. By the early 1800s, the scale of arsenic-as-waste in the CDS region had grown so large and the chemical and metallurgical sciences had advanced so far that people began envisioning waste arsenic as a potential raw material for commodity production. The production of dark value abounded and arsenic-as-waste gained the economies and ecologies of geographic scale necessary for capital to be able to see its social utility.

In 1840, arsenic's toxic use-value made its industrial debut. That year, the British military used white arsenic as a pesticide in a campaign to exterminate Australian aboriginals. This event, as well as any other could, also marks the crossing of a qualitative threshold in arsenic's life history. Capital could now see arsenic more clearly, and more and more arsenic flowed from the waste piles and waste streams of the CDS region into industrial production and the products and processes of everyday life (and death). In the 1870s, the discovery by US farmers that Paris green worked against the potato bug linked the westward march of US agriculture with the toxic waste of the British non-ferrous mining and smelting industry. By early 1900s, the mines and smelters of the American West had overtaken the CDS region to become the major global producer of red metal and its associated wastes. After WWI, agricultural use of arsenic exploded. In the interwar years, it became a one of the critical materials that enabled the industrialization of US agriculture in the face of chronic surplus production and the insect menace. Thus, between the late 1700s and WWII, a vast arsenic-as-resource regime developed, linking copper production and synthetic color to the dissipative chemicalization of US agriculture.

The second is that capitalist waste is not simply something that is unwanted but is the collection of material that is valueless yet bears the imprint of collective human labor, which I have attempted to capture via the concept dark value. Dark value, bestowed in all products of human labor production that have no value, allows us to group household waste, municipal waste, construction waste, and industrial waste together and to think more broadly about waste, materiality, and the nature of value. All materials imbued with dark value have at some point been materially sorted in the pursuit of value and are thus qualitatively different than nature's "free gifts," those produced by "spontaneous" to and fros of biogeochemical time. Dark value and the free gifts of capital are categories that freesus from tautological definitions of (consumer) waste and value.[227] All life, because it is alive, undergoes processes of bioselective material sorting. Therefore the creation of waste – the unwanted byproducts of metabolism – is a condition of all life. But the nature of waste under capitalism, like the value form, is unique. As the valueless chiral other of commodity production, waste is stamped with the metabolic imprint of abstract value and thus subject to the same laws of motion.

[227] By admitting that commodities in general expend all their value over their lifetime, we also admit that it is only human labor that can imbue valueless waste with new value.

Chapter 2 Preface

Making Sense of Cyanide: Chemical Wealth from the Wastes of 19th Century Philadelphia

"A mixture of potash or pearlash, as free as possible from sulphate of potash, with any cheap nitrogenized animal substance, such as horn waste, hoofs, tallow waste, or 'cracklings;' woolen rags, dried blood, hair of leather cutting, or preferable, with any of these substances previously carbonized, is heated is a closed iron crucible to a red heat…"

P.L. Simmonds, *Waste Products and Undeveloped Substance,* 1862[1]

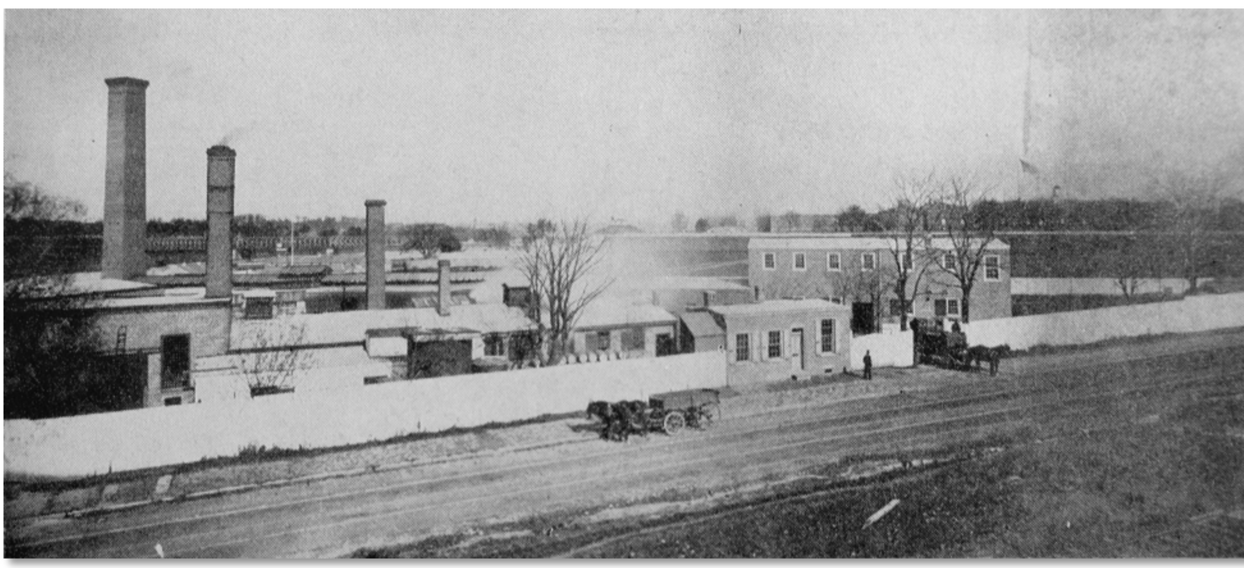


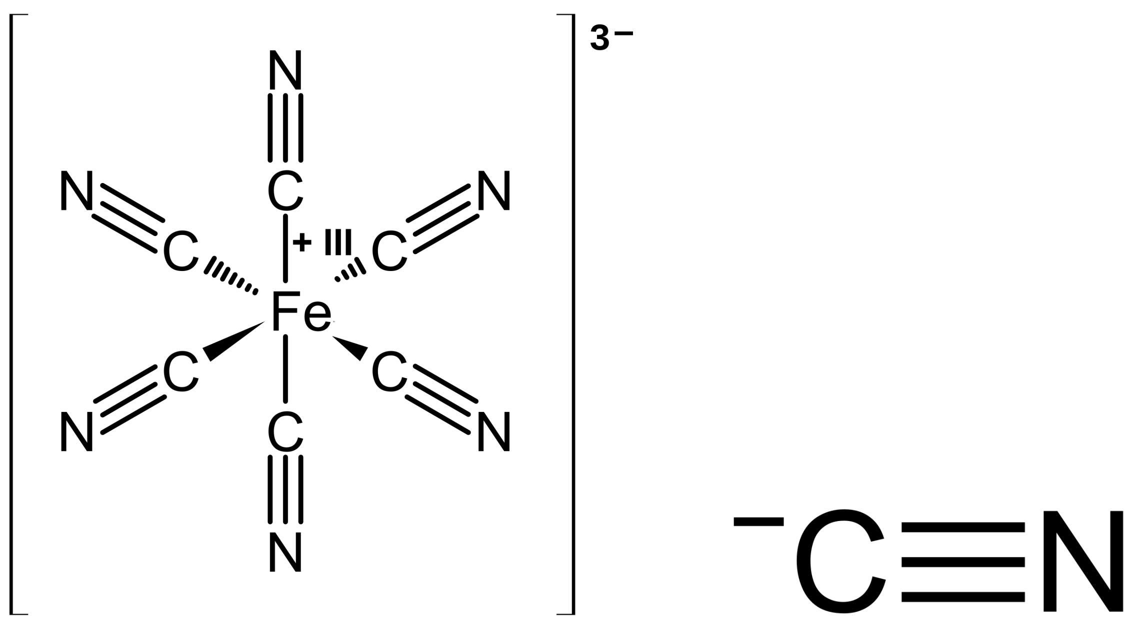
Figure 1 - Henry Bower Chemical Manufacturing Company, Philadelphia, PA, ca. 1865.[2]

Chapter 2 strays from the direct engagement with questions of industrial waste. It was written as a journal article that highlights the shared discourses, practices, and materials of chemical warfare and chemical pest control. In the chapter, I argue that a state of war is part of industrial pest control's infrastructure. As such, it does not emphasize the origins of industrial cyanide-as-waste. This preface provides additional background information and

[1] Simmonds, P L. *Waste Products and Undeveloped Substances: Or, Hints for Enterprise in Neglected Fields*. London: Robert Hardwicke, 1862. 341.
[2] Coleman Jr, R P. *A Century of Service in Chemicals: Henry Bower Chemical Manufacturing Co. 1855-1955*. Philadelphia, PA: The Henry Bower Chemical Manufacturing Co., 1955

sets the story told in Chapter 2 within the context of industrial waste reutilization and the development of the US chemical industry in the late 19th century.

In Los Angeles, in the late 1880s, citrus growers, scientists, and salesmen, made potassium cyanide (KCN) into the toxic agent of commercial pest control. The Roessler and Hasslacher Chemical Company (R&H), at their plant in Perth Amboy, New Jersey, manufactured the majority of the potassium cyanide (and eventually sodium cyanide) consumed by the citrus industry in the first two decades of fumigation. The intermediate compound that served as the feedstock for potassium cyanide production was prussiate of potash (potassium ferrocyanide). In the early 1880s, R&H began manufacturing potassium cyanide from the prussiates of two companies, Carter and Scattergood, and the Henry Bower Chemical Manufacturing Company, both of Philadelphia. These two companies synthesized potassium ferrocyanide by mixing nitrogenous animal derived waste – horns, hooves, organs, entrails, leather – with iron filings and potassium carbonate (K_2CO_3) in an oven over red heat. Roessler and Hasslacher would then react the potassium ferrocyanide in a furnace with anhydrous potassium carbonate (K_2CO_3), breaking the larger molecule into singular cyanogenic conformations (See Figure 2). [3]



a) b)

Figure 2 – a) Idealized structure of the ferrocyanide anion. Potassium (K) ferrocyanide is the potassium salt of the ferrocyanide ion and ferric (Fe) ferrocyanide is the iron (III) salt. b) Cyanide ion. Potassium cyanide (KCN) is the potassium salt of the cyanide ion (CN^-).[4]

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[3] Anhydrous is chemical term that denotes that compounds or substances that do not contain water.

[4] Wikipedia. "Ferricyanide Ion." http://en.wikipedia.org/wiki/Prussian_blue#/media/File:HexacyanidoferratIII_2.svg.; Wikipedia. "The Cyanide Ion." http://en.wikipedia.org/wiki/Cyanide#/media/File:Cyanide-montage.png.

Synthetic cyanide, produced at an industrial scale, owes it technological maturation to the large demand from the mining industry in the late 1880s. However, synthetic cyanide's origins are tied to color and a much longer history of coloration practice. Cyanide's name, bestowed upon it by Gay-Lussac in 1815, points to the fact that when chemistry is understood not as simply the elemental classificatory and laboratory science we learn in high school but instead as the complex social processes involved in active material transformation, we see that chemistry has a much longer history, not just in warfare, but across all human practices, particularly art and commerce. The word cyanide comes from a combination of the terms *cyanogen*, an Anglicization of the French term *cyanogéne* (derived from the Greek *kuanos* - blue), which means "comes from a dark blue mineral," and the suffix *ide*, which is a chemical term that describes a nonmetallic binary compound where one part of the molecule is more electronegative than the other.[5] The following historical sketch provides a brief outline of the domestic prussiate pigment trade of late 19th century United States, a trade centered in Philadelphia, PA. I highlight the role of industrial and post-consumer waste as the feedstock for prussiate of potash's synthesis.

Prussiate (ferric ferrocyanide) first emerged from the early 18th century pigment trade. Sometime during 1704 or 1705, Diesbach, the renowned Prussian colorist, in the process of synthesizing Florentine red accidentally combined organic carbon with reactive nitrogen distilled from animal blood and iron filings over red heat. That fortuitous day Diesbach pulled out of his oven ferric ferrocyanide, a striking synthetic blue compound, naming it Prussian blue for his motherland (See Figure 3).[6] Like so many chemical discoveries that followed, Diesbach was a "happy victim of impure reagents."[7]

Figure 3 – Sample of Prussian blue oil paint thinned with turpentine on canvas[8]

[5] *New Oxford American Dictionary*. Oxford University Press, 2011. A better translation would read that comes a mineral that is near black.
[6] Robine, R, M Lenglen, J A Le Clerc, and C E Munroe. *The Cyanide Industry: Theoretically and Practically Considered*. New York: John Wiley & Sons, 1906; Thorpe, T E. *History of Chemistry*. London: G.P. Putnam's sons, 1909.
[7] Ball, Bright Earth, 2001. 242
[8] Wikipedia. "Prussian Blue Oil Paint Thinned with Turpentine." http://en.wikipedia.org/wiki/Prussian_blue#/media/File:Prussian_blue.jpg.

As the fabled story goes, Diesbach, having run out of potash (a normal ingredient for Florentine red's synthesis from cochineal-based dyes), asked his friend, the infamous alchemist Dippel, for some of his leftover potash residues. Dippel's potash, however, not only contained potassium salts, it was also contaminated with organic nitrogen containing compounds that had come from the animal blood he had been alchemically probing. In the summer of 1704, after failing to transmute silver and mercury into gold within the depths of Castle Frankenstein, Dippel moved to Berlin and embarked on a quest to make a panacea from animal blood.[9] Some of his first investigations involved distilling different fractions of animal blood with potash in the hopes of something miraculous. This was the potash that he gave to Diesbach.

Diesbach knew of the potential commercial value of his discovery and he kept the recipe secret, sharing it only with his French pupil, De Pierre.[10] Prussian blue is first mentioned in the chemical literature in 1710 when an anonymous writer boldly claimed that it was "equal to or excelling ultramarine" (made from Afghani lapis lazuli stones) in its beauty. By the early 1720s, with Diesbach's approval, De Pierre was manufacturing Prussian blue in Paris and by the late 1720s Prussian made ferric ferrocyanide could be purchased from color salesmen across Europe and even in New York City.[11] The first publication of the chemical recipe appeared in the 1724 in the Philosophical Transaction of the Royal Society. This article by John Woodward broke open the jealously guarded secret of Diesbach's synthetic blue, opening its manufacture to anyone with access to abattoir wastes and a crude laboratory.

By the 1750s Prussian blue was in general use across Europe as a pigment for art and house paints, as well as being used extensively in calico printing.[12] Offering artificial attributes like fastness, consistency, and low-cost, Prussian blue quickly replaced ultramarine in many, though not all, artistic works. Synthetic blue's production rapidly grew across Europe throughout the second half of the 18th century. By the turn of the century, Prussian blue sold for a fraction of what it cost fifty years earlier, and Prussian blue's chemical resonances confronted lower class consumers, foretelling the coming democratization of color at the end of the 19th century.[13]

In 1811, the French chemist Gay-Lussac prepared the first pure hydrogen cyanide by treating ferric ferrocyanide with strong acids, and in 1815, he showed that the cyanide ion was a one to one combination of carbon and nitrogen.[14] Made from a blue pigment, he christened the compound: cyanide – the "blue" or "prussic" acid. In the 1820s and 1830s, the

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[9] Aynsley, EE, and WA Campbell. "Johann Konrad Dippel, 1673–1734." *Medical History* 6, no. 03 (1962): 281-86; Florescu, R. *In Search of Frankenstein: Exploring the Myths Behind Mary Shelley's Monster*. New York: Robson, 1999. 82.

[10] Ball, *Bright Earth,* 2001.

[11] Ball, *Bright Earth*, 2001.

[12] Robine et al., *The Cyanide Industry*, 1906

[13] Prussian blue is also used an antidote for heavy metal poisoning, such as from thallium and radioactive 137-Ceasium.

[14] In 1823, Gay-Lussac showed that Prussian blue and the salt obtained from "blood lye," yellow prussiate of potash (potassium ferrocyanide - $K_4[Fe(CN)_6] \cdot 3H_2O$), during the first step of Prussian blue synthesis, were both cyanogen compounds.

intermediate potassium salt in Prussian blue's synthesis, prussiate of potash, became the foundation of yellow pigments and an important component of the calico printing and pigment trades.

In 1844, the Philadelphia chemical company Carter and Scattergood became the first US company to manufacture prussiate of potash (See Figure 5).[15] For their chemical plant's feedstock, they turned to the production wastes of Philadelphia's abattoirs and tanning shops as well as the post-consumer leather waste of Philadelphia's households. In the early 1850s, Carter and Scattergood turned their entire chemical attention to the manufacture of yellow prussiate of potash. Its starting material was incredibly cheap, it was highly profitable to produce, and its demand was increasing among the color trades of the eastern seaboard.

In 1867, the Henry Bower Chemical Manufacturing Company of Philadelphia became the second manufacturer of potassium ferrocyanide in the United States (See Figure 1).[16] Henry Bower was a giant of Philadelphia society and the late 19th century US chemical industry. A graduate of Philadelphia College of Pharmacy, he believed that the role of chemistry in industrial society was to turn its wastes into new elements of production. In 1858, he founded the Henry Bower Chemical Manufacturing Company in southwest Philadelphia on the main artery of animal powered traffic that moved the countryside's products into the city's center. He decided that ammonia would be his anchor. Needing a source of raw material, he built a condenser on the waste flues of the nearby Philadelphia Gas Works "manufactured gas" plant. Ammonia wastes are produced in process of manufacturing illuminating gases from coal. Henry Bower's first condensers collected waste liquor at ~2% ammonia content. He would take this to his laboratory where he would further concentrate it, eventually mixing it with sulfuric acid to make ammonium sulfate, which he sold to east coast industries.

In the early 1860s, the Henry Bower Chemical Manufacturing Company built a network of underground pipelines that linked his chemical plant directly with the condensed wastes of Philadelphia's manufactured gas plants. He also developed a new condenser that increased ammonia yields to 15% directly at the gas plant. This technological development eventually spread, expanding his source of ammonia liquors. The owners of manufactured gas plants from cities across the eastern seaboard (even Alabama) found it profitable to install recovery technology and then ship their concentrated ammonia liquors by tank car to Philadelphia. He signed many of these plants to multi-year delivery contracts.[17] In the mid 1860s, Henry Bower introduced odorless glycerin. Not only was this an incredible chemical feat, he used the wastes of Philadelphia's stearine (beef tallow) candle manufactures as his

[15] Carter, J E, and G E Scattergood. "Transfer Leger Binder." In *Carter and Scattergood Business Records*. Wilmington, DE: Hagley Library and Archive, 1903.

[16] Prochazka, G. "American Dyestuffs: Reminiscently, Autobiographically, and Otherwise." *Industrial and Engineering Chemistry* 16, no. 4 (1924): 413-18; Coleman Jr, *Century of Service,* 1955.

[17] Bower, H. "Contract between the Henry Bower Chemical Manufacturing Company and the Ammonia Company of Philadelphia." In *Henry Bower Chemical Manufacturing Company*. Wilmington, DE: Hagley Library and Museum, 1898.

raw material.[18] Thus, the introduction of potassium ferrocyanide in 1867 was the third major waste derived commodity that the Henry Bower Chemical Company pursued.

By the early 1870s, the Henry Bower Chemical Manufacturing Company had a vast infrastructure of industrial and household waste networks that first collected and then transformed Philadelphia's manufactured gas plants' waste, its candle industry's waste, its abattoir's waste, it tanning factory's waste, as well as the leather wastes of the city's people, into new elements of production. In the late 1870 and early 1880s, Henry Bower streamlined prussiate synthesis, increasing yield and reaction velocity, and pioneered the recovery of ferricyanides directly from the wastes of manufactured gas. Henry Bower also pioneered the chemical processing of petroleum waste residues.[19] In the late 1880s, based on the recently built Ammonia Co. of Philadelphia manufactured gas plant, Henry Bower estimated that more than 90,000 pounds of prussiate went to waste from each of Philadelphia's manufactured gas plants every year.[20]

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[18] Haynes, W, and E L Gordy, eds. *Chemical Industry's Contribution to the Nation: 1635-1935*. New York: Chemical Markets, Inc., 1935;

[19]Bower, H. "Apparatus for the Manufacture of Ferrocyanide of Potassium." *Patent #210,086*, United States Patent Office. USA, 1878; Bower, H. "Apparatus for the Manufacture of Potassium Cyanide." *Patent #222,175*, United States Patent Office. USA, 1879; Cruse, E F, and C Parsons. "Obtaining Cyanide from Products of Manufacture of Coal Gas." *Patent #*, United States Patent Office. USA: Henry Bower 1879; Bower, H. "Process of, and Apparatus for, Treating the Residuum from Petroleum Refineries." *Patent #230,171*, United States Patent Office. USA, 1880; Bower, H, and W L Rowland. "Improvement in the Process of Obtaining Ferrocyanide from Gas-Liquor." *Patent #259, 802*, United States Patent Office. USA: Henry Bower, 1882; Parsons, C, and E F Cruse. "Improvement in the Process of Obtaining Cyanides." *Patent #259,908*, United States Patent Office. USA: Henry Bower, 1884; Bower, H. "Manufacture of Ferro-Cyanide of Potassium." *Patent #312,248*, United States Patent Office. USA, 1885; Bower, H. "Improvement in the Manufacture of Ferre-Cyanide of Potassium." *Patent #312,248*, United States Patent Office. USA, 1885.

[20] Bower, H. "Letter from Henry Bower to the Manager of the Ammonia Co. Of Philadelphia." In *Henry Bower Chemical Manufacturing Company*. Wilmington, DE: Hagley Library and Archive, 1892.

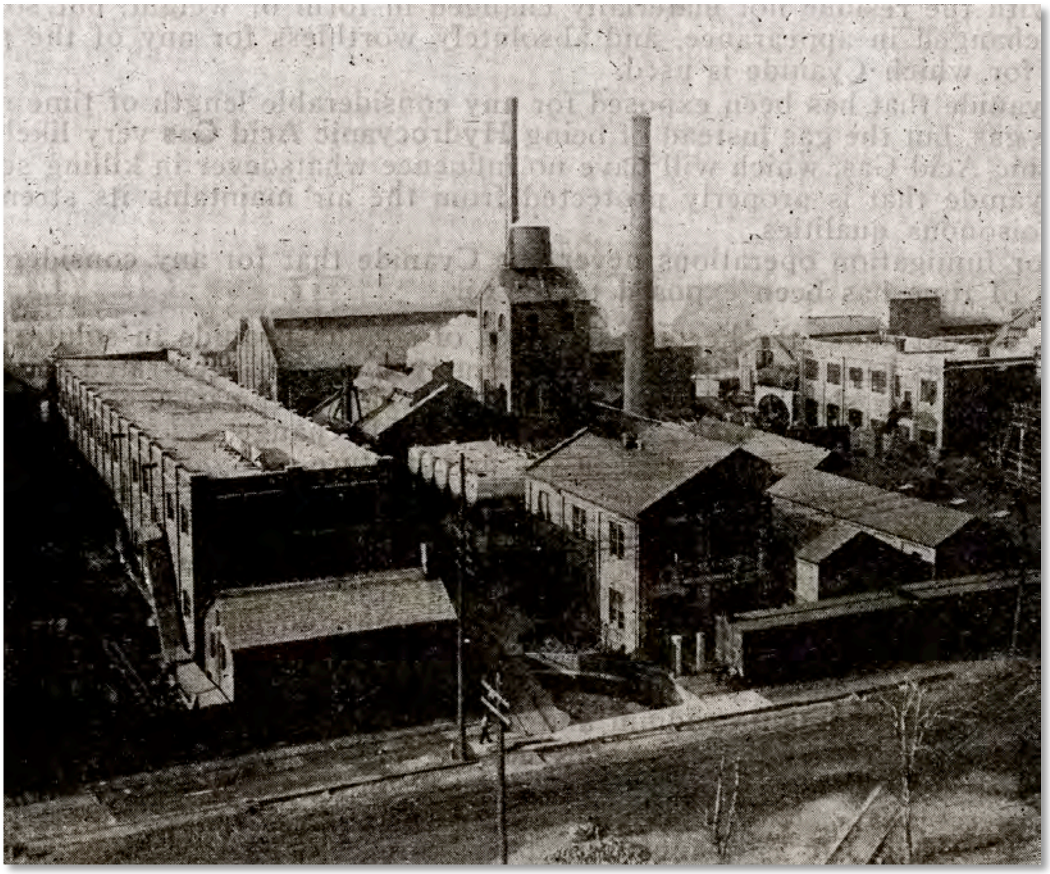

Figure 4 – Roessler and Hasslacher Chemical Company manufacturing plant, Perth Amboy, NJ, ca. 1910.[21]

In 1882, the Roessler and Hasslacher Chemical Company, a partial subsidiary of the German chemical company DEGUSSA, began manufacturing yellow and gold ceramic pigments and potassium cyanide from Philadelphia's prussiates at their plant in Perth Amboy, NJ (See Figure 4).[22] Cyanide's productive use in photography and electroplating was small but growing. The situation radically changed in the late 1880s. In 1886, in a basement laboratory in Glasgow, Scotland, J.S. MacArthur and the Forest brothers developed a cyanide extraction method for refractory gold ores.[23] The process allowed mining companies to profitably treat ores not amenable to the rocker or mercury amalgamation. Because it redefined the nature of gold ore, the discovery sent shockwaves across the gold

[21] Braun, F W. "The Manufacture of Sodium Cyanide." Paper presented at the School of Fumigation: Conducted by C. W. Woodworth, University of California, Pomona, CA, 1915.

[22] Anonymous. "History of American Chemical Industries: Roessler and Hasslacher–Partners." *Industrial and Engineering Chemistry* 21, no. 10 (1929): 989-91 DuPont. "Digest, R&H Chemical Company, Subsidiaries and Affiliates." In *Absorbed Companies*, Records of E.I. du Pont de Nemours. Wilmington, DE: Hagley Library, 1930; Wolf, M. *It All Began in Frankfurt: Landmarks in the History of Degussa Ag*. Frankfurt am Maim: Degussa AG, 1985.

[23] MacArthur, J S. "Gold Extraction by Cyanide: A Retrospective." *Journal of the Society of Chemical Industry* XXIV, no. 7 (1905): 311-15; Loughheed, A L. "The Anatomy of an International Cyanide Cartel: Cyanide, 1897-1927." *Prometheus* 19, no. 1 (2001): 1-10.

mining world. In the early 1890s, mining companies installed cyanide extraction plants in New Zealand, Southern Africa, Australia, Utah, and California.[24] Each plant consumed large amounts of potassium cyanide and R&H, the sole industrial producer of potassium cyanide in the US, ramped up its production of potassium cyanide in the early 1890s to meet demand.

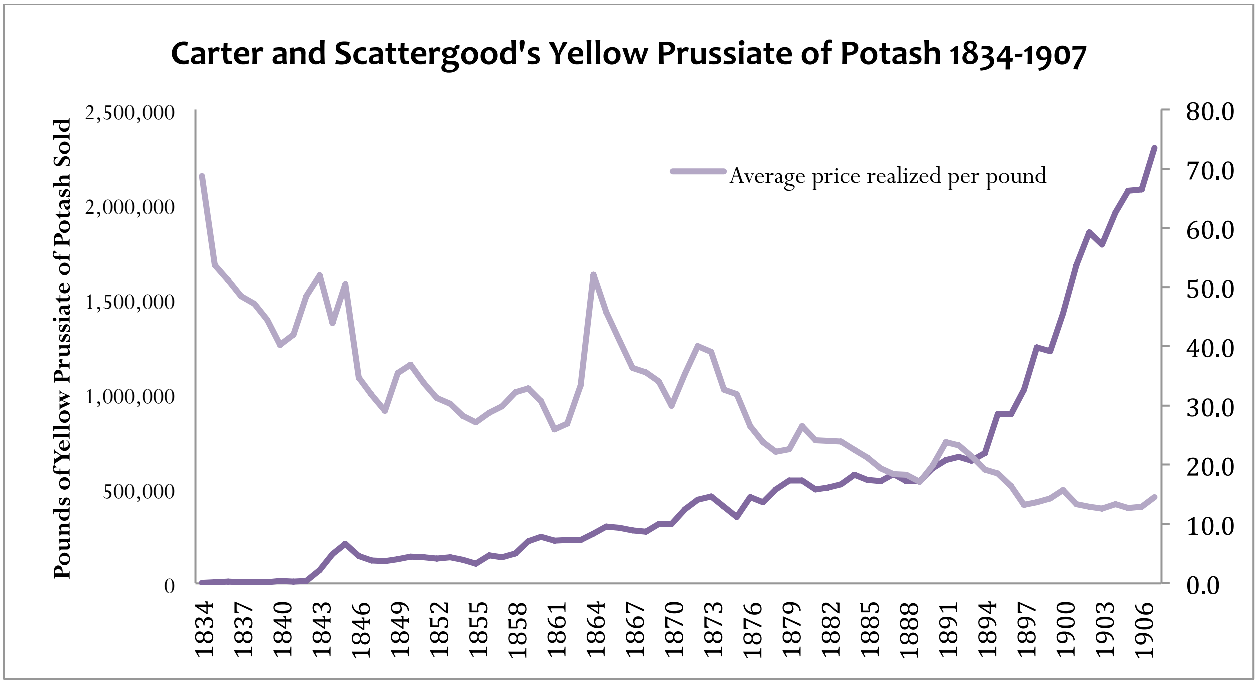

Figure 5 – Pounds of yellow prussiate of potash (potassium ferrocyanide) sold and average selling price from 1834-1907.[25]

The increased production of potassium cyanide for mining demanded an increase in the synthesis of prussiate feedstock. The uptick in prussiate of potash demand in the mid 1890s is clearly seen in the graph of Carter and Scattergood's historic production (See Figure 4).[26] In the late 1890s, the Roessler and Hasslacher Chemical Company became the sole buyer and seller of both Carter and Scattergood's and Henry Bower's prussiate of potash. In 1911, the Henry Bower Chemical Company bought the firm of Carter and Scattergood to become the main US producer of potassium ferrocyanide. What is interesting, however, is that the Henry Bower Chemical Manufacturing Company acquired Carter and Scattergood not for their manufacturing capacity, but instead for their waste stocks (including 55 tons of leather

[24] Scheidel, E M. "The Cyanide Process: Its Practical Application and Economical Results." In *California State Mining Bureau Bulletin*, edited by J J Crawford, 1894; Anonymous. "Gold Will Hurt Silver. Enormous Increase in the Production of the Yellow Metal." *Los Angeles Times*, December 15 1895; Robine et al., *The Cyanide Industry*, 1906.
[25] Data complied from ledger books of Carter and Scattergood. Carter, J E, and G E Scattergood. "Transfer Ledger Binder." In *Carter and Scattergood Business Records*. Wilmington, DE: Hagley Library and Archive, 1911.
[26] Unfortunately, pre-1905 records of the Henry Bower Chemical Company were lost in a fire.

waste) and their waste recovery infrastructure.[27] In other words, the Henry Bower Chemical Manufacturing Company wanted the waste recovery networks Carter and Scattergood had developed over its 75 years of operation, an infrastructure that, at the turn of the 20th century, linked Philadelphia's slaughterhouses, tanning factories, and the worn out shoes of its residents with the rapid expansion of gold mining in the western US and the development of an industrial citrus empire in Southern California (See Figure 6).

Figure 6 – Fleet of R&H Chemical Corporation trucks loaded with cyanide starting the day's deliveries, El Monte, CA. ca. 1920[28]

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[27] Scattergood, Carter and. "Agreement of Sale to The Henry Bower Chemical Manufacturing Company." In *Carter and Scattergood, Business Records*. Wilmington, DE: Hagley Library and Museum, 1911; Carter, J E, and G E Scattergood. "Transfer Leger Binder." In *Carter and Scattergood Business Records*. Wilmington, DE: Hagley Library and Archive, 1913.

[28] The Pacific R&H Chemical Corporation. *Useful Information on Fumigation of Citrus Trees for Growers and Fumigators*. El Monte, CA: The Pacific R&H Chemical Company, 1923.

Chapter 2

Commercializing Chemical Warfare: Citrus, Cyanide, and an Endless War

"In times of peace and prosperity, states and individuals alike follow higher standards… But war is a stern teacher."

Thucydides, *History of the Peloponnesian War*, ~400 BCE[1]

Figure 1 – Orange crate label, ca. 1915. *Courtesy of the Huntington Digital Library*[2]

[1] Thucydides. *History of the Peloponnesian War*. Translated by R Crawley. New York: E. P. Dutton 1910.
[2] Schmidt Lithographic Co. "Orange Crate Label: Over There Brand." In *Jay T. Last Collection of Lithographic and Social History*, #323891. San Marino, CA: Huntington Digital Library, 1915.

Astonishing changes have occurred to agricultural production systems since WWII. As such, many people tend to date the origins of industrial chemical agricultural to the early 1940s. The origins of industrial chemical agriculture, however, both on and off the field, have a much longer history. Indeed, industrial agriculture's much discussed chemical dependency – in particular its need for toxic chemicals – and the development of the industries that feed this fix, have a long and diverse past that extend well back into the nineteenth century. In this chapter, through the narrative of a late nineteenth century creation story, I go in search of a crucial linchpin in that longer history. I argue that industrial pest control has been imbued with the practices, discourse, materials, and ethics of modern chemical warfare since its inception.

Faced with pest-induced collapse, Los Angeles citrus growers and scientists of the USDA and UC Agricultural Extension chemically fixed the citrus pest problem by developing and utilizing the cyanide gas chamber. Cyanide fumigation quickly became the toxic cornerstone of the citrus industry, enabling its intensification and expansion as pest infection became systemic. By the turn of the century, furnished with an economic poison made cheap and weapons-grade due to changes in the world gold mining industry, growers transformed cyanide fumigation into a necessary agricultural input. In chemically overriding an agro-ecological contradiction of capitalist agriculture, growers, scientists, and government officials amalgamated industrially organized agriculture to accelerating and endless chemical warfare. These suddenly necessary agricultural practices signaled a state change in world-ecology and agroindustrial organization. Thus, the discovery of effective industrial control for citrus pests was not only a pivotal moment in the history of Southern California but it was also an event that has had world-historical implications.

Histories of chemical warfare and the gas chamber are written as 20th century tales.[3] So too are histories of industrial pest control.[4] And for the most part, these works are written upon

[3] For example: Fries, A A. *Chemical Warfare*. New York: McGraw-Hill Book Company, Inc., 1921; Fradkin, E K. "Chemical Warfare - Its Possibilities and Probabilities." *International Conciliation* 248 (1929): 7-191; Smart, J K. "History of Chemical and Biological Warfare: An American Perspective." *Medical Aspects of Chemical and Biological Warfare. Washington, DC: Office of the Surgeon General* (1997): 9-86; Harris, R, and J Paxman. *A Higher Form of Killing: The Secret History of Chemical and Biological Warfare*. New York: Random House, 2002; Jenkins. *The Final Frontier: America, Science, and Terror*. New York: Verso, 2002; Brophy, L P, W D Miles, and R C Cochrane. *Chemical Warfare: From Laboratory to Field*. Honolulu, HI: University Press of the Pacific, 2005; Tucker, J B. *War of Nerves: Chemical Warfare from World War I to Al-Qaeda*. New York: Pantheon Books, 2006; Christianson, S. *Fatal Airs: The Deadly History and Apocalyptic Future of Lethal Gases That Threaten Our World*. New York: Praeger, 2010; Preston, D. *A Higher Form of Killing: Six Weeks in World War I That Forever Changed the Nature of Warfare*. New York: Bloomsbury Press, 2015.

[4] For example: Carson, R. *Silent Spring*. New York: Houghton Mifflin 1962; Whorton, J C. *Before Silent Spring: Pesticides and Public Health in Pre-DDT America*. Princeton University Press Princeton, NJ, 1974; Perkins, J H. "Reshaping Technology in Wartime: The Effect of Military Goals on Entomological Research and Insect-Control Practices." *Technology and Culture* (1978): 169-86; Perkins, J H. *Insects, Experts and the Insecticide Crisis*: The Quest for New Pest Management Strategies. New York: Plenum Press, 1982; Russell, E. *War and Nature: Fighting Humans and Insects with Chemicals from World War I to Silent Spring*. Cambridge, UK: Cambridge University Press, 2001; Daniel, P. *Toxic Drift: Pesticides and Health in the Post-War South*. Baton Rouge, LA: Louisiana State University Press, 2005; McWilliams, J E. *American Pests: Losing the War on Insects from Colonial Times to DDT*. New York: Columbia University Press, 2008; Ceccatti, J S. "Natural Selection in the Field: Insecticide Resistance, Economic

separate storylines. Yet, historically, all three of these socioecological phenomena emerge from the same late 19th century creation story. In the late 1880s, among insect infested citrus groves on the western floodplain of the Los Angeles River, industrially efficient pest control emerged through the commercialization of chemical warfare and the deployment of the industrial gas chamber.

Historians of all stripes have written about the effects of war on states and peoples. Much less has been written about the effects of war on the environment.[5] And even less has been written about the links between warfare and longer-term processes of environmental change.[6] Agricultural historians, however, have long been interested in the links between agriculture and warfare.[7] It would be hard to study the history of economic or medical entomology and not notice a shared past battling pests on agricultural and military fields.[8] Thus, agricultural scholars have deftly shown us that since WWI, technological and scientific efforts to control agricultural and military enemies have developed hand and hand with each other. Industrial pest control and industrial chemical warfare, in other words, have coevolved and fed upon each other.

These scholars, however, situate the beginning of chemical warfare's influence on agricultural practices, and vice versa, with the onset of the First World War. World War I (WWI), regarded as the "chemists war," introduced the public to industrial warfare and weapons of mass destruction (See Figure 1).[9] Germany's use of chlorine gas on a warm spring day in 1915 is often the event credited with ushering in this new epoch in the evolution of war. Thus, most histories of chemical warfare open upon an April 1915 scene; as such, scholarship that links chemical warfare to pest control opens upon the same spring setting.

Entomology, and the Evolutionary Synthesis, 1914-1951." *Transactions of the American Philosophical Society* 99, no. 1 (2009): 199-217.

[5] Lanier-Graham, S D. *The Ecology of War: Environmental Impacts of Weaponry and Warfare*. New York: Walker & Co., 1993; Sanders, B. *The Green Zone: The Environmental Costs of Militarism*. Oakland, CA: AK Press, 2009; Slavin. "Warfare and Ecological Destruction in Early Fourteenth-Century British Isles." *Environmental History* 19 (2014): 528-50.

[6] Hamblin, J D. *Arming Mother Nature: The Birth of Catastrophic Environmentalism*. Oxford, UK: Oxford University Press, 2013; McNeill, J R, and C R Unger, eds. *Environmental Histories of the Cold War*. Washington, DC: German Historical Institute and Cambridge University Press, 2013.

[7] Cushing, E C. *History of Entomology in World War II*. Washington, DC: Smithsonian Institution, The Lord Baltimore Press, 1957.Russel, E P. "'Speaking of Annihilation': Mobilizing for War against Human and Insect Enemies." *The Journal of American History* 82, no. 4 (1996): 1505-29. Russell, *War and Nature*, 2001; Rasmussen, N. "Plant Hormones in War and Peace: Science, Industry, and Government in the Development of Herbicides in 1940s America." *Isis* 92, no. 2 (2001): 291-316.

[8] LAT. "Millions Cost of Pest War: Citrus Growers Prepare for Fumigation Season." *Los Angeles Times*, August 20, 1916; Howard, L O. "War against Insects." *Nature* 109, no. 2725 (1922): 79-80; Walker, HW, and JE Mills. "Progress Report of Work of the Chemical Warfare Service on the Boll Weevil - *Anthonomus grandis*." *Journal of Economic Entomology* 19, no. 4 (1926): 600-01; Walker, HW, and JE Mills. "Chemical Warfare Service Boll Weevil Investigation." *Industrial & Engineering Chemistry* 19, no. 6 (1927): 703-11; Fries, A A. "By-Products of Chemical Warfare." *Industrial and Engineering Chemistry* October (1928): 1079-84; Abraham, G. "Policeman's Tear Gas Used for Fumigating the Garden; for Counteracting Weeds, the Fungus Diseases and Insects in Soils and Composts." *New York Times*, September 1, 1940; Cecil, P F. *Herbicidal Warfare: The Ranch Hand Project in Vietnam*. New York: Praeger Publishers, 1986.

[9] Haber, L F. *The Chemical Industry 1900-1930: International Growth and Technological Change*. Oxford, UK: Oxford University Press, 1971.

But an April 1915 birthdate for chemical warfare is incorrect as evidence exists that chemical and biological warfare have been practiced for thousands of years.[10] Even the word *toxic,* in its etymology, reveals the long history of toxicants in warfare. Originating from the Greek word *toxikon*, the word toxic meant in its first iteration "poison for arrows."[11] It could be stressed, instead, that WWI marked the first time industrial gases were used directly in warfare. For warfare against humans, perhaps this is true. But the spring of 1915 was not the first time that industrial gas warfare was deployed against an enemy. That took place 28 years prior on a different kind of battlefield.

Historians of WWII and Nazi Germany often claim that "the creation of the gas chamber was a unique invention of Nazi Germany."[12] To scholars like these it isn't just the invention of the gas chamber per se, but its industrialization, its creation as an assembly line of death, that makes the Nazis' creation unique.[13] Recent scholarship, countering these claims, has argued that the gas chamber is a uniquely American creation that was first put into practice by United States (US) penal authorities in the early 1920s.[14] And although this recent scholarship links the shared material of death – cyanide – between the first US gas chamber and the California agrochemical company that provided it, it too fails to venture back beyond the Ypres front in the spring of 1915. By 1923, when hydrogen cyanide was first pumped into a specially constructed building in a Reno prison yard, the cyanide-based gas chamber had been in commercial operation for over 35 years, used across the US to disinfect trees, food, and nursery products; even whole train cars.[15]

Cyanide fumigation – the practice of releasing hydrogen cyanide gas under a tented tree – discovered in Los Angeles in the fall of 1886, bought a temporary reprieve from the ravages of industrial pests, allowing grower-capitalists to turn the valleys of Southern California into a citrus empire. The rapid development of industrial chemical control based upon the deployment of portable gas chambers saved the rudimentary Southern California citrus industry from pest-induced collapse by tying the efficient production of high quality citrus fruit to the commercial utilization of chemical weapons. Among the capitalist groves of late 19th century Southern California, on the backs of humans and horses, the industrial gas chamber became a working reality.

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[10] Browne, C A. "Early References Pertaining to Chemical Warfare." *The Journal of Industrial and Engineering Chemistry* 14, no. 7 (1922): 646; Kokatnur, V R. "Chemical Warfare in Ancient India." *Journal of Chemical Education* 25, no. 5 (1948): 268; Mayor, Adrienne. *Greek Fire, Poison Arrows, and Scorpion Bombs: Biological & Chemical Warfare in the Ancient World*. Penguin, 2008.

[11] *New Oxford American Dictionary.* Oxford, UK. Oxford University Press, 2011.

[12] Friedlander, H. *The Origins of Nazi Genocide: From Euthanasia to the Final Solution*. Chapel Hill, NC: The University of North Carolina Press, 1995. 93.

[13] Borin, J. *The Crime and Punishment of I.G. Farben*. New York: The Free Press, 1978; Jeffreys, D. *Hell's Cartels*. New York: Metropolitan Books, 2008.

[14] Christianson, S. *The Last Gasp: The Rise and Fall of the American Gas Chamber*. Berkeley: University of California Press, 2010.

[15] Johnson, Willis Grant. *Fumigation Methods: A Practical Treatise for Farmers, Fruit Growers, Nurserymen, Gardeners, Florists, Millers, Grain Dealers, Transportation Companies, Colleges and Experiment Station Workers, Etc*. New York: Orange Judd Company, 1902; Winters, S R. "Poison-Gas Chambers Disinfect Freight." *Popular Mechanics*, no. April (1922): 595-96.

Despite its formative impact on the agricultural production complex writ large, the story of industrial cyanide has remained largely unexplored among agricultural historians and critics of industrial agriculture. Even those that venture back beyond WWI fail to acknowledge cyanide's impact on agro-industrialization and western development. Were it not for cyanide fumigation, the history of industrial agriculture and Southern California' citrus industry would have looked much different. But the cleansing power of cyanide was discovered, and for about 6 months every year, as night fell upon the citrus groves, nocturnal executioners sprang to life: mixing chemicals, enshrouding trees, *and* repeating *and* repeating *and* repeating millions of times over.

The Nature of Industrial Pest Control

"But here the tailoring, the screening of basic truth, is done, not to suit a party line, but to accommodate the short term gain, to serve the gods of profit and production."

Rachael Carson, *Women's National Press Club Speech*, 1962[16]

The chemicalized nature of industrial agriculture has certainly resulted in awe-inspiring yields.[17] But it has also resulted in pollution and contamination on such an immense scale that it can now be found anywhere we look.[18] Industrial chemicals, as Rachael Carson said over half a century ago, now permeate the fabric of everyday life from the "moment of conception until death"[19] Children are now born into this world with hundreds of industrially made chemicals already flowing through their blood.[20] Life itself has become a vast repository of contamination, a documentary of exposure.[21]

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[16] Carson, R. "Women's National Press Club Speech." In *Lost Woods: The Discovered Writing of Rachel Carson*, edited by L Lear. Boston, MA: Beacon Press, 1999 (1962).

[17] Cochrane, W W. *The Development of American Agriculture*. Minneapolis, MN: University of Minnesota Press, 1993; Evenson, Robert E, and Douglas Gollin. "Assessing the Impact of the Green Revolution, 1960 to 2000." *Science* 300, no. 5620 (2003): 758-62; Associated Press. "USDA Boosts Corn, Soybean Harvest to New Records." *AGWEB*, 2014.

[18] Chen, M-H, E-H Ha, T-W Wen, Y-N Su, G-W Lien, C-Y Chen, P-C Chen, and W-S Hsieh. "Perfluorinated Compounds in Umbilical Cord Blood and Adverse Birth Outcomes." *PLoS One* 7, no. 8 (2012): e42474; Collotta, M, P A Bertazzi, and V Bollati. "Epigenetics and Pesticides." *Toxicology* 307 (2013): 35-41; Fu, P, and K Kawamura. "Ubiquity of Bisphenol A in the Atmosphere." *Environmental Pollution* 158, no. 10 (2010): 3138-43; Malaj, E, C Peter, M Grote, R Kühne, C P Mondy, P Usseglio-Polatera, W Brack, and R B Schäfer. "Organic Chemicals Jeopardize the Health of Freshwater Ecosystems on the Continental Scale." *Proceedings of the National Academy of Sciences* 111, no. 26 (2014): 9549-54.

[19] Carson, *Silent Spring*, 1962. 15.
Murphy, M. "Chemical Regimes of Living." *Environmental History* 13, no. 4 (2008): 695-703.

[20] Bradman, A, B Eskenazi, D B Barr, R Bravo, R Castorina, J Chevrier, K Kogut, M E Harnly, and T E McKone. "Organophosphate Urinary Metabolite Levels During Pregnancy and after Delivery in Women Living in an Agricultural Community." *Environmental Health Perspectives* 113, no. 12 (2005): 1802; Bradman, A, D Whitaker, L Quirós, R Castorina, B C Henn, M Nishioka, J Morgan*, et al.* "Pesticides and Their Metabolites in the Homes and Urine of Farmworker Children Living in the Salinas Valley, Ca." *Journal of Exposure Science and Environmental Epidemiology* 17, no. 4 (2007): 331-49; Grandjean, P, and P J Landrigan. "Neurobehavioural Effects of Developmental Toxicity." *The Lancet Neurology* 13, no. 3 (2014): 330-38.

[21] Corcoran, J, M J Winter, and C R Tyler. "Pharmaceuticals in the Aquatic Environment: A Critical Review of the Evidence for

Critics of industrial capitalist agriculture have repeatedly highlighted agriculture's dependence on industrially produced chemical inputs.[22] Using fertilizers derived from rocks and natural gas, we mask long-term fertility problems.[23] Chasing economies of scale and scope we simplify, standardize, and intensify, fabricating novel agroecosystems structured around production for, and realization of, value in a market.[24] And lured by the siren song of nature's control, we conjure ever-newer chemical weapons to override nature's resistance to our hostility.[25] In doing so, like Sisyphus with his stone, we have forced ourselves to forever run with Alice and Red Queen. Faster, ever faster we must run, just to stay in the same place.[26] And like Alice, who never figured out how she began running ever faster, the origins of industrial agriculture's toxic dependency have until now remained unknown. But addiction, whether individual or industrial, always has a ground zero – a first time, a first taste – and it to this moment that I turn.

In this chapter I traverse the political economic origins of agriculture's chemical addiction by historically navigating a critical threshold between two organizational states, a state before toxic chemicals were necessary for industrial agricultural production and our

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Health Effects in Fish." *Critical Reviews in Toxicology* 40, no. 4 (2010): 287-304; Singer, M. "Down Cancer Alley: The Lived Experience of Health and Environmental Suffering in Louisiana's Chemical Corridor." *Medical Anthropology Quarterly* 25, no. 2 (2011): 141-63; Guillette Jr, LJ, and T Iguchi. "Life in a Contaminated World." *Science* 337, no. 6102 (2012): 1614-15; Altman, R. "On What We Bury." *Interdisciplinary Studies in Literature and Environment* (2014): 1-11.

[22] Goodman, D, B Sorj, and J Wilkinson. "From Farming to Biotechnology: A Theory of Agro-Industrial Development." Oxford, UK: Basil Blackwell, 1987; Pollan, M. *The Omnivore's Dilemma: A Natural History of Four Meals*. Penguin, 2006; Weis, T. "The Accelerating Biophysical Contradictions of Industrial Capitalist Agriculture." *Journal of Agrarian Change* 10, no. 3 (2010): 315-41; Van Der Ploeg, J D. "The Food Crisis, Industrialized Farming and the Imperial Regime." *Journal of Agrarian Change* 10, no. 1 (2010): 98-106.

[23] Khan, S A, R L Mulvaney, T R Ellsworth, and C W Boast. "The Myth of Nitrogen Fertilization for Soil Carbon Sequestration." *Journal of Environmental Quality* 36, no. 6 (2007): 1821-32; Mulvaney, R L, S A Khan, and T R Ellsworth. "Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production." *Journal of Environmental Quality* 38, no. 6 (2009): 2295-314.

[24] Haila, Y, and R Levins. *Humanity and Nature: Ecology, Science, and Society*. London: Pluto Press, 1992; Henderson, G. *California and the Fictions of Capital*. Oxford, UK: Oxford University Press, 1999; Moore, J W. "Capitalism as World-Ecology Braudel and Marx on Environmental History." *Organization & Environment* 16, no. 4 (2003): 514-17; Folke, C, S Carpenter, B Walker, M Scheffer, T Elmqvist, L Gunderson, and C S Holling. "Regime Shifts, Resilience, and Biodiversity in Ecosystem Management." *Annual Review of Ecology, Evolution, and Systematics* (2004): 557-81; Hobbs, R J, S Arico, J Aronson, J S Baron, P Bridgewater, V A Cramer, P R Epstein*, et al.* "Novel Ecosystems: Theoretical and Management Aspects of the New Ecological World Order." *Global Ecology and Biogeography* 15, no. 1 (2006): 1-7; Lewontin, R, and R Levins. *Biology under the Influence: Dialectical Essays on Ecology, Agriculture, and Health*. New York: Monthly Review Press, 2007.

[25] Carson, Silent Spring, 1962; Naylor, R L, and P R Ehrlich. "Natural Pest Control Services and Agriculture." In *Nature's Services: Societal Dependence on Natural Ecosystems*, edited by G Daily, 151-74. Washington, DC: Island Press, 1997; Ceccatti, "Natural Selection," 2009; Weis, "Accelerating Biophysical Contradictions," 2010; USDA. "Dow Agrosciences Petitions (09-233-01p, 09-349-01p, and 11-234-01p) for Determinations of Nonregulated Status for 2,4-D Resistant Corn and Soybean Varieties." In *Draft Environmental Impact Statement*. Washington, DC: USDA APHIS, 2013; Alyokhin, A, D Mota-Sanchez, M Baker, W E Synder, S Menasha, M Whalon, and W F Moarsi. "The Red Queen in the Potato Field: Integrated Pest Management Versus Chemical Dependency in Colorado Potato-Beetle Control." *Pest Management Science* doi: 10.1002/ps.3826 (2014).

[26] Boyce, A M. "Studies on the Resistance of Certain Insects to Hydrocyanic Acid." *Journal of Economic Entomology* 21, no. 5 (1928): 715-20; Gray, G P, and A Kirkpatrick. "The Resistance of Black Scale (Saissetia Oleae Bern.) to Hydrocyanic Acid Fumigation." *Journal of Economic Entomology* 22, no. 6 (1929): 893-97; Schnailberg, A. *The Environment: From Surplus to Scarcity*. New York: Oxford University Press, 1980; Plucknett, D L, and N J Smith. "Sustaining Agricultural Yields." *BioScience* 36, no. 1 (1986): 40-45; Jansen, M, A Coors, R Stoks, and L De Meester. "Evolutionary Ecotoxicology of Pesticide Resistance: A Case Study in Daphnia." *Ecotoxicology* 20, no. 3 (2011): 543-51.

current state in which a continuous stream of chemotherapeutics are needed to soothe the chronic symptoms of capitalist agriculture. Drawing from Moore's concept of world-ecology, I argue that industrial pest control has been imbued with the practices, discourse, materials, and ethics of modern chemical warfare since its inception.[27]

Moore highlights how "capitalism does not develop upon global nature so much as it emerges through the messy and contingent relations of humans with the rest of nature."[28] Capitalism, in other words, is an ecological regime that translates complex ecological processes into sites of accumulation while simultaneously being constrained by the state of nature itself.[29] In doing so, capitalism undermines the conditions of its reproduction.[30] Thus, world-ecology is nothing if not a theory of socio-ecological organization, where "transitory but identifiable socio-ecological moments" can have revolutionary effects.[31] The discovery of cyanide fumigation was one such moment.

A revolution in capitalist agricultural organization occurred among the citrus trees of late 19th Century Southern California when growers and scientists temporarily overcame ecological crisis by tying the production of high-quality citrus fruit to an endless chemical war. This organizational change allowed growers, scientists, and chemical salesmen not only to overcome the growing insect plague descending upon the industrial citrus biome but also to expand and intensify as the infection became systemic. By the turn of the 20th century, for the first time, chemical pest control crossed an important threshold when it went from being used in an ad-hoc manner to a prerequisite of industrial citrus. In the Southland's citrus-scented killing fields, officially sanctioned commercially efficient mass death became a defining feature of industrial agricultural production.[32]

Many scholars before me have linked developments in warfare with developments in industrial pest control, but none has suggested that the ontology of industrial pest control is and has always been a state of war. The dominant structuring force of contemporary world-

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[27] Moore, "Capitalism as World-Ecology," 2003. Moore, Jason W. "Transcending the Metabolic Rift: A Theory of Crises in the Capitalist World-Ecology." *The Journal of Peasant Studies* 38, no. 1 (2011): 1-46; Moore, Jason W. "Ecology, Capital, and the Nature of Our Times: Accumulation and Crisis in the Capitalist World-Ecology." *Journal of World-Systems Research* 17, no. 1 (2011): 108-47.

[28] Moore, "Ecology, Capital, and Nature," 2011. 110.

[29] Levins, R. *Evolution in Changing Environments*. Princeton: Princeton University Press, 1968; Levins, R, and L Lewontin. *The Dialectical Biologist*. Cambridge, MA: Harvard University Press, 1985. Lewontin and Levins, Biology Under the Influence, 2007.

[30] Liebig, J. *Familiar Letters on Chemistry, in Its Relations to Physiology, Dietetics, Agriculture, Commerce, and Political Economy* London: Walton & Maberly, 1859; Benton, T. "Marxism and Natural Limits: An Ecological Critique and Reconstruction." *New Left Review* 178 (1989): 51-86; Foster, J B, B Clark, and R York. *The Ecological Rift: Capitalism's War on the Earth*. New York: Monthly Review Press, 2011.

[31] Moore, "Capitalism as World Ecology," 2003. 432; Scheffer, M, S Carpenter, J A Foley, C Folke, and B Walker. "Catastrophic Shifts in Ecosystems." *Nature* 413, no. 6856 (2001): 591-96. Folke et al., "Regime Shifts," 2004; Beisner, B E, D T Haydon, and K Cuddington. "Alternative Stable States in Ecology." *Frontiers in Ecology and the Environment* 1, no. 7 (2003): 376-82; Barnosky, A D, E A Hadly, J Bascompte, E L Berlow, J H Brown, M Fortelius, W M Getz*, et al.* "Approaching a State Shift in Earth's Biosphere." *Nature* 486, no. 7401 (2012): 52-58.

[32] PRP. "Killing Animals Humanely." *Pacific Rural Press*, April 7 1888, 305; Lough, J W. *Weber and the Persistence of Religion: Social Theory, Capitalism and the Sublime*. New York: Routledge, 2007; Peck, S L. "Death and the Ecological Crisis." *Agriculture and Human Values* 27 (2010): 105-09.

agriculture is more than just an historical matrix of agro-ecological nature patterned by endless accumulation, as many scholars suggest.[33] It is also, critically, an agriculture of endless war. We have fulfilled Hobbes' darkest philosophical incantations by turning the production of food and fiber in a state of endless war – a war in which "all life is caught in its violent crossfire"[34] In our war with nature, we are war with ourselves – together, a "community unto death."[35] And we do this, not to produce sufficient food, but "in service to the gods of profit and production."[36] Not in my name.

A Narrative History of Agroindustrial State-Change[37]

"Such are the facts of chemical warfare. They will not be believed because a belief in them would do violence to the sentiments of most people."

J.B.S. Haldane, *Callincus: A Defense of Chemical Warfare*, 1925[38]

Throughout the 1870s and 1880s, the valleys of Southern California were inundated with immigrants. From all corners of the earth they came, at first just a trickle, but soon a flood, seeking opportunities among the sun-drenched landscapes of the Golden State.[39] These immigrants came in many forms, including people, insects, and plants, even chemicals. At the turn of the 20th century, as the semi-tropical pot-of-gold on the western shores of

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[33] Altieri, M A. "Ecological Impacts of Industrial Agriculture and the Possibilities for Truly Sustainable Farming." *Monthly Review* 50 (1998): 60-71; Magdoff, F, J B Foster, and F H Buttel. *Hungry for Profit: The Agribusiness Threat to Farmers, Food, and the Environment*. NYU Press, 2000. Moore, Capitalism as World-Ecology, 2003; Moore, J W. "The End of the Road? Agricultural Revolutions in the Capitalist World-Ecology, 1450–2010." *Journal of Agrarian Change* 10, no. 3 (2010): 389-413. Moore, 2011. Moore, "Ecology, Capital, and Nature," 2011; Perfecto, I, J H Vandermeer, and A L Wright. *Nature's Matrix: Linking Agriculture, Conservation and Food Sovereignty*. London, UK: Earthscan, 2009; Weis, T. "The Accelerating Biophysical Contradictions of Industrial Capitalist Agriculture." *Journal of Agrarian Change* 10, no. 3 (2010): 315-41. Foster et al., The Ecological Rift, 2011.

[34] Carson, *Silent Spring*, 1962. 8.
Kavka, G S. "Hobbes's War of All against All." *Ethics* 93, no. 2 (1983): 291-310.

[35] Lough, *Weber and the Persistence of Religion*, 2007.

[36] Carson, R. "Women's National Press Club Speech." In *Lost Woods: The Discovered Writing of Rachel Carson*, edited by L Lear. Boston, MA: Beacon Press, 1999 (1962). 210. Perkins, J H. "Insects, Food, and Hunger: The Paradox of Plenty for US Entomology, 1920-1970." *Environmental History Review* 7, no. 1 (1983): 71-96; Cochrane, W W. *The Curse of Agricultural Abundance: A Sustainable Solution*. Lincoln, NE: University of Nebraska Press, 2003.

[37] Data and Methods: This history is compiled from the following archives: California State Library and Archive, Hagley Library, UC Riverside Citrus Experiment Station Archive, Chemical Heritage Foundation Archives, UC Irvine Special Collections, Bancroft Library at UC Berkeley, Huntington Library, USC Digital Library. I also draw from multiple newspaper archives including those of the Los Angeles Herald, the Los Angeles Times, the New York Times, and the Pacific Rural Press. Because most newspaper articles do not have author attribution, I use newspaper acronyms followed year (ex. a 2014 Pacific Rural Press article → PRP 2014). A full list of newspaper acronyms can be found at the end of the chapter.

[38] Haldane, J B S. *Callinicus: A Defense of Chemical Warfare*. New York: E. P. Dutton & Company, 1925.

[39] McWilliams, C. *Factories in the Field*. Vol. 342, Berkeley, CA: University of California Press, 1935; McWilliams, C. *Southern California: An Island on the Land*. Salt Lake City: Gibbs Smith, 1946; Street, R S. *Beasts of the Field: A Narrative History of California Farmworkers, 1769-1913*. Stanford, CA: Stanford University Press, 2004; Sackman, D C. *Orange Empire: California and the Fruits of Eden*. Berkeley, CA: University of California Press, 2005.

manifest destiny, Southern California began producing something golden in color yet far sweeter than precious metals: citrus.[40] Beginning in the 1850s and rapidly accelerating as the turn of the century approached, the flooding of the promised land's valleys with homogenous citrus trees sparked a radical reorganization in the life histories of California's insects and the historical trajectories of California's ecologies.[41] By the early 1880s, as the non-linear population dynamics of native and introduced insects began to realign with an emerging industrial citrus biome, the economic pest problem grew exponentially.[42]

The number of citrus trees offers a quantitative proxy for the radical social and ecological change that came to the valleys of Southern California. In 1870, there were fewer than 35,000 citrus trees in the entire state of California, with only 8,000 of them in Los Angeles.[43] By the mid-1880s, there were more than 500,000 citrus trees on 13,000 acres in LA County alone. By 1900, there were over 3 million citrus trees of only a few varieties bearing fruit across Southern California, with millions more coming into production over

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[40] Guinn, J.M. "From Cattle Ranch to Orange Grove." *Annual Publication of the Historical Society of Southern California* 8, no. 3 (1912): 145-57. Spalding, W A. "Early Chapters in the History of California Citrus Culture." *California Citrograph* 7, no. 4 (1922): 94-95, 122-124, 150-151; Webber, H J, and L D Batchelor. *The Citrus Industry. Vol. I. History, Botany and Breeding*. The Citrus Industry. Berkeley, CA: University of California Press, 1943.

[41] I use the term *life history* throughout the narrative for two reasons, one passive and one active. The first is that the term *life history* was used in the late 19th century to describe a particular type of economic entomological study. The study of an insect's life history – defined in this case as a descriptive analysis of the ecological physiology of an insect – was critical to determining what stages of an insect's life were most susceptible to economic poisons. For example, the egg stage of reproduction was often the least vulnerable to economic poisons. The second, active meaning of *life history* resonates from current evolutionary and ecological theory. Stearns, S C. "Life-History Tactics: A Review of the Ideas." *Quarterly Review of Biology* 51, no. 1 (1976): 3-47; Stearns, S C. *The Evolution of Life Histories*. Oxford, UK: Oxford University Press 1992; Byrne, M. "Impact of Ocean Warming and Ocean Acidification on Marine Invertebrate Life History Stages: Vulnerabilities and Potential for Persistence in a Changing Ocean." In *Oceanography and Marine Biology: An Annual Review*, edited by R Gibson, R Atkinson, J Gordon, I Smith and D Hughes, 1-42, 2011; Selman, C, J D Blount, D H Nussey, and J R Speakman. "Oxidative Damage, Ageing, and Life-History Evolution: Where Now?". *Trends in Ecology & Evolution* 27, no. 10 (2012): 570-77; Nik-Zainal, S, P Van Loo, D C Wedge, L B Alexandrov, C D Greenman, K W Lau, K Raine*, et al.* "The Life History of 21 Breast Cancers." *Cell* 149, no. 5 (2012): 994-1007. In this case *life history* describes the influence of eco-evolutionary selection on an organism's developmental/reproductive/senescent timing and duration to maximize fitness (defined as offspring survival). Thus, when I use the term, I use it in both senses, as way to describe the adaption of insects' ecological physiology – for example, their rate of reproduction or instar size – to new niches created by value-oriented agroecological change, and as a way to link the developmental stages of a insect's life (and the historical study of this) with industrially efficient death. Although I disagree with fitness described solely in terms of maximum offspring survival, I like the term *life history* because it captures the complexity of insects' physiology/behavior over dynamic ecological space and generational time and because it also can be used to view agricultural pests and pesticide resistance as effects of anthropogenic eco-evolutionary forcing. In this way agricultural pests embody both object and subject, both passive non-agent and active agent, in dialectical tension over time and space. Levins, *Evolution in Changing Environments*, 1968; Levins and Lewontin, Dialectical Biologist, 1985; Mitchell, Timothy. *Rule of Experts: Egypt, Techno-Politics, Modernity*. Berkeley, CA: University of California Press, 2002; Odling-Smee, F J, K N Laland, and M W Feldman. *Niche Construction: The Neglected Process in Evolution*. Princeton University Press, 2003; Lewontin and Levins, *Biology Under the Influence*, 2007; Kirksey, S E, and S Helmreich. "The Emergence of Multispecies Ethnography." *Cultural Anthropology* 25, no. 4 (2010): 545-76; Monosson, E. *Unnatural Selection: How We Are Changing Life, Gene by Gene*. Washington, DC: Island Press, 2015.

[42] Holt. "Orange Tree Diseases." *Southern California Horticulturist* 1, no. 2 (1877): 61-62; Bristol, S. "The Oleander and Orange Scale-Bug." *Southern California Horticulturist* 1, no. 12 (1878): 374-75; SCH. "The Red Scale." *Southern California Horticulturist* II, no. 9 (1879): 280; Holt, L M. "The Red Scale on Citrus Trees." *Pacific Rural Press*, January 31 1880.

[43] CSAS. "Table of Statistics." In *Transactions of the California State Agricultural Society*. Sacramento: California State Agricultural Society, 1872.

the next decade (See Figure 2).[44] The winter ripening Navel orange, which emigrated from Brazil via Washington DC in 1873, dominated the arid inland "citrus belt" that ran along the eastbound line of the Southern Pacific from Pasadena to Riverside. The summer ripening Valencia orange, imported from the Azores in 1876, was grown in the coastal valleys from San Diego to Santa Barbara, and the ever-bearing Eureka lemon, originating in Los Angeles from Italian seed stock in the late 1850s, was grown in both regions.

Figure 2 – Redlands orange groves, various ages, ca. 1880. Note the Southern Pacific Railroad in the background, *Courtesy of the USC Digital Archive*[45]

In 1841, William Wolfskill planted the first commercial orange grove in Los Angeles, at what is now the corner of 4th and Alameda.[46] Securing trees from the San Gabriel Mission,

[44] Spalding, W A. *The Orange, Its Culture in California*. Press and Horticulturist Steam Print, 1885; Webber and Batchelor, Citrus Industry, 1943; Sackman, *Orange Empire,* 2005.
[45] Everitt, E P. "Orange Grove, Showing Southern Pacific Passenger Train Moving in the Background, Ca.1880." In *California Historical Society Collection, 1860-1960*, edited by CHS-43696: USC Digital Archive, 1880.
[46] Spalding, Citrus Culture, 1885; Coit, J E. *Citrus Fruits: An Account of the Citrus Industry with Special Reference to California*

he planted two acres of oranges. Wolfskill, a trapper who arrived in Los Angeles from Kentucky after a brief detour into Mexico, was a founding member of the city of Los Angeles and perhaps California's first agro-capitalist.[47] On his extensive lands, which he had received from the Mexican government in 1836 (hence the detour), he planted vineyards and fruit trees, made wine, and grazed sheep.[48] He even planted a banana grove.

By the 1850s, with the help of his neighbor, Jean-Louis Vignes – also known as the father of California Wine and the first to import French varieties into California – William Wolfskill and other growers had turned the fertile lands near the Los Angeles River into a major wine producing region.[49] By the mid-1850s, he had over 40,000 grape vines in production, and cuttings from his "celebrated vineyards" were sold across California.[50] In 1870, these floodplain vineyards produced almost 20% of the wine made in the United States.[51] Thus, it was not preordained that citrus would come to dominate the agricultural production of Southern California.

By the mid-1850s, Wolfskill had added more than two thousand more citrus trees to his Los Angeles groves, and by 1860, he had over 70 acres of citrus, mostly orange, but also lemon, lime, and citron. He also had extensive lands and plantings in the San Gabriel Valley and southern Los Angeles near what is now the city of Vernon. Upon his passing in 1866, his land – the richest agricultural property in Los Angeles County – was divided, with most of it deeded to his two sons, Louis, and J.W.[52] Louis received his father's holdings in the San Gabriel valley and J.W. received his father's LA groves, as well as large swaths of land east of the LA River.[53] J.W. would take up where his father left off, expanding and intensifying citrus production, as well as becoming the first local producer of cut flowers.[54] In the early 1870s, in conjunction with a grape disease outbreak (*phylloxera*), J.W. turned away from grapes, razing his vineyards and planting more citrus.[55] Lewis turned his attention toward

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Requirement and Practices and Similar Conditions. New York: The MacMillan Company, 1915.

[47] DAC. "Wolfskill of Los Angeles and His Vineyard." *Daily Alta California*, December 20 1858; LAH. "History of the Orange in Los Angeles." *Los Angeles Herald*, April 5 1882; Barrows, H D. "William Wolfskill, the Pioneer." *Annual Publication of the Historical Society of Southern California and of the Pioneers of Los Angeles County* (1902): 287-94; Wilson, I H. *William Wolfskill: 1798-1866: Frontier Trapper to California Ranchero*. Glendale, CA: Arthur H. Clark Company, 1965.

[48] Wolkskill, W. "Petition for Guillermo Wolfskill for Grant of Agricultural Parcel." In *Los Angeles City Archives, 1836-1872*: USC Digital Archive, 1836; DAC. "Wolfskill of Los Angeles and His Vineyard." *Daily Alta California*, December 20, 1858.

[49] DAC. 1863. California Wine-Growers Association: Secretary's Report. Daily Alta California, June 25.

[50] SDU. "Advertisement: Grape Cuttings: Grape Cuttings." *Sacramento Daily Union*, April 9, 1851; DAC. "Later from the South: Arrival of the Southerner." *Daily Alta California*, September 5 1854.

[51] Wilson, Iris Ann. "Early Southern California Viniculture 1830-1865." *The Historical Society of Southern California Quarterly* 39, no. 3 (1957): 242-50; Spalding, W A. *The Orange, Its Culture in California*. Press and Horticulturist Steam Print, 1885.

[52] DAC. "Death of William Wolfskill." *Daily Alta California*, October 5 1866; Wolfskill, J J. "William Wolkskill, the Pioneer." *Daily Alta California*, October 12 1866; Solano, A. "Land of L. Wolfskill in the Rancho Santa Anita." In *Maps*: Huntington Digital Library, 1871.

[53] Knox, G C. "Map of the Wolfskill Orchard." In *Maps*: Huntington Digital Library, 1886; Hansen and Solano Co. "Moulton Crystal Springs Property of J.W. Wolfskill on the East Side of the Los Angeles River." In *Maps*, edited by 313637. San Marino, CA: Huntington Digital Library, 1888.

[54] PRP. "Agricultural Notes: California - Los Angeles." *Pacific Rural Press*, April 6, 1872.

[55] SDU. "Pacific Coast Items." *Sacramento Daily Union*, March 18, 1874.

the railroads, the development of a cooperative warehouse and shipping association, and eventually politics.[56]

In 1877, J.W. Wolfskill loaded a carload of his oranges onto a Southern Pacific train bound for St. Louis in what was the first commercial interstate export of oranges from Los Angeles.[57] By the early 1880s, J.W. Wolfskill's Los Angeles grove, a product of his father's initiative, his business acumen, and the sweat of countless laborers, bordered by Third street on the north and Sixth street on the south, Alameda on the east and San Pedro on the west, was the pinnacle of progressive agriculture.[58] The arrival of the Santa Fe railroad in 1885 and the subsequent decline in shipping costs that resulted from its competition with the Southern Pacific meant that by 1886, East Coast markets were becoming more lucrative.[59] On February 4, 1886 the first special train loaded only with citrus left Los Angeles bound for St. Louis.

Since the Wolfskill groves were the first commercial citrus groves planted in California, it is not a coincidence that by the mid-1880s they were some of the more heavily infested, "dirty," groves.[60] The intensive production of a single crop over a large geographic area was a historically novel set of socio-ecological environments for insects, both foreign and domestic, to colonize. Attracted by the irrigated, fertilized, and repetitious flesh of citrus, insects colonized these new ecological niches, integrating their life histories with the rapidly expanding industrial citrus biome.

The creation of intensive monocultural agriculture in the second half of the 19th century was increasingly complicated by insects and pathogens that rode piggyback on the rapid expansion of the transportation and communication networks developed throughout the first half of 19th century. Sometimes these introductions were intentional, sometimes not. The European gypsy moth, (*Lymantria dispar*), an insect that has caused untold damage to US agriculture and forestry since the mid-1870s, was imported into Boston in 1869 for the purpose of creating an American "silk" industry.[61] The white or cotton cushiony scale (*Icerya purchasi*) was inadvertently introduced into California from Australia on nursery stock that arrived at the port of San Francisco sometime in the late 1860s. It was first identified in Southern California in 1872, again, on infested nursery stock. By the late 1870s, white scale had spread throughout the established groves in Los Angeles.[62] By 1884, white scale, along

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[56] Wilson, B D, F P F Temple, J D Shorb, N C Jones, P Banning, Wolfksill. L, and L J Rose. "Warehouse and Shipping Association: Articles of Association." *Los Angeles Herald*, January 7, 1874; LAH. "Railroad Meeting." *Los Angeles Herald*, December 20, 1874.

[57] CF. "Orange Culture." *California Farmer and Journal of Useful Sciences*, September 5, 1878; SDU. "Practical Agriculture: Orange Culture in California." *Sacramento Daily Union*, January 3 1880.

[58] PRP. "Horticulture: Los Angeles Fruit Growers Association." *Pacific Rural Press*, May 19, 1877; PRP. "Agricultural Notes: California - Los Angeles." *Pacific Rural Press*, March 3, 1877; LAH. "Growing Interest–the Money in Raising Oranges." *Los Angeles Herald*, August 25 1878. Street, *Beasts of the Field*, 2004.

[59] DAC. "Agricultural Notes." *Daily Alta California*, February 28, 1885.

[60] PRP. "Entomological: Citrus Scale and Their Foes." *Pacific Rural Press*, March 10 1883.

[61] Elkington, J. S. "Gypsy Moth." In *Encyclopedia of Insects*, edited by V. Resh and R. Cardé, 493-97. New York: Academic Press, 2003.

[62] Coquillet, D W. "Talks with Citizens." *Los Angeles Times*, May 27, 1888.

with red and black scale (also foreign invaders) was causing serious commercial damage to citrus in many Southern California locations. In 1885, much of the orange crop failed "because of the ravages of insects."[63] Even the Wolfskill groves – "the pride of Southern California" – were reduced to fields of stubs alive with insect pests.[64] Without any effective recourse, many growers burned their trees. Many others simply abandoned their groves. Growers, politicians, horticultural commissioners, and local businessmen foresaw a complete collapse of commercial citrus.[65]

In 1885, C.V. Riley, Chief Entomologist of the USDA Division of Entomology, after years of persistent grower appeal, finally recognized the magnitude of the citrus scale problem and deputized D. W. Coquillet, a trained entomologist and Southern California resident originally from Illinois to investigate the scale problem and to devise a solution.[66] Asked about the pest situation by a Los Angeles Times reporter shortly after his appointment, Coquillet lamented, "Only a few years ago it was one of the boasts of California that we had no fruit pests–or scarcely any. They have been brought in, however, and the climate of this State seems to suit them as well as it suits other animate beings, for they have increased and multiplied at an alarming rate, and are now more destructive than in the East. By far the most dangerous to citrus fruit trees is the white cotton cushiony scale (*Icerya purchasi*)."[67]

For Coquillet, scale infestation was more than a scientific problem to decipher.[68] It was foremost a commercial problem. In 1886, Coquillet approached perhaps the most progressive grower in Los Angles, J.W. Wolfskill, and his orchard manger, Alexander Craw, with the desire to couple their resources in the hopes of finding a solution to the plague that was descending on Southern California. Because the Wolfskill groves were the pinnacle of intensive horticulture (see Figures 3 and 4), yielding more than $1000 in profit per acre in the late 1880s, J.W. Wolfskill had both more to lose and more to gain than others if a solution could be worked out, and he had made the research and development of citrus pest control a commercial priority.[69]

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[63] Kercheval, A F. "What Shall We Do About the Scale?" *Los Angeles Times*, March 22, 1885.
[64] DAC, "Agricultural Notes," 1885.
[65] Kerchevel, "What Shall We Do,"1885; Kercheval, A F. "Shall the White Scale Go, or Shall We?" *Los Angeles Times*, July 11, 1886; Coquillet, D W. "Farm and Range: Cotton Cushiony Scale, Experiments with Remedies for Their Destruction." *Los Angeles Times*, July 18, 1886; Coquillet, D W. "Insect Killing by Fumigation. An Essay Read at the Santa Barbara Convention of Fruit Growers." *Pacific Rural Press*, May 5, 1888; Coquillet, D W. "Report on the Gas Treatment for Scale Insects." In *Agriculture Yearbook for 1887*, 123-42. Washington, DC: USDA, 1888; Coquillet, D W. "Entomological: Origin of the Gas Treatment for Scale Insect." *Pacific Rural Press*, September 5, 1891; LAH. "The White Scale: Some Terribly Infested Orange Groves. Where Are the Inspectors?" *Los Angeles Herald*, June 12 1886.
[66] Henry, W A. "Pacific Coast Work of the Division of Entomology." *Insect Life* II, no. 5 (1889): 141-44; Coquillet, D W. "Another Foe for Icerya." *The Pacific Rural Press*, December 27, 1890; Coquillet, "Origin of Gas Treatment," 1891.
[67] Coquillet, Talks with Citizens, 1888.
[68] Coquillet, D W. "Us Department of Agriculture Report for 1886." 522-69. Washington, DC: USDA, 1887.
[69] DAC. "State Notes." *Daily Alta California*, June 30, 1886; Essig, E O. *A History of Entomology*. New York: Hafner Publishing Company, 1931.

Figure 3 – Artistic representation of the Wolfskill Grove circa 1882. Courtesy of the *USC Digital Archive.*[70]

[70] CC Pierce & Co. "Drawing Depicting William Wolfskill's Pasadena Orange and Lemon Grove and Residence, Between Alameda and San Pedro Streets, Los Angeles, Ca. 1882." In *California Historical Society Collection*, edited by CHS-7310. Los Angeles: USC Digital Archive, 1882.

Figure 4 - The Wolfskill grove ca. 1885. Courtesy of the Bancroft Library at UC Berkeley.[71]

Two years earlier, growers had declared war on the unwanted occupants of the rapidly expanding industrial citrus biome. Skirmishes with soaps and other sprays had flared between growers and citrus pests across Southern California since the late 1870s, but in 1884, these battles escalated into full-fledged war.[72] Alexander Craw, manager of the Wolfskill orchards during the 1880s and 1890s recalled, "Previous to the year 1884, we had only black scale (Lecanium oleae) to contend with and only in the Wolfskill orange groves, and these were kept in check by application of whale-oil soap in the form of a spray; one application every two years was sufficient. In the fall of the year 1884 we found a few trees on the south side of the large grove infested with the Cottony Cushion-scale (Icerya purchasi). They became infested from an adjoining grove. We prepared for war…"[73] Indeed they did.

Throughout late 1884 and 1885, they threw every weapon in their arsenal at the scale. In recalling the events of 1885, Craw wrote that no matter what they hurled at the scale, it "would not check this prolific creeping curse."[74] The following year, the scale cottony front advanced across Los Angeles so that many trees were, as a horticultural

[71] Taber, I W. "Wolfskill Orange Grove." In *Riverside and Los Angeles Area Views, circa 1880-1889*, edited by BANC PIC 1905.06211:18. Berkeley, CA: Bancroft Library, 1885.
[72] PRP. "Entomological: Citrus Scale and Their Foes." *Pacific Rural Press*, March 10 1883.
[73] A. Craw quoted in: Coquillet, "Insect Killing," 1888.
[74] A. Craw quoted in: Coquillet, "Insect Killing," 1888.

commissioner in the Los Angeles Times put it, “literally white with the voracious and virile insects in all stages of development, every leaf, limb and twig being coated completely.”[75]

In the early summer of 1886, J.W. Wolfskill and Alexander Craw undertook what can be considered the most sophisticated scientific experiments to date for the chemical control of citrus pests.[76] The fact that they were using a canvas tent, bathed in linseed (flax) oil, to enclose a tree and introduce a gas produced in situ, was more than cutting edge. It was downright revolutionary. The first use of economic poisons, particularly the arsenical dusts, dates back two decades prior in the US, and examples of previous experiments with greenhouse and tent fumigation can be found.[77] But none of these were done with the determination that came from the expansive disquiet of California’s late 19th century industrial landscapes.[78]

Wolfskill and Craw first used stoves to raise the temperature inside a tented tree, but while this appeared effective against black scale, cotton cushiony scale, the Aussie emigrant, seemed to thrive on the heat. Then they tried steam, tobacco, sulfur, muriatic acid, chloroform, arsenic fumes, and carbon disulfide. The only promising experiment involved carbon disulfide (CS_2), but this required fumigation with noneconomic concentrations of highly explosive CS_2 for at least 3 hours.

By late summer, Dr. Coquillet of the USDA had joined their research. He was so impressed with the carbon disulfide fumigation results that he decided to lead the USDA mandated “crusade” on scale the following month in the Wolfskill groves.[79] Enlarging the scale of their “science in the orchard”, Coquillet first tried a strong solution of whale-soap, but it was so strong that while it appeared to remove the scale, all the trees used in the experiment were defoliated.[80] Although the scales appeared to be wiped out, the treated trees were soon infested again. During September of 1886, Coquillet performed 163 experiments with soaps, sprays, and fumigants, including caustic soda, caustic potash, chloride of lime, chloroform, muriatic acid, methyl alcohol, whale-soap, sheep-dip, vinegar, Paris Green, and carbon disulfide. But when Coquillet and his team removed the tent after

[75] Kercheval, A F. "Letters to the Times: Are the Bugs Sick?" *Los Angeles Times*, October 4 1888.

[76] Coquillet, "USDA Report," 1887; Koebele, A. "United States Department of Agriculture Report for 1886." 558-69. Washington, DC: USDA, 1887.

[77] For example: Dimmock, G. "The Effect of a Few Common Gases on Arthropods." *Psyche: A Journal of Entomology* 2, no. 35-36 (1877): 19-22.

[78] McWilliams*, Factories in the Field*, 1935. Moses, H V. "" The Orange-Grower Is Not a Farmer": G. Harold Powell, Riverside Orchardists, and the Coming of Industrial Agriculture, 1893-1930." *California History* 74, no. 1 (1995): 22-37; Stoll, S. *The Fruits of Natural Advantage: Making the Industrial Countryside in California*. Berkeley, CA: University of California Press, 1998; Henderson, G. *California and the Fictions of Capital*. Oxford, UK: Oxford University Press, 1999; Igler, D. "The Industrial Far West: Region and Nation in the Late Nineteenth Century." *The Pacific Historical Review* 69, no. 2 (2000): 159-92; Igler, David. *Industrial Cowboys: Miller & Lux and the Transformation of the Far West, 1850-1920*. Berkeley, CA: University of California Press, 2001; Walker, R. "California’s Golden Road to Riches: Natural Resources and Regional Capitalism, 1848–1940." *Annals of the Association of American Geographers* 91, no. 1 (2001): 167-99; Walker, R. *The Conquest of Bread: 150 Years of Agribusiness in California*. The New Press, 2004; Sackman, *Orange Empire*, 2005.

[79] PRP. "The Gas Treatment for Scales." *Pacific Rural Press*, July 30, 1887, 85; Coquillet, “Insect Killing,” 1888; Coquillet, “Report on Gas Treatment,” 1888.

[80] Hilgard, E. "Science in the Orchard." *Riverside Daily Press*, April 16, 1895.

the hydrogen cyanide experiment, they witnessed the selective annihilation that would become the biochemical future of industrial pest control.[81] For the first time in the Wolfskill groves the chemical "mode of warfare" was "extended to trees and plants growing in the open air"[82] (Coquillet 1888c). The machine in the garden now had offensive capabilities.

By combining water and potassium cyanide with sulfuric acid, the team liberated a buoyant, pungent, and lethal gas amongst the branches, leaves, and orange fruits. Under the portable gas chamber of oiled canvas, the hydrogen cyanide front advanced, "permeat[ing] the entire space between branches and leaves of a tree," chemically seeking out the scale.[83] As the cyanide swirled around the interstitial spaces between the branches, leaves, and fruit, some of it found the innermost biology of the scale insects, where it bound irreversibly to the metal cofactors buried deep inside *Icerya purchasi's* cytochrome oxidase, internally suffocating them. Among intensively managed monocultural citrus trees on the western floodplain of the Los Angeles River, Coquillet, Wolfskill, and Craw created the first effective and economically efficient gas chamber.

Immediately recognizing cyanide's potential, they set out to remedy its only flaw, foliage injury. They found that by removing the water from the reaction, a pure stream of hydrogen cyanide could be produced, killing the scale "without even injuring a blossom."[84] After a bit of practice with the dry technique of cyanide gas fumigation, the team of Coquillet, Wolfskill, and Craw could kill black scale (*Lecanium oleae*), red scale (*Aspidiotus aurantii*), San Jose Scale (*Aspidiotus perniciosus*) and their eggs in 10 minutes, and cotton cushiony scale (*Icerya purchasi*) and its eggs in 30 minutes. Upon the realization that hydrocyanic acid was an effective economic poison, Wolfskill and Craw rapidly developed an apparatus for faster deployment of tents on tall trees (see Figure 5).

[81] Coquillet, "Insect Killing," 1888; Coquillet, "Report on Gas Treatment," 1888. Without knowing it, growers and scientists turned citrus' alternative oxidase biochemical pathway, and scale insects lack thereof, into an agroindustrial exaptation. As streams of hydrogen cyanide gas evolved, the evolutionary characteristic developed over hundreds of millions of years that allows many plants to physiologically resist cyanide meant that plants would emerge from fumigation relatively unscathed while the insects succumbed. Over the next few years, growers unconsciously coopted an evolutionary characteristic of the citrus tree by industrially mimicking the tactical strategies of many higher plants, in turn, recasting the citrus AOX pathway with a capitalist hue and introducing biochemical selectivity as an active participant in the development of the industrial citrus empire. Solomos, T. "Cyanide-Resistant Respiration in Higher Plants." *Annual Review of Plant Physiology* 28, no. 1 (1977): 279-97; Gould, S, and E S Vrba. "Exaptation: A Missing Term in the Science of Form." *Paleobiology* 8, no. 1 (1982): 4-15; Way, J. "Cyanide Intoxication and Its Mechanism of Antagonism." *Annual Review of Pharmacology and Toxicology* 24, no. 1 (1984): 451-81; Siedow, J N, and D A Berthold. "The Alternative Oxidase: A Cyanide-Resistant Respiratory Pathway in Higher Plants." *Physiologia Plantarum* 66, no. 3 (1986): 569-73; Siedow, J N, and D A Berthold. "The Alternative Oxidase: A Cyanide-Resistant Respiratory Pathway in Higher Plants." *Physiologia Plantarum* 66, no. 3 (1986): 569-73; Poulton, J E. "Cyanogenesis in Plants." *Plant Physiology* 94, no. 2 (1990): 401-05; Harborne, J B. *Introduction to Ecological Biochemistry*. New York: Academic Press Limited, 1993; Zagrobelny, M, S Bak, A Rasmussen, B Jørgensen, C Naumann, and B Lindberg Møller. "Cyanogenic Glucosides and Plant–Insect Interactions." *Phytochemistry* 65, no. 3 (2004): 293-306.

[82] Coquillet, D W. "Report on the Gas Treatment for Scale Insects." In *Agriculture Yearbook for 1887*, 123-42. Washington, DC: USDA, 1888.

[83] Coquillet, "Insect Killing," 1888.

[84] Coquillet, "Insect Killing," 1888.

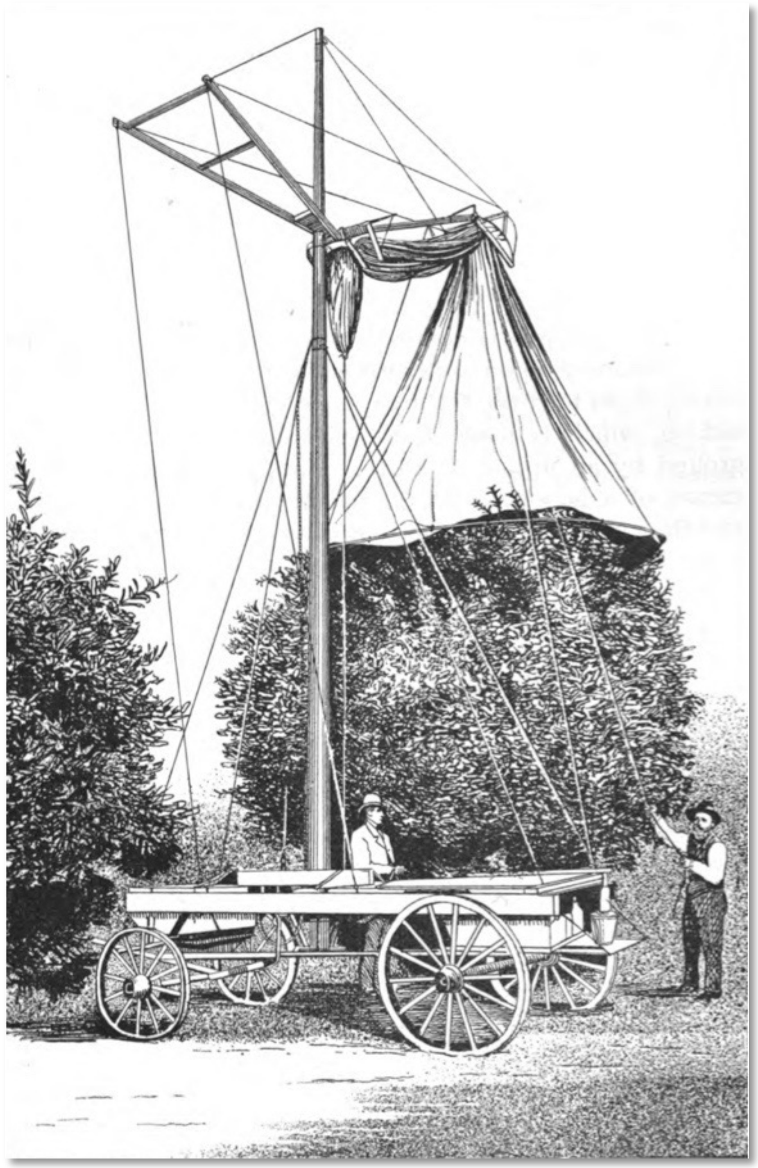

Figure 5 - The Wolkskill Fumigator[85]

Coquillet did not immediately publish his findings, which was partly due to the fact that, in late fall of 1886, after only a year of work, he was dropped from the USDA payroll due to funding problems. Coquillet's first publication came following his reinstatement with the USDA in July of 1887.[86] However, even without publication, rumors began to spread of Coquillet's success with the gas method.[87]

[85] Wallace. *Farming Industries of the Cape Colony*. Johannesburg, South Africa: J. C. Juta and Co., 1896.
[86] Coquillet, "Insect Killing," 1888.
[87] Coquillet, "Origin of Gas Treatment," 1891;Woodworth, C W, and M B Messenger. "Introductory Lecture: School of Fumigation." Paper presented at the School of Fumigation: Conducted by C. W. Woodworth, University of California, Pomona, CA, 1915.

With no official reports published, A.B. Chapman and L.H. Titus, two prominent San Gabriel growers who were desperately in need of a scale pest solution, became impatient at the appearance of slow progress. Impatience turned to imposition and they appealed to Eugene Hilgard, head of the UC Agricultural Experiment Station to send them a chemist, whose salary and expenses they would provide. In April of 1887, Hilgard sent the UC chemist F. W. Morse to San Gabriel to investigate and determine the efficacy of certain gases as economic poisons for control of citrus pests.[88]

By the end of April, Morse had also discovered the cyanide fumigation method in the San Gabriel groves of one of J. W. Wolfskill's main rivals.[89] A witness at one of these trials said that it was the "best killing" they had ever seen.[90] In June of 1887, one month before Coquillet, Morse published his findings.[91] Morse followed his first publication with an attempt to patent the cyanide fumigation process, but many fruit growers as well as C. V. Riley, head of the USDA Division of Entomology opposed this. Morse never filed the patent.[92]

In spring of 1888, Coquillet observed that hydrocyanic acid treatment was coming into general use. Patents had been filed for fumigators and others began using fumigators of their own devising.[93] In a few short years, the cyanide fumigation process had been brought to such a perfection "that the application of the gas is safe, sure, and easy. The only drawback is the cost of the gas."[94] It wasn't just the cost of the gas, however, that limited fumigation's spread.

Impure potassium cyanide was also causing tree injury, some serious enough to question whether fumigation had any benefits. In 1886, potassium cyanide, while not a new chemical, was not an industrially made chemical. Still derived from charcoal and slaughterhouse wastes and still made from the alchemical methods of Diesbach and Dippel, the composition of potassium cyanide in mid 1880s was at best was 60% pure KCN, and this was after purification. "Mining cyanide," which was first the first cyanide used by Coquillet and Morse, was only about 30% pure KCN. During separate experiments in 1887, among rival grower's trees, Coquillet and Morse introduced various gases, such as carbon dioxide, into the tents along with the potassium cyanide and sulfuric acid to see if they would help prevent foliage damage.[95] These protective measures all failed, but from their failure and the

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[88] Morse, F W. "The Uses of Gases against Scale Insects." *California Agricultural Experiment Station Bulletin* 71 (1887); Morse, F W. "Use of Hydrocyanic Acid against Scale Insects." *California Agricultural Experiment Station Bulletin* 73 (1887); Morse, F W. "The Use of Gases against Scale Insects." *Pacific Rural Press*, June 18, 1887; PRP. "Gas Treatment," 1887.

[89] Morse, "Use of Hydrocyanic Acid," 1887; Morse, F W. "Entomological: Comments by Mr. Morse." *Pacific Rural Press*, September 5, 1891.

[90] Chapman, A C. "Letter to the Editor." *Pacific Rural Press*, June 18, 1887, 539.

[91] Morse, "Use of Hydrocyanic Acid," 1887.

[92] Essig, *History of Entomology*, 1931.

[93] Culver, J P. "Tree Cover and Fumigator." *United States Patent Office*. USA: Patent No. 367,134, 1887.

[94] PRP. "Entomological: More Foes of Icerya." *Pacific Rural Press*, December 29, 1888.

[95] Morse, "Use of Gases," 1887; Morse, F W. "Doses of Acids of Different Strengths." *Pacific Rural Press*, September 3, 1887; Morse, F W. "Scale Insects. The Use of Hydrocyanic Acid to Exterminate Them." *Sacramento Daily Union*, September 3, 1887.

results from a chemical assay of the brands of potassium cyanide available in Los Angeles, both Coquillet and Morse concluded that the problem of foliage damage came from impurities in the cyanide. Protectant gases were unnecessary, only better quality cyanide was needed.[96]

As cyanide fumigation shifted from scientific experiment to bonafide grower practice, three Los Angeles growers tried to profit from its spread by patenting the fumigation of citrus trees at night. In the fall of 1889, under the consultation of Coquillet, who was still an agent of the USDA, amongst a grove of Valencia orange trees in the city of Orange, fumigation moved from a daytime activity to the graveyard shift. Growers, especially in Orange County, had noticed that every fumigation technique they tried produced poor results. (Unbeknownst to them, the humidity levels of the coastal valleys of Southern California created complications for potassium cyanide fumigation). But, W. Wall and A.D. Bishop found that with dark tents they could achieve a sufficient level of commercial control. These painted, oiled, denim tents were cumbersome and much more expensive than the oiled duck tents that other fumigators were using. "Then came the woman on the scene," C.W. Woodworth later recalled, "and Mrs. Bishop asked why, instead of going to the expense of making opaque tents, they did their work at night."[97] The practice of nighttime fumigation was born.

Less than two months later, on December 10th 1889, Ball, Bishop, and Jones filed for a patent for the night process of citrus fumigation.[98] Though their patent was granted on January 27, 1891, no grower, county official, or government scientist paid any heed to it. By the end of the 1891 fumigation season, daytime fumigators had metamorphed into nocturnal executioners, their deeds now hidden in the darkest shadows of the citrus scented killing fields.

Chemical control was not the only solution that growers sought. In 1888, after persistent grower appeal, C. V. Riley sent A. Koeble to Australia to look for parasites of the white cotton cushiony scale.[99] Koeble, a naturalized German immigrant and an "enthusiastic and comical bug hunter," was a USDA scientist first sent by Riley to Alameda, CA, in 1885 to investigate the life histories of California's insects.[100]

Two important discoveries came from Koeble's first trip to Australia, and these arrived as several packages from December to February of 1888-89. In December of 1888, Coquillet received Koeble's first shipment of the fly *Cryptochaetum iceruae,* a parasite of the

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[96] DAC. "Horticulture. The Fumigation of Trees without the Use of Carbonate of Soda." *Daily Alta California*, December 9, 1887; Coquillet, "Another Foe,"1890; Coquillet, Origin of Gas Treatment, 1891.

[97] Woodworth and Messenger, "School of Fumigation," 1915.

[98] Wall, W B, M S Jones, and A D Bishop. "Process of Fumigating Trees and Other Plants." *Patent #445,342*, United States Patent Office. USA, 1891; LAH. "Patent Twilight: The Orange Tree Fumigator Patent to Be Bought." *Los Angeles Herald*, May 30, 1891.

[99] Riley. "Importation of Icerya Enemies from Australia." *Pacific Rural Press*, December 21, 1889; Doutt, R L. "Vice, Virtue, and Vedalia." *Bulletin of the Entomological Society of America* 4, no. 4 (1958): 119-23.

[100] DAC. "Chasing a Beetle: Our Foreign Relations with the Icerya Purchasi, an Enthusiastic Entomologist, Surprising Adventures of One of Our State Department Diplomats in Search of a Bug." *Daily Alta California*, April 30, 1890.

white cotton cushiony scale, discovered a few years earlier in a garden in Adelaide, Southern Australia.[101] Coquillet released this parasite under a tented orange tree in Wolfskill's Los Angeles groves. The following month, after receiving another package, and again in the Wolfskill grove, Coquillet released the Vedalia beetle (*Rodolia cardinalis*) under another tented orange tree that was thickly covered with white scale. The discovery of the Vedalia beetle was pure coincidence and came from Koeble's perceptive eye. Sent to Adaleide to find a parasitic fly, Koeble found the now familiar beetle "feeding upon a large female Icerya" in a garden in Northern Adelaide.[102]

By the end of 1889, the "blessed bugs," the 129 beetles sent in 4 shipments, had multiplied into the tens of millions by swarming from one infested orchard to another to feed their voracious appetite.[103] The effectiveness that the dipterus parasite and the Vedalia beetle had in controlling cotton cushiony scale still stands as the one the hallmarks of biocontrol success in California.[104] However, both the beetle, with its voracious appetite, and the parasitic fly, with its insidious work ethic, could not check the prolific creeping curse of red, brown, black, and purple scale that, by 1890, had launched a sinister counter attack.

With the discovery of cyanide fumigation, a suite of private fumigation companies quickly formed. Some tried to develop and sell new fumigating machines for practical use, some to organize outfits to fumigate groves, and others to provide the necessary chemical inputs and fumigation supplies. Fumigation equipment was very expensive and out of the reach of most growers, making fumigation prohibitably expensive. But by using fumigation outfits, growers were only liable for the cost of chemicals and the labor of the outfit, and not the large upfront capital outlay needed to buy fumigation equipment. Designs for fumigators and tent enclosures varied widely, but by 1890, most fumigation outfits had settled on generation of hydrocyanic gas using the dry pot method (no water) and the use of oiled No. 2 Duck (linseed oil and often the juice of the prickly pear cactus) tents rigged to a cumbersome system of pulleys (see Figures 6 and 7).[105]

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[101] PRP, " More Foes of Icerya," 1888.

[102] Koebele, A. "Report of a Trip to Australia Made under Direction of the Entomologist to Investigate the Natural Enemies of the Fluted Scale." In *Division of Entomology Bulletin 21*, 1-32. Washington, DC: USDA, 1890.

[103] Carr, J C. "The Blessed Bugs." *The Pacific Rural Press*, May 18, 1889; Dobbins, J R. "Extracts from Correspondence: The Spread of the Australian Lady-Bird." *Insect Life* II (1889): 112.

[104] Caltagirone, L E, and R L Doutt. "The History of the Vedalia Beetle Importation to California and Its Impact on the Development of Biological Control." *Annual Review of Entomology* 34 (1989): 1-16; Sawyer, R C. *To Make a Spotless Orange: Biological Control in California*. The Henry Wallace Series on Agriculture and Rural Life. Ames, IA: Iowa State University Press, 1996.

[105] Lelong, B M. "Improved Fumigating Apparatus." In *Annual Report*, 469-72: State Board of Horticulture of the State of California, 1890; Woodworth, C W. "Orchard Fumigation." In *Agricultural Experiment Station Bulletin 122*, 1-34. Berkeley: University of California, 1899.

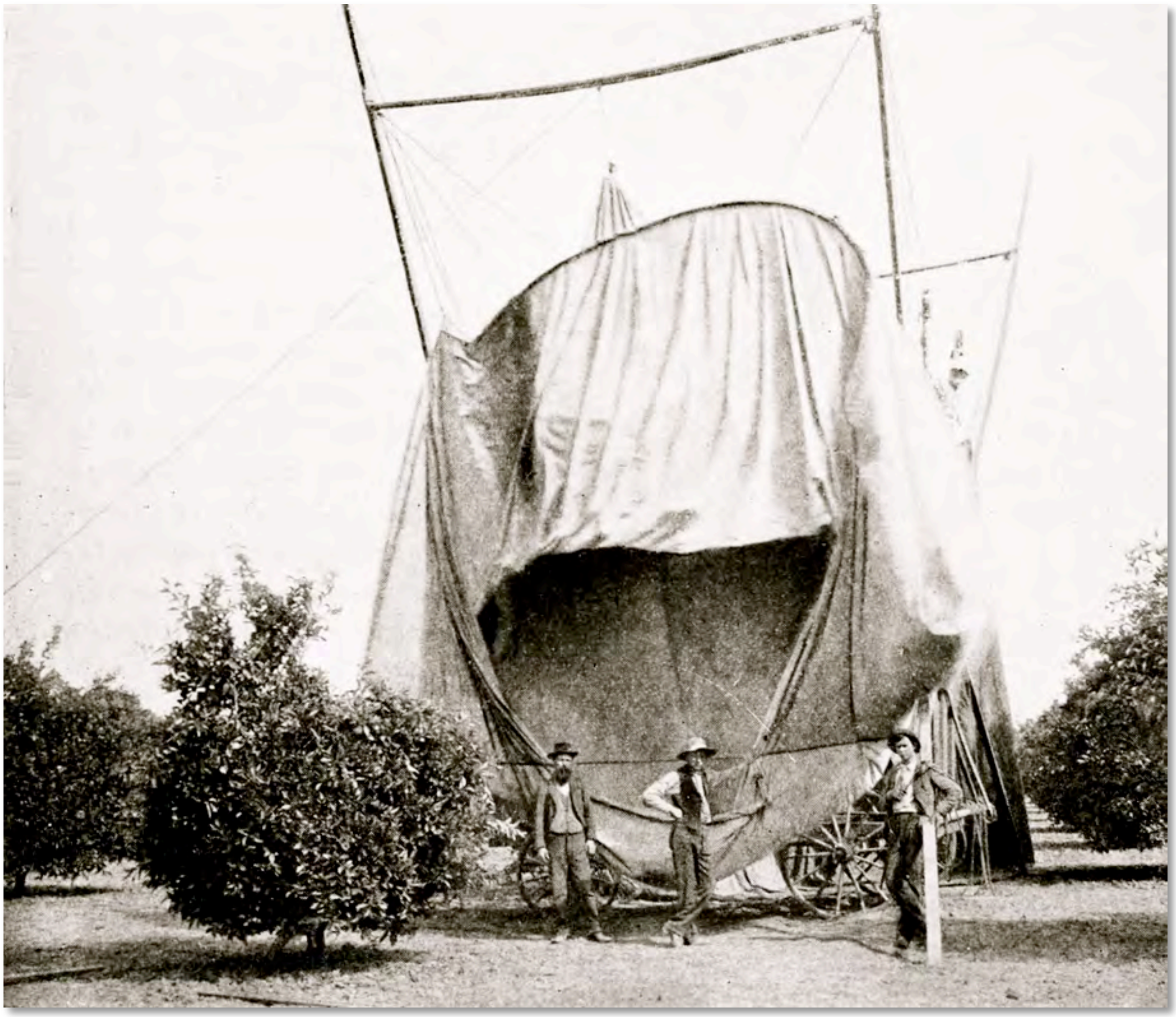

Figure 6 - Crew with fumigating derricks and tents, Chino Valley, ca. 1893.[106]

[106] Shinn, C H. "The Fruit Industry of California." *Popular Science Monthly* 44, no. December (1893): 200-17.

Figure 7 - Example of fumigation derricks and tents, ca. 1895, Courtesy of the *USC Digital Archive*[107]

For the first three years of use, citrus fumigation was commercially haphazard and driven by the desire to rid citrus trees of the white cottony masses that collected on the branches of infested groves. By 1890, most scientists and growers working to perfect citrus fumigation had turned to trying to control red scale (LAT 1889). As the Vedalia "phalanx" advanced, white scale exponentially declined, and the red scale, an immigrant from Southern China and a pest first recognized more than a decade earlier on citrus trees in Los Angeles, was taking its turn as the apex predator of the industrial citrus tree, exploding as a commercial pest across Southern California. This pattern would repeat, and still repeats to this day. With the control of one pest, others would realign their life histories to fill the abruptly vacant niches that chemical toxicity continuously brought to the industrial citrus ecosystem. Control of the red scale menace was followed by black scale outbreak, the purple scale problem, the Argentine ant invasion, the yellow scale question, the red spider threat, and

[107] Anonymous. "Fumigating Equipment, Workers and Children in a Citrus Orchard, Ca. 1892-1910." In *California Historical Society Collection, 1860-1960*, CHS-1376. Los Angeles, CA: USC Digital Archive, 1895.

then red scale again, but now resistant to hydrogen cyanide gas.[108] All of this took place before the outbreak of WWI.

Between 1887 and 1893, fumigation practice expanded from Los Angeles to all of the satellite citrus growing regions – the counties of Riverside, Orange, San Diego, Santa Barbara, and San Bernardino – and to all varieties of citrus. As it spread, the three men that had patented the nighttime fumigation process grew increasing frustrated with the fact that they had not received any royalties, nor profited in any way from the expansion of cyanide fumigation. In the late summer of 1893, Wall, Bishop, and Jones decided to test the validity of their patent by getting the police to arrest two growers who had recently fumigated (W.L. Adams and H.N. Kellum) and charge them with patent infringement. They sought to redress their lack of compensation by suing Adams and Kellum in Los Angeles circuit court, seeking license fees and any profit that resulted from using their invention.[109]

News of Adams' and Kellum's arrest spread rapidly throughout the citrus growing regions. If Wall and Jones were successful with their lawsuit, the rapid expansion of fumigation would slow, and perhaps stop in many areas. It would also open up the possibility of taking the citrus growing counties to court, seeking compensation for use of the nighttime process. Because of the high initial cost of fumigation equipment, counties would often front the cost for the equipment and then rent it out to the growers in their district at nominal cost. It was in the county's best interest to maintain groves free of infestation, and thus they made sure that as many growers had access to fumigation as wanted it.

On Tuesday, the 15th of October 1893, the District Attorney of Los Angeles County called together an emergency meeting in San Bernardino to address the fumigation situation and devise an organized approach. Present at the meeting were the DAs of all of the citrus growing regions, as well as legal advisors and some prominent growers. The legal position that emerged from discussions was that the fumigation process was public property and thus non-patentable. The District Attorney of Los Angeles took this same legal position in court, arguing that the process was general knowledge.

Then the DA pulled out the big guns and called Coquillet to the stand. Coquillet not only explained how he was the first to discover cyanide fumigation, but he also brought

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[108] Bennet, J E. "Black Scale Pest. Lively Enemy of the California Horticulturist." *Los Angeles Times*, March 1, 1896; LAT. "Hunting for Enemies of the Red Scale: Mischievous Foe of Oranges Is Hard to Combat." *Los Angeles Times*, November 23, 1902; LAT. "Purple Scale Disappearing: Speaker at Farmers' Institute Meeting Gives Encouraging Address on Tree Fumigation." *Los Angeles Times*, September 20, 1906; LAT. "After the Scale Pest: Black and Purple Varieties Especially Guarded against by County Horticulturist." *Los Angeles Times*, July 26, 1912; Chapman, C C. "The Purple Scale in Fullerton." *Claremont Pomological Club Proceedings* March 22, (1909): 4-5; Horton, J R. *Control of the Argentine Ant in Orange Groves*. Farmer's Bulletin. Vol. 928, Washington, DC: US Dept. of Agriculture, 1918; Boyce, A M. "Studies on the Resistance of Certain Insects to Hydrocyanic Acid." *Journal of Economic Entomology* 21, no. 5 (1928): 715-20; Gray and Kirkpatrick. " Resistance of Black Scale,1929; Woglum, R S. "The History of Hydrocyanic and Gas Fumigation as an Index to Progress in Economic Entomology." *Journal of Economic Entomology* 16, no. 6 (1923): 518-21; Woglum, R S. "Observations on Insects Developing Immunity to Insecticides." *Journal of Economic Entomology* 18, no. 4 (1925): 593-97; Essig, *History of Entomology*, 1933.

[109] LAT. "The Night Process. The Gas Treatment in the Courts." *Los Angeles Times*, October 20 1893.

plenty of evidence to prove that the plaintiff's lawsuit was entirely erroneous. Two items in particular were quite damming.[110] The first was that Coquillet had the paperwork to prove that Bishop, who was listed on the patent but not on the lawsuit, participated in some of the first fumigation experiments in the fall of 1886 at the Wolfskill grove. On the 26th of September, 1886, Bishop was part of the fumigation team when Coquillet, Wolfskill, and Craw fumigated seven lemon trees at night to much success.

On April 9, 1894, Judge E.M. Ross of the Federal Court of Southern California invalidated the patent on the night process. The basis for his decision was twofold: 1) doing something at night does not make it novel and 2) the original discovery was made by the USDA and the Patent Office's interpretation of the Hatch Act provisions made sure the discoveries of the USDA and the state agricultural experiment stations remained public property.[111]

Between 1895 and the early 1900s, millions of citrus trees across Southern California were in production, millions more reached commercial age, and millions of others were just planted. Every tree planted was another tree to be infested; scale infestation became the multicolored silhouette draped on the contours of citrus expansion. Every year that the industrial citrus ecosystem matured, every year that it spread across Southern California's valleys, the infection became more systemic, and the demand for fumigation grew with it. By the late 1890s, county fumigation outfits of the early 1890s gave way to outfits organized by cooperative associations. This change magnified the expansion of fumigation through multiple means, but the most basic reason was a decrease in the cost of fumigation per tree by tapping into the agroeconomies of scale that resulted from the formation of citrus cooperatives. By buying chemical inputs in large lots, especially potassium cyanide, the unit price of cyanide fumigation per tree rapidly fell. And by coordinating fumigation labor, cooperatives were able to streamline fumigation practices, fumigating more trees per person-hour. Taken together, cooperatives were often able to cut the cost of fumigation per tree in half.[112]

In 1896, the Covina association of the Southern California Fruit Exchange was the first branch to undertake the general fumigation of all its "stockholders through the cooperative plan."[113] However, recognizing the need to inaugurate a "general crusade" against red and black scale, which was causing increased commercial damage, they also offered their services to non-members in the hope of cleansing as much of the district as possible. Leaving pockets of uncleansed groves meant cooperative groves would be more easily reinfested. With its high costs and selective labor requirements, not everyone was

[110] LAT. "The Patent on the Gas Treatment Declared Void." *Pacific Rural Press*, April 28, 1894.
[111] Coquilett, D W. "The Patent on Hydrocyanic Acid Gas Process Declared Invalid." *Insect Life* VII, no. 3 (1894): 257-58; LAT, "Patent on Gas Treatment," 1894.
[112] PRP. "A County Fumigation Outfit." *Pacific Rural Press*, September 17, 1898; SFC. "Will Study Fumigation: Berkeley Man Will Spend a Month Experimenting in the South." *San Francisco Chronicle*, August 18, 1902.
[113] LAT. "Covina." *Los Angeles Times*, August 9, 1896; LAT. "Covina." *Los Angeles Times*, August 23, 1896.

convinced of fumigation's promise and many growers turned to sprays as their weapon of choice in the assault against scale in their groves.

In the first two decades of chemical control in California there were no state or federal statues regulating anything about economic poisons – production, composition, use, waste – which meant there were as many brands of citrus treatments for sale as there were brands of citrus. These concoctions contained plants extracts, coal-tar extracts, soaps, acids, caustic sodas, and arsenicals, but the only group of possible poisons that showed any promise were the various distillate fractions of crude oil that were available in increasing amounts from Southern California refineries as byproducts of kerosene and gasoline production.[114] These crude distillates were emulsified in water with soap, glue, blood, or another binder, and sprayed under pressure onto trees, in the hope that they would coat the tree with a deadly film.[115] Reflecting the state of crude oil refining at the time, these sprays, while physically similar, often differed in chemical composition from batch to batch.[116] This meant that repeated spraying with the same brand could bring widely varying results, including damaging groves to the point of killing all the trees. Other growers tried resin washes and arsenic based sprays, which although much cheaper than fumigation, did not provide the disinfection power needed and damaged foliage and fruit. Responding to a promoter of distillate spays, one fumigation operator quipped that the "answer to all this is seen in the endless array of fumigation tents now in operation in the orchards of Southern California." These tents "make no mistake in summing up the impotency of all other methods."[117]

What began to convince growers of the value of clean orchards, more than the site of tents extending to the horizon, was the higher price that growers received for their fumigated fruit. No one wanted to have to fumigate, "few citrus growers look[ed] with favor upon any tree wash or spray."[118] Economic poisons were not only highly toxic; they were also very expensive and labor intensive to apply. However, after 1886, as the final destination of Southern California's citrus moved east progressive growers began to rethink the way they envisioned loss from pests. Wholesale sellers began looking for citrus with the best carrying quality, that is, citrus that would arrive unspoiled, in prime eating condition, a week or more later in cities across the Midwest and East Coast (see Figure 8).

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[114] Woodworth, CW. "The Insecticide Industries in California." *Journal of Economic Entomology* 5, no. 4 (1912): 358-64; Gray, G P. "The Workings of the California Insecticide Law." *The Journal of Industrial and Engineering Chemistry* 6, no. 7 (1914): 590-94; Gray, George P. "The Consumption and Cost of Economic Poisons in California in 1916." *Industrial & Engineering Chemistry* 10, no. 4 (1918): 301-02; Gray, G P. "Economic Toxicology." *Science* 48, no. 12 (1918): 329-32.

[115] Cooper, E. "Insects and Insecticides." *Pamphlet*, 1-23. Sacramento, CA: California State Commission of Horticulture, 1905.

[116] Vickery, R K. "Petroleum Insecticides." *Journal of Economic Entomology* 13, no. 6 (1920): 444-47; Gray, G P, and E R de Ong. "California Petroleum Insecticides." *Industrial & Engineering Chemistry* 18, no. 2 (1926): 175-80; de Ong, E. "Specifications for Petroleum Oils to Be Used on Plants." *Journal of Economic Entomology* 21, no. 5 (1928): 697-702; Essig, "History of Entomology,"1931; Ellis, C. *The Chemistry of Petroleum Derivatives*. Vol. 1, New York: The Chemical Catalog Company Inc., 1934; Williamson, H F, R L Andreano, A R Daum, and G C Klose. *The American Petroleum Industry: The Age of Energy 1899-1959*. Evanston, IL: Northwestern University Press, 1963.

[117] LAT. "The Land: Orchard, Farm, Garden, Rancho, and Stockyard." *Los Angeles Times*, October 5, 1900.

[118] Jeffreys, J W. "The Land: Orchard, Farm, Garden, Rancho and Stockyard." *Los Angeles Times*, August 17, 1900.

Figure 8 - Packinghouse of the Covina Citrus Association ca. 1900, Covina, CA, Courtesy of the *USC Digital Archive*[119]

Throughout the 1890s, oranges from groves where fumigation wasn't practiced often had to be washed to make them sellable to eastern markets. The honeydew excrement of scale insects that rained down from the encrusted branches above led to "black smut," a sooty mold, on the fruit. Consumers could be picky and any blemishes on the skin of the fruit would ruin the consumer's increasingly constructed conception of the orange as a condensed nugget of California's healing sunshine.

Since eastern buyers did not want fruit with black smut, cooperatives and their branches organized washing houses as end-of-pipe solutions to dirty fruit. The presence of smut and the rudimentary practices and technology of early washing houses (which spread decay causing organisms), would decrease the carrying quality of citrus by inducing the rapid onset of decay.[120] This fruit had to be sold and shipped east immediately.[121] Sellers had to

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[119] Anonymous. "Men and Women Working inside of an Orange Packing House, Probably Covina, California, Ca.1900." In *California Historical Society Collection, 1860-1960*, CHS-1348. Los Angeles, CA: USC Digital Archive, 1900.

[120] Powell, G H. "Causes of Fruit Decay." *Riverside Daily Press*, April 7, 1905; Powell, G H. "The Decay of Oranges While in

take the first offer; they could not wait for another. When fumigation was done effectively, the fruit harvested on the cleaned trees usually did not have to be scrubbed and was of prime quality for shipping east. Now blessed with first-rate produce not prone to decay, wholesalers had the upper hand; they could sit on the boxes until their price was met. By the turn of the century, as scale pests became generalized throughout Southern California, the difference between a carload of prime shipping citrus and one that lacked any carrying quality was the difference between fumigated and non-fumigated fruit.[122]

A Popular Science Monthly writer summed up the new agricultural market conditions best. "How goes the fight?" he asked rhetorically. "The statistics of the fruit industry answer this question. The cost of destroying insect pests has become a permanent item of expense, the results of which are increased profits. Care and management of orchards now include preparation of the soil; selection of varieties adapted to the place; planting and culture of the trees; pruning, according to different systems for different species and localities; the use of special fertilizers, and the destruction of noxious insect life."[123] As citrus markets moved east, industrial pest control, "active warfare," became a necessary industrial input.[124]

As growers converted more and more sunshine, water and capital into more and more citrus fruit for Eastern markets, more and more cyanide was needed to cleanse the

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Transit from California." In *Bulletin* 1-79. Washington DC: USDA Bureau of Plant Industry, 1908.

[121] Coit, *Citrus Fruits*, 1915.

[122] Jeffreys, "Land, Orchard, Farm," 1900. Webber and Batchelor, *Citrus Industry*, 1943; Reuther, W, E C Calavan, and G E Carman, eds. *The Citrus Industry, Volume V*. Oakland, CA: UC Agriculture and Natural Resources 1989.

[123] Shinn, "Fruit Industry," 1893.

[124] By this time cyanide fumigation had also become a common industry practice of west coast nurseries and quarantine operations. In 1894, L.O. Howard, recently appointed Chief of the USDA Bureau of Entomology, introduced cyanide fumigation to East Coast nurserymen in a USDA Circular and by 1896 it was in limited but general use in the nursery trade across the US. By 1900, there was network of specialized buildings across the US constructed for the sole purpose of fumigating nursery stock, creating a nodal and agglomerative geography of agroindustrial gas chambers. Cyanide fumigation was also introduced to other commercial orange growing regions in the 1890s. For example, C. V. Riley, former Chief of the Bureau of Entomology introduced it to Montserrat, British West Indies in 1894 and word of its success reached Capetown, South Africa, about the same time. Although UC Agriculture Extension and the USDA would eventually help the practice spread to citrus growing regions around the world, early extension of the practice into other citrus growing regions was met with commercial failure, likely due in part to the lack of intensive and economically efficient (cooperative) organizational structure of Southern California's industry and the lack of government subsidy that first brought cyanide fumigation within reach of the average grower. R. S. Woglum of the USDA introduced Florida citrus to California's fumigation techniques in 1905. Howard, L O. "An Important Enemy to Fruit Trees. The San Jose Scale (*Aspidiotus pernidosus*): Its Appearance in The Eastern United States; Measures to Be Taken to Prevent Its Spread and Destroy It." *Circular 3, Second Series*. Washington, DC: USDA Division of Entomology, 1894; Howard, L O, and C L Marlatt. "The San José Scale: Its Occurrence in the United States with a Full Account of Its Life History and the Remedies to Be Used against It." *Bulletin 3, New Series*. Washington, DC: USDA Division of Entomology, 1896; Howard, L O. "Progress in Economic Entomology in the United States." In *Yearbook of Department of Agriculture for 1899*. Washington, DC: USDA, 1899; Pugsley, C. "Gas Treatment for Scale Insects: Treating of the Operations of the Horticultural's Board Fumigating Outfit, the Applicability of the Fumigation Process in Cape Colony, and Embodying a Full Description of the Equipment Necessary for Fumigation with Hydrocyanic Acid Gas." 45. Cape Town: Horticultural Board of the Cape Colony, 1897; Quayle. "Correspondence between H. J. Quayle and the University of California Agricultural Departments as Well as Horticultural and Entomological Agencies Throughout the World 1908-1914." In *Henry J. Quayle Papers*: UC Riverside Special Collections, 1910; Tyrrell, Ian R. *True Gardens of the Gods: Californian-Australian Environmental Reform, 1860-1930*. Berkeley, CA: University of California Press, 1999; Essig, *History of Entomology*, 1931.

industrial citrus tree of its insect enemies. From box to wagon to train load, with each harvest season that passed, the agricultural demand for potassium cyanide grew.[125] However, synthetic cyanide didn't arrive in Southern California as a pesticide.

It was cyanide's ability to separate gold from ore, eventually perfected by the MacArthur and the Forest Brothers in Scotland in 1887 that brought large quantities of cyanide to the mineral rich west.[126] With cyanide, miners could unlock the refractory gold bearing quartz ores that remained once the thin layer of placer gold was scraped off in the mad dash gold rushes of the 1850s, 1860s, and early 1870s.[127] The subsequent boom in industrial cyanide production in Scotland, Germany, and New Jersey to meet the mining demand in Southern Africa, Australia, and the US, was critical in making potassium cyanide available – geographically, economically, compositionally – for a rapidly industrializing citrus industry.[128]

With the introduction of synthetic chemicals into mining, the potential of California's mining landscapes was recast with the pungent hue of potassium cyanide. Suddenly ores once considered low-quality or waste became profitably exploitable resources.[129] In the late 1880s, miners armed with industrial cyanide, made from the blood of Europe's abattoirs, ventured deep underground into pyritic and sulphureted quartzes, in turn not only shifting the geography of gold mining across the world, but also revolutionizing the industrial art of winning gold from the earth (See Figure 9).[130]

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[125] SFC. "Issues Bulletin on Fumigation: Professor Woodworth Settles Several Important Questions for the Orchardists." *San Francisco Chronicle*, July 24, 1903; Woodworth, "Insecticide Industries," Woglum, "Hydrocyanic and Gas Treatment," 1923.

[126] Scheidel, E M. "The Cyanide Process: Its Practical Application and Economical Results." In *California State Mining Bureau Bulletin*, edited by J J Crawford, 1894; MacArthur, J S. "Gold Extraction by Cyanide: A Retrospective." *Journal of the Society of Chemical Industry* XXIV, no. 7 (1905): 311-15.

[127] NYT. "The Gold Output." *New York Times*, March 9, 1896; Economist. "The World's Production of Gold." *The Economist*, November 11, 1911.

[128] YAM. "Financial Records 2297-2299." In *Yellow Aster Mining and Milling Company Records, 1898-1918*. Sacramento, CA: California State Library, 1900; Braun, F W. "The Manufacture of Sodium Cyanide." Paper presented at the School of Fumigation: Conducted by C. W. Woodworth, University of California, Pomona, CA, 1915; Wolf, M. *It All Began in Frankfurt: Landmarks in the History of Degussa Ag*. Frankfurt am Maim: Degussa AG, 1985; Loughheed, A L. "The Anatomy of an International Cyanide Cartel: Cyanide, 1897-1927." *Prometheus* 19, no. 1 (2001): 1-10.

[129] Young, T G, and W Smith. "The Cyanide Process for the Extraction Of Gold from Low-Grade Gold Ores." *Journal of the Society of the Chemical Industry* 10 (1891): 93-98; Preston, E B. "California Gold Mill Practices." *Bulletin No. 6*, 115. Sacramento: California State Mining Bureau, 1895; Packard, G A. "The Cyanide Process in the United States." *Transactions of the American Institute of Mining Engineers* XXVI (1897): 709-21; LAT. "San Bernardino County." *Los Angeles Times*, January 1, 1899. Economist, "World's Gold." 1911.

[130] Munroe, C E. "Precious Metals Recovered by Cyanide Processes." In *Special Reports: Mines and Quarries 1902*, 593-603: US Department of Commerce and Labor, Bureau of the Census, 1905; Mudder, T, and M Botz. "Cyanide and Society: A Critical Review." *European Journal of Mineral Processing and Environmental Protection* 4, no. 1 (2004): 62-74.

Figure 9 - Cyanide tanks, Karma Mining Company, Mojave mining district, Kern County, ca. 1900.
Courtesy of the USC Digital Archive[131]

In California the geography of gold mining shifted south and the desert mines of Southern California began to complete with the once glorious mother lode for the title of biggest gold producing region[132] This shift to industrial chemical extraction across the world brought with it demand for industrially made chemicals and new industries arose to produce and provide these chemicals to the mining industry.[133]

The resurgence of California mining in late 1880s and early 1890s and the influx of potassium cyanide into Southern California for mining coincided with an uncontrollable pest

[131] Anonymous. "View of Cyanide Tanks at a Mining Operation in the Mojave Desert. Ca. 1900." In *California Historical Society Collection, 1860-1960,* CHS-5101. Los Angeles, CA: USC Digital Archive, 1900.

[132] LAT. "Industrial Mining & Citrus Exhibit." *Los Angeles Times*, March 3, 1900; Dittmar, M E. "Southern California." In *California Mines and Minerals*, edited by E H Benjamin, 395-405. San Francisco: California Miner's Association, 1899; Dunbar, A R. *Western Mining Directory Embracing the Principal Operating Mines, Stamp Mills, Smelters, Dredges, Cyanide and Chlorination Plant in Arizona, California, Colorado, Idaho, Montana, Wyoming, British Columbia and Mexico*. Denver, CO: Western Mining Directory Company, 1902.

[133] Robine et al., *The Cyanide Industry*, 1906; Wolf, *It All Began in Frankfurt*, 1985; Loughheed, "International Cyanide Cartel," 2001.

outbreak among the commercial citrus groves of Los Angeles.[134] Thus, as industrial mining moved on from its mechanical birth, amalgamating itself to the chemicalized nature of the second industrial revolution, it helped agriculture make the leap as well by providing the toxic material that allowed for the intensification of citrus production in the face of pest outbreak. In the late 1880s, only a few years removed from the antagonistic relationship of agricultural and hydraulic mining capital that raged in the courthouses of Sacramento – resulting in a ban on hydraulic mining in the Sierra foothills – a chemo-economic synergism fulminated between the desert mines of Southern California and the groves of the Los Angeles Basin.[135] Mining and citrus, two industries faced with crisis – one geological, one ecological – both subsumed cyanide's materiality into an industrial logic, whereby cyanidation became the chemical practice around which the two industries developed. In other words, in the late 1880s, industrial cyanide became the critical material – the chemical fix – that allowed for the intensification of both gold mining and citrus.

Chemical companies, however, would not consider agricultural use a serious commercial outlet until after the turn of the century. Thus, it was mining that brought potassium cyanide to the chemical markets of Southern California. It was demand from the global mining industry that spurred competition among cyanide manufactures, leading to increased purity and lower prices.[136] It was only with the general shift to hard rock mining in the late 1880s and early 1890s that Southern California's uniformly-beautiful-sun-kissed-citrus became possible.

The first potassium cyanide (KCN) used in the mines and groves of Southern California was made in small batches in crude laboratories across Europe, making its way in small amounts to cities like New York and San Francisco via the German company DEGUSSA, the sales agent for most of the cyanide produced in the world before the discovery of its use for mining.[137] This cyanide would then be distributed and sold through various middlemen, chemical wholesalers, and pharmacists across the United States. Before 1887, emergent electroplating and photography industries consumed most of the crude cyanide imported into the US.[138]

Following the discovery of the MacArthur-Forest process, the global cyanide industry rapidly reconfigured to meet the explosive demand for potassium cyanide by mining. By the mid-1890s, almost all the potassium cyanide industrially consumed in the US was made in New Jersey. At their plant in Perth Amboy, the Roesslacher & Hasslacher Chemical Company (R&H), a partial subsidiary of DEGUSSA, manufactured 98% pure potassium

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[134] SFC. "California Mines." *San Francisco Chronicle*, July 28, 1895; NYT, "Gold Output," 1896; Hobart, F. "Our Mineral Wealth. The Progress of American Mining -- Its Great Extent and Promising Outlook." *New York Times*, Feb 21 1898; Wynn, M R. *Desert Bonanza: The Story of Early Randsburg, Mojave Desert Mining Camp*. Glendale, CA: The Arthur H. Clark Company, 1963.
[135] YAM, "Financial Records," 1900; Braun, "Sodium Cyanide," 1915.
[136] Robine et al., *The Cyanide Industry*, 1906; Loughheed, "International Cyanide Cartel," 2001.
[137] Wolf, *It All Began in Frankfurt*, 1985.
[138] Clennell, *The Cyanide Handbook*, 1910.

cyanide (KCN) and other chemical products for the American market.[139] And although it was not R&H cyanide that Coquillet introduced into the experimental fumigation tents in the fall of 1886, it was R&H cyanide that was pumped under tent-enclosed citrus trees millions of times over by the turn of the century. It was R&H cyanide that made its way by the ton to the deserts east of Los Angeles, where it provided the chemical ability to unlock refractory ores, and to the valleys of Southern California, where it provided selective killing power to disinfect the industrial citrus tree.[140]

At the close of the 19th century, the cost of cyanide had fallen by half since fumigation began in 1886.[141] As the costs of fumigation plummeted, and as the demand of distant markets grew, grower-capitalists continued to unfurl the industrial citrus ecosystem upon the valleys of the promised-land. In the process cyanide fumigation crossed an agroindustrial threshold and became a critical yet ordinary input of industrial citriculture.[142] These new agricultural practices signaled a state change in world-ecology, one in which toxic chemicals became necessary for industrial agriculture. In overriding an agro-ecological contradiction of capitalist agriculture, growers, scientists, and government officials amalgamated industrially organized agriculture to an accelerating and endless war. In "service to the gods of production and production," industrial agroecology irreversibly bound itself to an endless reliance on ever-newer toxic chemicals.[143]

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[139] Robine et al., *The Cyanide Industry*, 1906; Braun, "Sodium Cyanide," 1915; Anonymous. "History of American Chemical Industries: Roessler and Hasslacher–Partners." *Industrial and Engineering Chemistry* 21, no. 10 (1929): 989-91; DuPont. "Digest, R&H Chemical Company, Subsidiaries and Affiliates." In *Absorbed Companies*, edited by Records of E.I. du Pont de Nemours: Euleutherian Mills Historical Library, Hagley Museum, 1930.

[140] Cyanide extraction tanks also contributed to the mass death of birds, fish, and insects via tank effluent disposed in water bodies or by birds and insects drinking from or landing on the tanks. Donato, D, O Nichols, H Possingham, M Moore, P Ricci, and B Noller. "A Critical Review of the Effects of Gold Cyanide-Bearing Tailings Solutions on Wildlife." *Environment International* 33, no. 7 (2007): 974-84. "Birds and insects by the millions have been killed by drinking from the cyanide tanks. At first contact they fall dead. " LAT. "Arizona News - Deadly Cyanide of Potassium." *Los Angeles Times*, December 9, 1896. "Another place [for birding in the desert], and a most deadly trap it proved judging from the dead birds floating on its surface, was the cyanide tanks… Birds that essayed to quench their thirst at this fount toppled over dead in an instant." Daggett. "Winter Observations on the Colorado Desert." *The Condor* 4, no. 2 (1902): 37-39.

[141] Woodworth, "Orchard Fumigation." 1899.

[142] Shinn, "Fruit Industry," 1893; SFC, "Will Study Fumigation," 1902.

[143] Carson, "Women's National Press Club Speech." 1999.

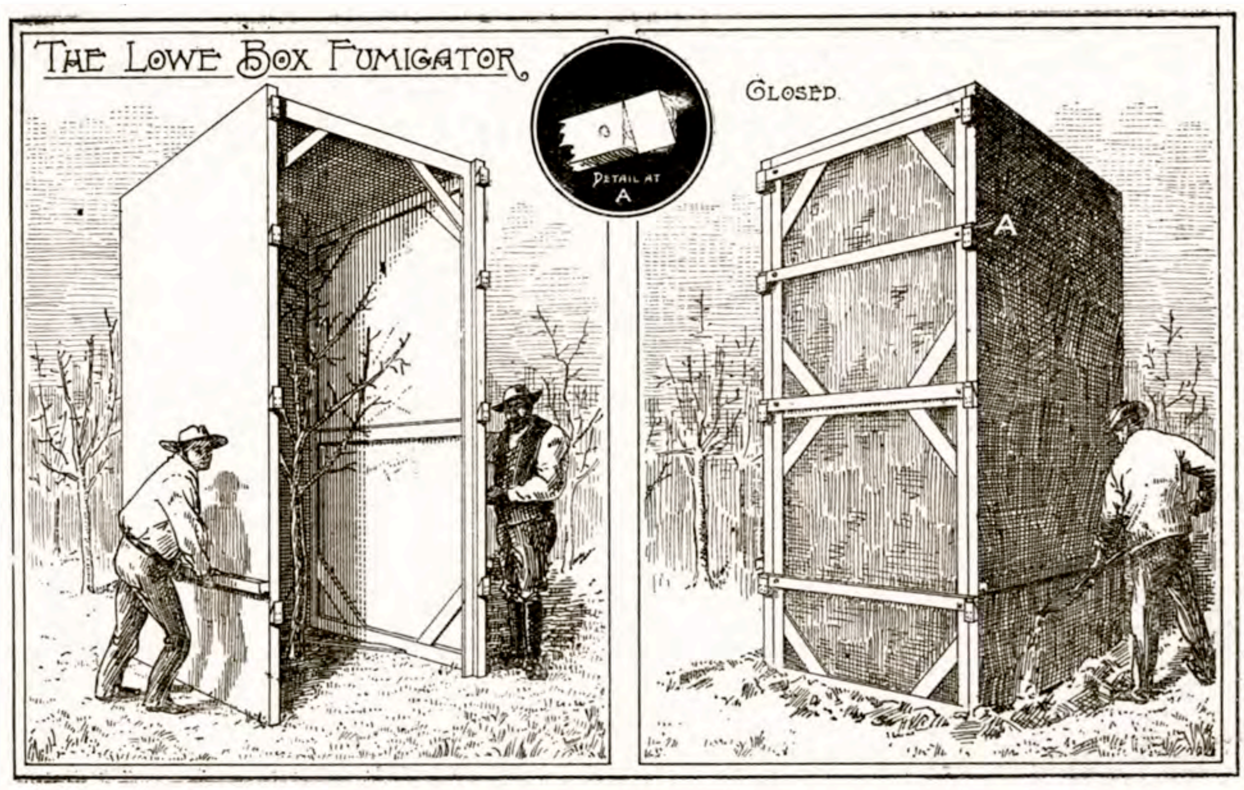

Figure 10 – A box cyanide fumigating method for deciduous fruit trees developed in Cape Town, South Africa, ca. 1900[144]

By 1900, the Faustian bargain that allowed industrial citrus to flourish in the face of ecological crisis was more than a decade removed and rapidly spreading (see Figure 10 and footnote X). A Los Angeles Times reporter, after spending a week shadowing fumigation crews, summed it up best. "Perhaps never in the history of the world" he said, "have there been so many specimens of animal life slaughtered by artificial means as are now succumbing to the cyanide process. As the shades of night fall upon the orange groves, one hundred, five hundred large sheets of canvas enshroud the trees, and when they are drawn away death has claimed every living thing within them …"[145] Industrial death, "active warfare," saved an industry from collapse and made possible the industrial production of commercial quality citrus fruit. Chemical warfare became the battlefield practice that enabled the full-fledged industrialization of citrus groves on the western shores of the capitalist world.[146]

[144] Lounsbury, C P. "Fumigation under Box Covers." 19. Cape Town: Department of Agriculture, 1902.
[145] LAT, "Orchard, Farm, Garden," 1900.
[146] Woodworth, "Orchard Fumigation," 1899; Woglum, "Hydrocyanic and Gas Treatment," 1923; Essig, "History of Entomology," 1931; Moses, "The Orange-Grower Is Not a Farmer," 1995.

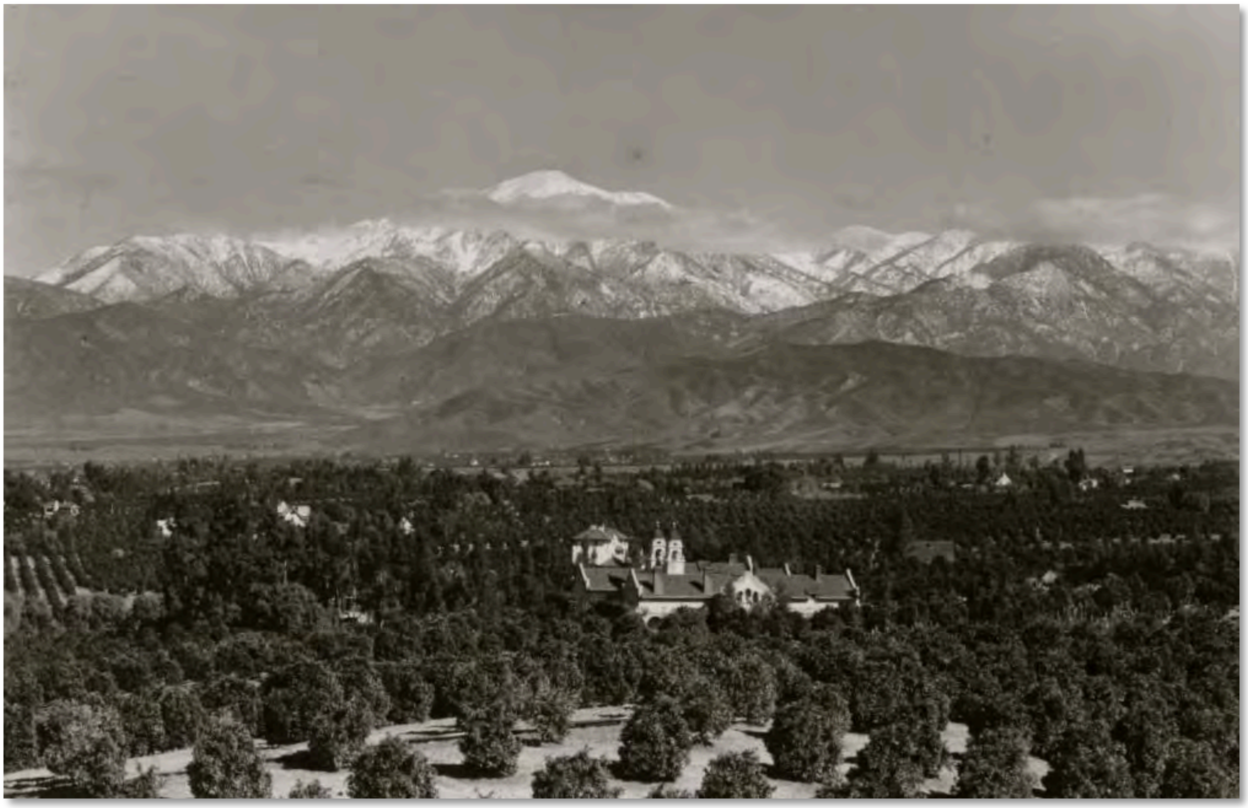

Figure 11 - Redlands in winter looking north toward the San Gabriel Mountains, ca. 1900, Courtesy of the *USC Digital Archive*[147]

The vast citrus empire that once occupied Southern California's valleys has receded from view (See Figure 11). For younger generations, only street names and city festivals reveal its past glory. After WWII, the citrus industry packed its bags and moved to the artificially greener pastures of the Central and Imperial Valleys, ceding its once dominant claim over Southern California's golden sunshine to the colonists of tract houses, strip malls, and traffic jams. Although the industrial citrus biome has given way to the concrete oasis of today, the chemicalized nature of industrial agriculture that emerged among LA's trees still confronts us every day, no matter where we live, with every bite, with every breath. We are both participants and casualties of a totalizing chemical war, forever altering humanity's life history.[148]

[147] Anonymous. "Orange Orchards During Midwinter in Redlands, Ca. 1900." In *California Historical Society Collection, 1860-1960*, edited by CHS-43108. Los Angeles, CA: USC Digital Archive, 1900.

[148] Eskenazi, B, K Huen, A Marks, K G Harley, A Bradman, D B Barr, and N Holland. "PON1 and Neurodevelopment in Children from the CHAMACOS Study Exposed to Organophosphate Pesticides in Utero." *Environmental Health Perspectives* 118, no. 12 (2010): 1775; Guthman, J. *Weighing In: Obesity, Food Justice, and the Limits of Capitalism*. Berkeley, CA: University of California Press, 2011; Vandenberg, L N, T Colborn, T B Hayes, J J Heindel, D R Jacobs Jr, D-H Lee, T Shioda*, et al.* "Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses." *Endocrine Reviews* 33, no. 3 (2012): 378-455; Friedrich, M. "Endocrine-Disrupting Chemicals." *Journal of the American Medical Association* 309, no. 15 (2013): 1578-78; Monosson, *Unnatural Selection*, 2015.

For our food and our fiber we wage endless war. But "[w]ar… like the effect of a fog or moonshine," as Carl Von Clausewitz (1832) said, "gives to things exaggerated dimensions and an unnatural appearance."[149] Thus, pesticide protagonists past and present, by appealing to our deep seeded fears of starvation and famine, exaggerate the need for toxic inputs by giving their historical use an unnatural appearance.[150] Pesticides have never been necessary for the US to produce sufficient food, as the mythology still suggests.[151] The story of cyanide fumigation, industrial agriculture's first chemical fix, and the historical record make this abundantly clear. Pesticides, however, have been critical to the production of other goods and services – goods and services critical not to the survival of the population but to the survival of a particular form of political economy.[152] All of this is not to say that there isn't a need for agriculture to manage pests but that these techniques should be "geared to realities, not to mythical situations, and the methods employed must be such that they do not destroy us along with the insects."[153] A fog of endless war has descended upon agriculture, and all life is caught in the crossfire. Not in our name.

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[149] Von Clausewitz, C. 1909 (1832). *On War*. Translated by J. J. Graham. Vol. 1. London.

[150] For example: CLA. "About crop protection." CropLife America, http://www.croplifeamerica.org/crop-protection.

[151] Mullen, R A. "Why Poison Bugs, Foes or Surpluses?" *The Washington Post*, June 25, 1933; Wallace, H A. "May." In *Extension Service Review*. Washington, DC: USDA, 1933; Cochrane, W W. "Farm Technology, Foreign Surplus Disposal and Domestic Supply Control." *Journal of Farm Economics* 41, no. 5 (1959): 885-89; Cochrane, *American Agriculture*, 1999; Cochrane, *The Curse of Agricultural Abundance*, 2003; Cochrane, W, and M E Ryan. *American Farm Policy: 1948-1973*. Minneapolis: University of Minnesota Press, 1976; Perkins, "Insects, Food, and Hunger," 1983.

[152] Romero, A. "'From Oil Well to Farm:' Industrial Waste, Shell Oil, and the Petrochemical Turn." *Agricultural History,* Forthcoming 90, no. 1. Winter (2016).

[153] Carson, *Silent Spring*, 1962. 9.

Chapter 3

Second Nature's Services:
Capital's Dependence on Industrial AgroEcosystems

"As the capitalist mode of production extends, so also does the utilization of the refuse left behind by production and consumption."

Marx, *Capital, Volume III*, ca. 1875[1]

"Good seed, plenty of high grade fertilizer, and careful cultivation are necessary to produce a crop that is worth poisoning."

Anonymous, *Wall Street Journal*, 1924[2]

Figure 1 – Application of calcium arsenate on cotton by airplane, North Carolina, November 28, 1925.[3]

[1] Marx, K. *Capital, Volume III*. New York: Penguin Books, 1981 (1893). 195.
[2] WSJ. "Increasing Use Calcium Arsenate." *Wall Street Journal*, January 28, 1924.

In 1983, environmental historian John Perkins posed a key paradox when he asked rhetorically, "If prevention of famine and hunger do not stand as universally compelling reasons for the current functions of insecticides, what must have been the case in previous years?"[4] It was clear to Perkins, writing in the early 1980s, that the current rationale for pesticide use didn't hold factual water, and thus he wondered if hunger and famine had served as an adequate explanation during a period of their widespread adoption, like the 1920s and 1930s.

The problem in the United States, Perkins argued, has never been not enough food. The problem has always been too much.[5] In market based agricultural systems, as Amartya Sen, Michael Watts, William Cochrane, and Mike Davis, among others, have elegantly shown, the poor go hungry because they are poor, not because of absolute scarcities.[6] Yet the trope of hunger and famine is and has almost always been the justification for the use of toxic pest control chemicals in agriculture. This was the case in the 1920s and 1930s.[7] It was the case in the late 1970s and early 1980s when Perkins was writing, and it is still the case today. Scroll through recent literature on the benefits of pest control and you read about the fact that by 2050, there will be 2.5 billion more mouths to feed, mouths that will crave mass-produced heterotrophic flesh.[8] Proponents claim that it is only with ubiquitous chemical pest control that we, as a global community, can meet this challenge.[9]

From 1865 to the present, with the exception of the 15-year period prior to the outbreak of WWI, food production in the United States has far outpaced population growth.[10] Farm economics during the interwar period clearly demonstrates this. In 1914,

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[3] USDA. "Plane Crop Dusting Cotton Field." In *Agricultural Extension and Research Services*. Raleigh, NC: Special Collections Research Center at NCSU, 1925.

[4] Perkins, J H. "Insects, Food, and Hunger: The Paradox of Plenty for US Entomology, 1920-1970." *Environmental History Review* 7, no. 1 (1983): 71-96. Rachel Carson also examined this paradox in Silent Spring. "We are told that the enormous and expanding use of pesticides is necessary to maintain farm production. Yet is our real problem not one of overproduction." Carson, R. *Silent Spring*. Cambridge, MA: The Riverside Press, 1962. 9.

[5] Mullen, R A. "Why Poison Bugs, Foes or Surpluses?" *The Washington Post*, June 25 1933; "It merely indicates that our major peace-time problem is not that of increasing our volume of production." Bradfield, R. "Our Job Ahead: Presidential Address." *Journal of the American Society of Agronomy* 34, no. 12 (1942): 1065-75. 1069; Cochrane, W W. *The Development of American Agriculture*. Minneapolis, MN: University of Minnesota Press, 1993.

[6] Sen, A. *Poverty and Famines: An Essay on Entitlement and Deprivation*. Oxford, UK: Oxford University Press, 1983; Watts, M. *Silent Violence: Food, Famine, and Peasantry in Northern Nigeria*. Berkeley, CA: University of California Press, 1983; Cochrane, W W. *The Curse of Agricultural Abundance: A Sustainable Solution*. Lincoln, NE: University of Nebraska Press, 2003; Davis, M. *Late Victorian Holocausts: El Niño Famines and the Making of the Third World*. New York: Verso, 2002.

[7] Anonymous. "Minutes of the Conference of Plant Pathologists, Entomologists, and Manufacturers of Insecticides and Fungicides at the National Research Council, June 30." In *Institutions: Association Individuals*, National Research Council. Washington DC: Archive of the National Academy of Sciences, 1920; Anonymous. "Minutes of the Conference of Plant Pathologists, Entomologists, and Manufacturers of Insecticides and Fungicides at the National Research Council, September 28." In *Institutions: Association Individuals*, National Research Council. Washington DC: Archive of the National Academy of Sciences, 1920.

[8] Anonymous. "About Crop Protection." CropLife America. http://www.croplifeamerica.org/crop-protection.

[9] Tilman, D, C Balzer, J Hill, and B L Befort. "Global Food Demand and the Sustainable Intensification of Agriculture." *Proceedings of the National Academy of Sciences* 108, no. 50 (2011): 20260-64.

[10] Cochrane, *Development of American Agriculture*, 1993. Schultz, T W. "Impact and Implications of Foreign Surplus Disposal on Underdeveloped Economies." *American Journal of Agricultural Economics* 42, no. 5 (1960): 1019-30; Bonnen, J T, and D B Schweikhardt. "The Future of Us Agricultural Policy: Reflections on the Disappearance of the "Farm Problem"." *Review of*

the entry of US foodstuffs into the European theatre drove the rapid intensification and expansion of US agriculture.[11] As the fighting escalated in the trenches of Europe, the price of agricultural goods and agricultural land in the United States skyrocketed. When the war abruptly ended in 1918, wartime demand ceased with it. In the early 1920s, the invisible hand assailed the American farmer, now cursed with abundance, via harsh yet fully rational market corrections.[12] Between the war's end and the 1920 harvest season, the price of wheat fell over 50%.[13] The values of US farmland followed this same pattern. Farmers who had just lived through a spectacular boom, many of whom had borrowed money to expand, specialize, and intensify, now experienced severe depression.

Yet, in the 1920s and 1930s, in the midst of agricultural depression and massive overproduction, the use of insecticides rose dramatically, particularly on specialty and nonfood row crops like cotton.[14] Making this possible were, of course, the pesticide protagonists – scientists, politicians, chemical and food companies, even the Chemical Warfare Service – that painted discourses of famine and hunger upon a jingoistic canvas to sell their project to the American public.[15] After WWII pesticide use exploded in tandem with the transition to cheap, petroleum-derived pesticides, along with an era of commodity production controls, subsidies, and international food assistance, all policies that were designed to deal with chronic overproduction (See Chapter 4).[16]

Agricultural Economics 20, no. 1 (1998): 2-36. Cochrane, W, and M E Ryan. *American Farm Policy: 1948-1973*. Minneapolis, MN: University of Minnesota Press, 1976. Chapter 1; Cochrane, *Curse of Agricultural Abundance*, 2003. Henry Wallace put it best in a 1933 USDA extension service review. He said that not regarding the negative effects of the unique (scalar) efficiencies of agriculture (i.e. inelastic demand and social/geographical extensiveness) is "criminally negligent… [as] our surpluses of food crops seem to have had as disastrous effect upon national well-being as crop shortages used to have on the isolated communities of a simpler age." Wallace, H A. "May." In *Extension Service Review*. Washington, DC: USDA, 1933.

[11] Perkins, Van L. *Crisis in Agriculture: The Agricultural Adjustment Administration and the New Deal, 1933*. Vol. 81: University of California Press, 1969. Chapter 2.

[12] Alston, L J. "Farm Foreclosures in the United States During the Interwar Period." *Journal of Economic History* 43, no. 04 (1983): 885-903; Phillips, S T. *This Land, This Nation: Conservation, Rural America, and the New Deal*. New York: Cambridge University Press, 2007. Chapter 1.

[13] Wildman, M S. *Prices of Food*. History of Prices During the War. edited by W C Mitchell Washington, DC: Government Printing Office, 1919.

[14] Russell, E. *War and Nature: Fighting Humans and Insects with Chemicals from World War I to Silent Spring*. Cambridge University Press, 2001; Perkins, "Insects, Food, and Hunger," 1983; Perkins, J H. *Insects, Experts and the Insecticide Crisis*. New York: Plenum Press, 1982; Stoll, S. *The Fruits of Natural Advantage: Making the Industrial Countryside in California*. University of California Press, 1998; McWilliams, J E. *American Pests: Losing the War on Insects from Colonial Times to DDT*. New York: Columbia University Press, 2008.

[15] Howard, L O. "War Against Insects." *Nature* 109, no. 2725 (1922): 79-80; Howard, L O. "Two Billion Crop Loss Spur Fight on Insects: Entomologists Waging War on a Hundred Agricultural Pests, Half of Foreign Origin–Changes in Methods of Growing and Harvesting Urged." *New York Times*, February 24, 1924; NYT. "Peace-Time Pursuits Keep Our Army Busy." *New York Times*, 1927; Fries, A A. "By-Products of Chemical Warfare." *Industrial and Engineering Chemistry* October (1928): 1079-84; Russell, *War and Nature*, 2001; McWilliams, *American Pests,* 2008; Walker, H W, and J E Mills. "Chemical Warfare Service Boll Weevil Investigation." *Industrial & Engineering Chemistry* 19, no. 6 (1927): 703-11; Whorton, J C. *Before Silent Spring: Pesticides and Public Health in Pre-DDT America*. Princeton University Press Princeton, NJ, 1974.

[16] Rasmussen, W D, and G L Baker. *The Department of Agriculture*. Praeger Library of U.S. Government Departments and Agencies. New York: Praeger Publishers, 1972; Cochrane, W W. "Farm Technology, Foreign Surplus Disposal, and Domestic Supply Control." *Journal of Farm Economics* 41, no. 5 (1959): 885-89; Perkins, J H. "Reshaping Technology in Wartime: The Effect of Military Goals on Entomological Research and Insect-Control Practices." *Technology and Culture* (1978): 169-86; Perkins, *Insects, Experts*, 1982; Friedmann, H. "The Political Economy of Food: The Rise and Fall of the Postwar International

This is why Perkins, writing in the midst of pesticide controversies and cold-war food policies of the early 1980s first posed the "paradox of plenty."[17] But if famine and hunger are not sufficient to explain the rapid adoption of economic poisons from the 1920s onward, then what is? Both Perkins and his scholarly successors have offered many other factors that contributed to the rapid adoption of pesticides in American agriculture in the interwar era. These include: changing farm labor and tenure structures, new mechanical technologies like the tractor, varietal specialization, the managerial revolution, early adoption benefits, the promotion of chemical control by government officials, financial discipline, the use of pesticides as crop insurance, changing consumer demands, enhanced agricultural extension outreach following the Smith-Lever Act of 1914, and the emergence of biology in the chemical industry.[18] Other scholars have pointed to the role of the Chemical Warfare Service and its peacetime activities along with the advertisers of Madison Avenue in contributing to both the increased use of pesticides on the farm and their naturalization among American farmers and consumers.[19]

Direct government intervention also contributed to the widespread adoption of economic poisons, especially in the 1930s. New Deal programs like the Civilian Conservation Corps paid people to spread poisonous chemicals and the message of chemical

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Food Order." *American Journal of Sociology* 88, no. S (1982): 248-86; Goodman, D, B Sorj, and J Wilkinson. *From Farming to Biotechnology: A Theory of Agro-Industrial Development*. Oxford, UK: Basil Blackwell 1987; Wright, David E. "Alcohol Wrecks a Marriage: The Farm Chemurgic Movement and the USDA in the Alcohol Fuels Campaign in the Spring of 1933." *Agricultural History* 67 (1993); Cochrane, *Curse of Agricultural Abundance*, 2003; Miner, J. "Market Incentives Could Bring Us Agriculture and Nutrition Policies into Accord." *California Agriculture* 60, no. 1 (2006): 8-13. Romero, A. "'From Oil Well to Farm:' Industrial Waste, Shell Oil, and the Petrochemical Turn." *Agricultural History* Forthcoming 90, no. Winter (2016). The first subsidy program proposals were introduced in congressional 1924, 1926, 1927, and 1928 the senators Charles McNary and Gilbert Haugen (McNary-Haugen Farm Relief Bill). Cochrane and Ryan. *American Farm Policy*, 1976. The bill proposed a price support mechanism in which the US Government would buy up surplus crops and ship them overseas. The point of the bill was not for the government to make a profit, but to keep domestic farm prices artificially high and thus allow farmers to remain profitable in in the face of chronic overcapacity and rapid technological change. The bill had its share of proponents, including Henry C. Wallace and son, and opponents, mostly industrial manufactures and agricultural "middlemen" (food processors, transporters, and distributors), who feared lost profit from a rise in agricultural prices. Debates over the bill often revolved around the question of whether to favor modernization and industrialization or the independent family farm. Coolidge vetoed the bill both times it with a rational that echoes the arguments of the business community against the bill. Porter, K K. "Embracing the Pluralist Perspective: The Iowa Farm Bureau Federation and the McNary-Haugen Movement." *Agricultural History* 74, no. 2 (2000): 381-92. Gleason, John Philip. "The Attitude of the Business Community toward Agriculture During the McNary-Haugen Period." *Agricultural History* (1958): 127-38.

[17] Van Der Bosch, R. *The Pesticide Conspiracy*. Berkeley, CA: University of California Press, 1978; Friedmann, H. "The Political Economy of Food: The Rise and Fall of the Postwar International Food Order." *American Journal of Sociology* 88, no. S (1982): 248-86.

[18] Dunlap, T R "The Triumph of Chemical Pesticides in Insect Control 1890-1920." *Environmental Review* 1, no. 5 (1978): 38-47; Dunlap, T R. "Farmers, Scientists, and Insects." *Agricultural History* 54, no. 1 (1980): 93-107; Perkins, "Insects, Food, and Hunger," 1983; Cochrane, *Development of American Agriculture*, 1993; Ceccatti, J S. "Biology in the Chemical Industry: Scientific Approaches to the Problem of Insecticide Resistance, 1920s–1960s." *Ambix* 51, no. 2 (2004): 135-47; McWilliams, J E. "" The Horizon Opened up Very Greatly": Leland O. Howard and the Transition to Chemical Insecticides in the United States, 1894-1927." *Agricultural History* (2008): 468-95.

[19] Allen, W. *The War on Bugs*. White River Junction, VT: Chelsea Green Publishing Company, 2008; Sackman, D C. *Orange Empire: California and the Fruits of Eden*. Berkeley, CA: University of California Press, 2005. Whorton, *Before Silent Spring*, 1974. "'Hydro-Cy' Fumigation – Good Looks… Good Taste… Good Sales." Anonymous. "Hydro-Cy Ad." In *Absorbed Companies*, E. I. Du Pont De Nemours & Company. Wilmington, DE: Hagley Library, 1941.

control (war) across the landscapes of the American West.[20] And although, in the interwar years, fundamental differences existed between agriculture on the Pacific Slope and the rest of the country, it is likely that all or most of the above explanations did play some part in the larger project of chemicalization that amalgamated itself to agriculture and daily life throughout the interwar years. Indeed, there is a complex web of likely explanations for the increased use of agrichemicals during this period. The one thing we can rule out however is food scarcity. The transition to pesticides was not necessary for American farmers to produce sufficient food. But their use had been critical to the production of other goods and services – goods and services that are not critical to the survival of the population but to the survival of a particular form of political economy.

Last year, more than one hundred billion pounds of pesticides rained down upon US farms, the lawns and gardens of suburban households and urban parks, and food storage, transportation and processing facilities.[21] If antibiotics and other microbial biocides are counted, then annual pesticide consumption in agriculture grows considerably.[22] According to the last official estimate, not counting antimicrobials, the United States uses 22% of the world's pesticides, representing 35% of global expenditure. Thus, with each circle of the Sun, with each harvest season that comes and goes, more than fifty million tons of toxic chemicals are consumed by US farms and food processors to maintain the productive homeostasis of the awe-inspiring US agroindustrial complex.

The chemicalized nature of industrial agriculture and life in general has laid dear Parson Malthus to rest. But it has also resulted in pollution and contamination on such an immense scale that it will continue to stalk humanity for so long that we might as well as think of it as forever.[23] Children born today, even before they take their first breath, have hundreds of industrially made chemicals flowing through their blood, interacting in ways we can only begin to guess at.[24] And although all bodies are now repositories of industrial contamination, certain groups face greater burdens by sacrificing their bodies upon the altar

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[20] NYT. "Poison Bait Is Set for Grasshoppers: Federal Drive in Plains States Limited by Paucity of Funds." *New York Times*, July 26, 1936; Siverson, H S. "Arsenic Breakfasts Ready for 'Hoppers: Middle West Preparing for Grasshopper Swarms Predicted by Experts to Be Greatest in Many Years of Farm History." *The Washington Post*, May 16, 1937.

[21] There is no exact number for this, as the EPA only lists what they call active ingredients. Active ingredient makes up very small percentages of all pesticides applied. Inert ingredient, such as horticultural oils and other inert agents can also be toxic and/or increase the toxicity/persistence of the active ingredient or be used as endocrine disrupting compounds (plant hormones). EPA. "2006 – 2007 Pesticide Market Estimates: Usage." http://www.epa.gov/opp00001/pestsales/07pestsales/usage2007_2.htm#3_6.

[22] Agriculture consumes ~80% of antibiotics used annually in the US. National Research Council. *The Use of Drugs in Food Animals: Benefits and Risks*. Washington DC: The National Academies Press, 1999. Antibiotics are also routinely used on specialty crops and high-value seeds. McManus, P S, V O Stockwell, G W Sundin, and A L Jones. "Antibiotic Use in Plant Agriculture." *Annual Review of Phytopathology* 40, no. 1 (2002): 443-65.

[23] Murphy, M. "Chemical Regimes of Living." *Environmental History* 13, no. 4 (2008): 695-703; Altman, R. "On What We Bury." *Interdisciplinary Studies in Literature and Environment* (2014): 1-11.

[24] Feron, VJ, J P Groten, D Jonker, F R Cassee, and P J Van Bladeren. "Toxicology of Chemical Mixtures: Challenges for Today and the Future." *Toxicology* 105, no. 2 (1995): 415-27; Kaiser, Jocelyn. "Synergy Paper Questioned at Toxicology Meeting." *Science* 275, no. 5308 (1997): 1879-79; Environmental Working Group. "Human Toxome Project." http://www.ewg.org/sites/humantoxome/. 2014.

of agricultural employment; or by living near the industries that make modern agriculture possible – subsidizing our cheap food through bodily internalization of industrial agriculture's externalities.[25]

There are many good people out there already imagining a new agrarian future, and I applaud their efforts.[26] But for me, I was unable was to begin imagining that future until I knew how the present system began. For as much I want to believe in the potential for the agro-utopian future that many imagine,[27] I am dogged by the question of whether it is even ecologically or socially possible. Over the last 500 years, and especially over the last 150, we have radically changed our agroecological landscapes so much that a return to any sort of fully non-chemicalized agricultural system may not be possible even with radical transformations in how we approach our agricultural system, especially over the short term. (Just think about all the endocrine disrupting plastics that so-called sustainable agriculture uses). Thus, this chapter, in offering a political economic solution to Perkin's paradox, is also an intervention into the diversity of imagined futures. If we are going to attempt to change the dominant agrarian culture, we will need to dig deeper into the origins and justifications of industrial agriculture than most alternative visions have done to date.

Historical investigation into the origins of today's agricultural political economy reveals a key role that broader processes of industrialization have had in producing the agriculture of today.[28] Expanding the focus of agro-historical investigation beyond the agricultural field and its institutions, as Goodman et al. suggested, allows tangential yet critical questions to be asked, such as, besides the production of food and fiber, what *ecosystem services* does industrial agriculture provide to the expanded reproduction of capital.

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[25] Bradman, A, B Eskenazi, D B Barr, R Bravo, R Castorina, J Chevrier, K Kogut, M E Harnly, and T E McKone. "Organophosphate Urinary Metabolite Levels During Pregnancy and after Delivery in Women Living in an Agricultural Community." *Environmental Health Perspectives* 113, no. 12 (2005): 1802; Bradman, A, D Whitaker, L Quirós, R Castorina, B Henn, M Nishioka, J Morgan*, et al.* "Pesticides and Their Metabolites in the Homes and Urine of Farmworker Children Living in the Salinas Valley, Ca." *Journal of Exposure Science and Environmental Epidemiology* 17, no. 4 (2007): 331-49; Singer, Merrill. "Down Cancer Alley: The Lived Experience of Health and Environmental Suffering in Louisiana's Chemical Corridor." *Medical Anthropology Quarterly* 25, no. 2 (2011): 141-63; Willsher, K. "French Children Exposed to Dangerous Cocktail of Pesticides, Campaigners Say." *The Guardian*, April 29, 2014; Mascarelli, A. "Growing up with Pesticides." *Science* 341, no. 6147 (2013): 740-41; Guillette Jr, L J, and T Iguchi. "Life in a Contaminated World." *science* 337, no. 6102 (2012): 1614-15.

[26] National Research Council. *Toward Sustainable Agricultural Systems in the 21st Century*. Washington DC: The National Academies Press, 2010; Foley, J A, N Ramankutty, K A Brauman, E S Cassidy, J S Gerber, M Johnston, N D Mueller*, et al.* "Solutions for a Cultivated Planet." *Nature* 478, no. 7369 (2011): 337-42.

[27] For example: Crowder, D W, T D Northfield, M R Strand, and W E Snyder. "Organic Agriculture Promotes Evenness and Natural Pest Control." *Nature* 466, no. 7302 (2010): 109-12; Robin, Marie-Monique. *The World According to Monsanto: Pollution, Corruption, and the Control of the World's Food Supply*. The New Press, 2010.

[28] Goodman et al., *From Farming to Biotechnology*, 1987. 132. "However, if there is neither a natural division of labor between agriculture and industry nor the possibility of directly organizing agriculture production along rural lines, we must look not to rural production for the secret of capitalist subordination but to the rise and development of various agro-industrial branches, both upstream and downstream. 'Agriculture' then represents the increasingly residual activities which have resisted transformation into industrial processes… In widening the focus away from the 'point of production,' we risk accusations of technological determinism and of eliminating social relations from the analysis. However, it would be myopic to ignore the social consequences of the transformation of agriculture orchestrated by industrial capitals from *outside* the immediate labor process."

[29] It is from this vantage point that I offer a political economic solution to Perkin's paradox by arguing that the rapid adoption of pesticides in American agriculture in the interwar years proceeded on two distinct yet intimately related fronts: 1) as a temporary fix for overproduction in the chemical industry and 2) as a sink for industrial, often highly toxic, wastes.

But an abstract political economic solution that purportedly tells us why does not necessarily give us the satisfying historical richness of how. Thus, I tell the first history of the Crop Protection Institute, extracted from the archives of the National Academy of Sciences, to frame my narrative and to make my case. Founded in 1920 under the aegis of the National Research Council, the Crop Protection Institute was a non-governmental organization tasked with linking private industry to public science by bringing together expertise and facilities of state, university, and extension scientists in the emerging fields of crop protection with the toxic materials and capital of a rapidly developing post WWI US chemical industry.[30] Through the industrial, scientific, and political networks of the Crop Protection Institute, chemical manufacturers, agricultural producers, and crop protection scientists collaborated to facilitate new agricultural outlets for primary chemical products and discover new methods to transmute the growing masses of inorganic and organic industrial wastes from costs of production into valuable and effective pest control products. By helping standardize agricultural toxicology, by geographically homogenizing crop protection research and pesticide use, and by establishing and naturalizing private-public agro-industrial research networks, the Crop Protection Institute helped shift crop protection to the forefront of capital investment and industrial R&D, laying the techno-social infrastructure necessary for the generalization of industrially produced chemicals across American agriculture following WWII.[31]

New Markets, Novel Metabolisms

Histories of agricultural development are usually written through a lens of production.[32] In California, where I mostly work, this can be seen in the historiographical privileging of the harvest labor system and agricultural mechanization.[33] The privileging of production can be

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[29] (Toxicological) dilution, (value and nutrient) recycling, (industrial) detoxification, (legal) management, (surplus) absorption, (legal) sequestration, and (profitable) treatment of wastes. Daily, G C, and K Ellison. *The New Economy of Nature*. New York: Island Press, 2002. Economists underestimate the economic and social value of the waste sink services provided by (industrial) ecosystems. Howarth, R B, and S Farber. "Accounting for the Value of Ecosystem Services." *Ecological Economics* 41, no. 3 (2002): 421-29, Assessment, Millennium Ecosystem. *Ecosystems and Human Well-Being*. Vol. 5, Washington, DC: Island Press 2005.

[30] O'Kane, W C. "The Crop Protection Institute: A Get-Together Movement on the Part of Three Great Groups, the Intelligent Grower, the Scientist, and the Businessman," Crop Protection Institute, Washington DC. 1920.

[31] Larkin, B. 2013. "The Politics and Poetics of Infrastructure." *Annual Review of Anthropology* 42:327-343.

[32] Goodman et al., *From Farming to Biotechnology*, 1987.

[33] McWilliams, C. *Factories in the Field*. Berkeley, CA: University of California Press, 1935. Hightower, J. "Hard Tomatoes, Hard Times: Failure of the Land Grant College Complex." *Society* 10, no. 1 (1972): 10-22. Walker, R. *The Conquest of Bread: 150 Years*

also be seen in past and present debates in rural sociology, political economy, and peasant studies, where questions of wage labor, farm ownership structure, and privatization prevail.[34] For the most part, among these histories and theories of capitalist agriculture, the role of the farm as a provider of critical ecosystem services to industrial capital remains unexplored.[35]

Positioning agriculture as a site of productive consumption opens whole new areas of investigation within historical and political economic scholarship. However, although a focus on agriculture as a site of productive consumption – that is, as a metabolic process where commodities are consumed – shifts the analysis away from the field and points it toward the linkages between larger developments in industry and aggregate changes in agriculture, it maintains the primacy of agriculture's basis in natural processes.[36] Agriculture's fundamental basis in nature means that it holds a unique place as a consumer of other industries' commodities. For it is only in modern agriculture and the pharmaceutical/public health industries where the use value of toxicity actively circulates.[37] As such, this places medicine, public health, and agriculture as the potential prime consumers of society's most noxious concoctions.

Since the latter part of the 19th century, chemistry and capital have been reinvigorating the dregs of industrial production with new life.[38] The alchemist's pursuit of making gold from lead has been realized in the ability of industrial chemistry to transmute waste into value.[39] The reutilization of industry's refuse, however, must be distinguished from efficiency in the creation of waste.[40] While they are materially related processes, they are not synonymous. The reduction of waste in production and consumption to its minimum through better technology or higher quality raw material is qualitatively different than the maximum use of all of the raw materials of production and consumption.[41] In other

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of Agribusiness in California. The New Press, 2004; Garcia. *A World of Its Own: Race, Labor and Citrus in the Making of Greater Los Angeles, 1900-1970*. Chapel Hill, NC: University of North Carolina Press, 2001; Olmstead, Alan L, and Paul Rhode. "An Overview of California Agricultural Mechanization, 1870-1930." *Agricultural History* (1988): 86-112.

[34] Kautsky, K. *The Agrarian Question*. 3rd ed. London: Zwan Publications, 1988; Mann, S A. *Agrarian Capitalism in Theory and Practice*. Chapel Hill, NC: University of North Carolina Press, 1990; Borras Jr, S M. "Agrarian Change and Peasant Studies: Changes, Continuities and Challenges–an Introduction." *The Journal of Peasant Studies* 36, no. 1 (2009): 5-31.

[35] With the exception of services for finance capital: Henderson, G. *California and the Fictions of Capital*. Oxford: Oxford University Press, 1999.

[36] Olmstead, A L, and P W Rhode. *Creating Abundance: Biological Innovation and American Agricultural Development*. Cambridge, UK: Cambridge University Press, 2008; Mann, *Agrarian Capitalism*, 1990; Henderson, *Fictions of Capital*, 1999.

[37] Romero, "From Oil Well to Farm," 2016.

[38] Haynes, W. *Chemical Economics*. New York: D. Van Nostrand Company, Inc., 1933.

[39] Wilson, CP. "The Manufacture of Citric Acid from Lemons." *Industrial & Engineering Chemistry* 13, no. 6 (1921): 554-58.

[40] Marx, *Capital, Vol. III*, 1981. Chapter 5. This includes the wasting of human life as a way to economize the use of constant capital.

[41] These modern socioecolgical phenomena could be thought of as emerging from different levels of cooperation (social labor) within a capitalist economy, the former first arising from aggregate changes to industry that give rise to the common production of waste, while the latter first emerges through better machines, more skilled laborers, and higher quality raw materials. In *Volume III* of *Capital*, Marx outlines the three necessary conditions for the utilization of industrial waste. These conditions are: 1) the massive and common production of industrial waste 2) advances in scientific understanding, particularly in chemistry, and 3) advances in machinery that can serve as the apparatuses for waste's transmutation into new elements of production. While Marx

words, while efficiency affects the scale of waste produced, it does not account for the reutilization of waste. This distinction, however, does not mean that these political economic phenomena are entirely mutually exclusive, as one firm can dominate an entire industry.[42] This distinction is more important in the chemical industry than other arenas of manufacture as the ontology of large-scale *chemistry* manufacture creates distinct problems due to elemental (chemical) and not simply mechanical transformation. (See Chapter 1)

Current waste scholarship reads waste through lenses of market and production efficiency, and it is through these polarized glasses that scholars across diverse fields have categorized the waste byproducts of social metabolism as externalities.[43] But by doing this, these scholars conceptually relegate waste – the commodity's chiral other – to a lesser history.[44] But capitalism's detritus is not a minor history.[45] Take for instance the fact that throughout the first half of the 19th century, a period commonly known as the Industrial Revolution, the tailings of industrial production volumetrically outpaced the production and consumption of commodities. For many witnesses of the industrial revolution, it wasn't

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unsatisfactorily sites industrial waste reutilization in a theoretical discussion of constant capital, thoroughly discounting the role of waste in producing and maintaining the chemicalized nature of everyday life, he insists that the production and utilization of waste is fundamental to the logic of capitalism. In arguing that waste reutilization (for example, inter- and intra-firm recycling) is one of the two scaling functions in industrial capitalist production (the other being economies of scale, of course) he makes the case that waste reuse must be distinguished from questions of efficiency in the creation of waste.

[42] This distinction is thus not just a question of efficiency is the use of raw materials, but also a question of yield and the creation/use of byproducts. Both the products and the byproducts of industrial chemical synthesis are novel to humanity. (The distinction is readily apparent in the difference between the waste products involved in the manufacture of furniture vs. the waste products involved in the destructive distillation of wood. Haynes, *Chemical Economics*, 1933. Take for instance Dow Chemical and the phenol market post WWI. Through the development of the Hale-Britton process during WWI, Dow emerged as most efficient producer of phenol in the interwar era. However, the success of the process and its industrial dominance during the 1920s and 1930s was not entirely determined the primary product of production, phenol. The Hale-Britton process utilized chlorine instead of sulfur in the synthesis of phenol and it produced four byproducts that reduced the overall cost of manufacturing phenol. Two of theses products, salt and hydrogen, were immediately cycled back though Dow's chemical operations. The other two byproducts, paraphenylphenol and orthophenylphenol, are anthropogenically produced chemical novelties. In the late 1920s and 1930s, they reentered the circuits of capital as broad spectrum disinfectants. These two chemicals, marketed under the name Dowicides, are still used many consumer products like laundry detergents, fabric softeners, dishwashing liquids, and other industrial cleaners. Brandt, E N. *Growth Company: Dow Chemical's First Century*. East Lansing, MI: Michigan State University Press, 1997; Whitehead, Don. *The Dow Story: The History of the Dow Chemical Company*. New York: McGraw-Hill 1968; Haynes, W. *American Chemical Industry: The World War I Period, 1912-1922*. Vol. III, New York: D. Van Nostrand Company, Inc., 1945; Haynes, W. *American Chemical Industry: 1912-1922*. Vol. II, New York: D. Van Nostrand Company, Inc., 1945.

[43] Coase, R H. "The Problem of Social Cost." *Journal of Law & Economics* 3 (1960): 1-44; Gregson, N, and M Crang. "Materiality and Waste: Inorganic Vitality in a Networked World." *Environment and Planning A.* 42, no. 5 (2010): 1026-32. Even Marxist scholarship treats waste as an externality. For example: O'Connor, M. *Is Capitalism Sustainable?* New York: The Guilford Press, 1994; Moore, Jason W. "Environmental Crises and the Metabolic Rift in World-Historical Perspective." *Organization & Environment* 13, no. 2 (2000): 123-57.

[44] Gidwani, V, and R N Reddy. "The Afterlives of "Waste": Notes from India for a Minor History of Capitalist Surplus." *Antipode* 43, no. 5 (2011): 1625-58.

[45] Foster, J B. "Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology." *American Journal of Sociology* 105, no. 2 (1999): 366-405; Leslie, E. *Synthetic Worlds: Nature, Art, and the Chemical Industry*. London: Reakton Books Ltd, 2005; Marx, *Capital, Vol. III*, 1981; Simmonds, P L. *Waste Products and Undeveloped Substances*. London: R. Hardwicke, 1862; Perry, G P. *Wealth from Waste: Or, Gathering Up Fragments*. London: Fleming H Revell, 1908; Howe, H E, and J V Antwerpen. "Utilization of Industrial Wastes." *Industrial & Engineering Chemistry* 31, no. 11 (1939): 1323-230; Koller, T. *Utilisation of Waste Products: A Treatise on the Rational Utilisation, Recovery, and Treatment of Waste Products of All Kinds*. London: Scott, Greenwood, & Co., 1902.

cheap textiles or wage labor that signaled the arrival of modernity. It was the mountains of anthropogenic wastes that emerged from Victorian England's industrial landscapes.[46]

Indeed, by insisting, instead, that the production, utilization, and circulation of waste is *fundamental* to the expansion and maintenance of capitalism, terms such as "externality" lose their theoretical purchase, and the acts of commodity production and consumption can be reimagined as sites of industrial service provisioning. In other words, it is in the duality of agricultural productive consumption that industrial agriculture emerges as both a potential market for toxic commodities and a profitable sink for industrially produced toxic waste.[47]

In this chapter, I am concerned with the two infrastructural circuits from which economic poisons are derived: 1) the networks that produce industrial chemicals and 2) the networks that manage industrial waste.[48] My thesis, again, is twofold: that in the interwar years the rapid adoption of toxic chemicals in agriculture served nonfarm capital through the adsorption of surplus product and absorption of industrial waste. During the interwar years the classic problem of being long of product and short on market acquired a novel twist when the widening sphere of commodity circulation amalgamated the use value of toxicity to agricultural productive consumption. It is also my contention that agriculture, as a unique site of bio-industrial productive consumption, can serve as a threshold of waste's transmutation, whereby the burden of point source waste disposal is transformed into a widely distributed agricultural input.[49] One particular historical example illustrates this general theoretical point.

The development of extensive US copper smelting capacity in the Western US throughout the 1890s led to extensive forest damage downwind of smelters.[50] Shortly after the turn of the century President Roosevelt had decided things had to change and by the end

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[46] For contemporary scholars, the epoch of human dominance began when industrial wastes from these very same factories stared to change the climate Crutzen, P J. "Geology of Mankind." *Nature* 415, no. 6867 (2002): 23-23.

[47] This claim is similar to Henderson's (1999) discussion of the duality of nature as both constraint and opportunity for the circulation and realization of capital. Henderson, *Fictions of Capital*, 1999.

[48] Lamberth, C, S Jeanmart, T Luksch, and A Plant. "Current Challenges and Trends in the Discovery of Agrochemicals." *Science* 341, no. 6147 (2013): 742-46; Romero, "From Oil Well to Farm," 2016.

[49] Geographical biogeochemistry shows this as well. Murphy, E A, and M Aucott. "An Assessment of the Amounts of Arsenical Pesticides Used Historically in a Geographical Area." *Science of the Total Environment* 218, no. 2 (1998): 89-101; Magalhães, M. "Arsenic. An Environmental Problem Limited by Solubility." *Pure and Applied Chemistry* 74, no. 10 (2002): 1843-50; Robinson Jr, G R, and R A Ayuso. "Use of Spatial Statistics and Isotopic Tracers to Measure the Influence of Arsenical Pesticide Use on Stream Sediment Chemistry in New England, USA." *Applied Geochemistry* 19, no. 7 (2004): 1097-110; Renshaw, C E, B C Bostick, X Feng, C K Wong, E S Winston, R Karimi, C L Folt, and C Y Chen. "Impact of Land Disturbance on the Fate of Arsenical Pesticides." *Journal of Environmental Quality* 35, no. 1 (2006): 61-67. Garbarino, J R, A J Bednar, D W Rutherford, R S Beyer, and R L Wershaw. "Environmental Fate of Roxarsone in Poultry Litter. I. Degradation of Roxarsone During Composting." *Environmental Science & Technology* 37, no. 8 (2003): 1509-14; Rutherford, D W, A J Bednar, J R Garbarino, R Needham, K W Staver, and R L Wershaw. "Environmental Fate of Roxarsone in Poultry Litter. Part II. Mobility of Arsenic in Soils Amended with Poultry Litter." *Environmental Science & Technology* 37, no. 8 (2003): 1515-20.

[50] Haywood, J K. "Injury to Vegetation and Animal Life by Smelter Fumes." *Journal of the American Chemical Society* 29, no. 7 (1907): 998-1009; Swain, Robert E. "Atmospheric Pollution by Industrial Wastes." *Industrial & Engineering Chemistry* 15, no. 3 (1923): 296-301; MacMillan, D. *Smoke Wars: Anaconda Copper, Montana Air Pollution, and the Courts, 1890-1924*. Helena, MT: Montana Historical Society, 2000.

of his presidency this change had begun.[51] In 1909, Roosevelt's successor, William Taft and his Attorney General, George Wickersham, filed a suit in Montana state court against the Anaconda Mining Company seeking a permanent cessation of all of its mining activities.[52] The Taft administration argued that technology existed that could capture more of the arsenic and sulfur fumes being released from the smelter's smokestacks, yet Anaconda refused to upgrade. This situation wasn't unique to Anaconda, however.

A few years earlier, the Roosevelt administration had informed several other mining and smelting companies that the "wanton and wholesale" destruction of American forests would not be tolerated. These mining companies responded that the only way they could operate their plants profitably was the current method, and that even though the technology existed to capture smelter fumes, it was too expensive to install. The companies argued that the proposed regulations would shutter mines and smelters, resulting in job and economic losses. The Roosevelt administration called their bluff, and responded with threats of lawsuits and permanent injunctions. The companies relented and installed the new flue scrubbing technologies. But whereas the forests gained, the problem of toxic waste remained.[53]

These newly installed scrubbing devices did not eliminate the waste; they just concentrated it throughout mining country. All forms that arsenic takes are toxic, but the arsenic oxides in smelter excreta are especially so, which makes the disposal of these wastes particularly difficult.[54] Incredibly toxic arsenic oxides now collected in ever-larger piles surrounding smelters. But the toxic waste piles didn't sit there for long. As the demand for agricultural arsenic increased in the lead up to WWI, mining companies found themselves blessed with an anthropogenically sorted natural resource that could be sold and shipped to chemical manufacturers across the United States.[55] This highly toxic smelter waste, instead of percolating into downwind forests, now found its way onto the farms across the country, where it was consumed raw as an herbicide or poison bait, or transformed into lead or copper based poisons to kill insects like the codling moth or the potato bug.[56] The Anaconda Mining Company eventually caved to executive pressure and installed technology to capture their poisonous emissions, and those mining wastes also found their way into agriculture.

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[51] NYT. "May Sue Copper Company: President Will Learn If Poisonous Fumes Can Be Prevented." *New York Times*, December 6, 1908.

[52] NYT. "Montana Smelters Sued: Government Action against Anaconda Company to Protect Forests." *New York Times*, March 17, 1910.

[53] Forest damage was also caused by high-sulfur content coal used in the smelters.

[54] Swain, R E. "Wastes Problems in the Nonferrous Smelting Industry." *Industrial & Engineering Chemistry* 31, no. 11 (1939): 1358-61; Hopkin, W. "The Problem of Arsenic Disposal in Non-Ferrous Metals Production." *Environmental Geochemistry and Health* 11, no. 3-4 (1989): 101-12; Hughes, M F. "Arsenic Toxicity and Potential Mechanisms of Action." *Toxicology Letters* 133, no. 1 (2002): 1-16. Frankenberger, W T, ed. *The Environmental Chemistry of Arsenic*. New York: Marcel Decker, Inc., 2002.

[55] LAT. "Wide Use of Arsenic: Is Principally Employed in Glass Making and in Insecticides, as Well as Paints and Medicines." *Los Angeles Times*, May 10 1914; SFC. "Arsenic Poison Spray Used to Destroy Weeds." *San Francisco Chronicle*, November 15, 1915.

[56] Davis, J J. "The Value of Crude Arsenious Oxide in Poison Bait for Cutworms and Grasshoppers." *Journal of Economic Entomology* 12, no. 2 (1919): 200-03.

At the outbreak of WWI, these few factories that were forced by the Roosevelt and Taft administrations to recover white arsenic (arsenic trioxide) from flue gases accounted for less than 10% of US arsenic demand, with the Anaconda Mining Company's byproducts making up the largest share.[57] More than 10,000 tons of arsenic oxide was consumed by US industries in 1915, most of it by agriculture, but at a price of 3 cents a pound it was not profitable for US companies to install recovery technology.[58] Even though the US produced more than twice domestic demand, most of this production left the smelter in flue gases.[59] Hence, at this time, 90% of US arsenic consumption was imported from Mexico, Japan, Spain, and Germany.

In 1916, wartime demand for arsenic by industry, agriculture, and chemical munitions manufacturers, along with restricted international trade, led to a tighter supply and a rise in price.[60] That same year, nearly all the smelters across the western United States installed recovery technology and began collecting highly toxic white arsenic that they could now profitably sell to agro-chemical companies. A process that a few years earlier needed threats of lawsuits, now generalized across the smelting industry with wartime demand. By the end of the war, miners, engineers, and industrial chemists had turned an externality of US smelter pollution into a industrial input, internalizing it in the production of apples, pears, cotton, signal flares, lead shot, and chemical weapons. "The companies spent the money necessary to convert their harmful fumes to a valuable product and many additional men got work."[61]

In late 1916, as the US marched toward war, the Council on National Defense (via the War Production Board) took the production and consumption of arsenic under its control. In 1917, in the midst of wartime intensification, a boll weevil outbreak struck the fields of Southern cotton growers. Accompanying this outbreak, however, was the realization that a seemingly continuous saturation of the cotton plant with calcium arsenate might possibly ward off the insidious boll weevil.[62] In 1918, the price of white arsenic tripled, reaching 18c per pound. By the end of the war, although the US still imported white arsenic, mainly from Mexico, domestic supply made up the majority of demand.[63]

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[57] Mitchell, W C, M L Goldsmith, and F K Middaugh. *History of Prices During the War: International Price Comparisons*. Washington DC: Department of Commerce in Cooperation with the War Industries Board, 1919.

[58] Haynes, *Chemical Economics*, 1933.

[59] LAH. "Domestic Arsenic." *Los Angeles Herald*, December 15, 1907; Parsons, C L. "Miscellaneous Mineral Wastes." *Industrial & Engineering Chemistry* 4, no. 3 (1912): 185-88.

[60] Gray, G P. "The Consumption and Cost of Economic Poisons in California in 1916." *Industrial & Engineering Chemistry* 10, no. 4 (1918): 301-02.

[61] NYT, "Montana Smelters Sued, 1910.

[62] Coad, B R. "Recent Experimental Work on Poisoning Cotton Boll Weevils, USDA Dept." In *Bulletin 731*, 1-15: USDA, 1918; Coad, B R. "Killing Boll Weevils with Poison Dust." *Agricultural Yearbook for 1920*, 241-52. Washington, DC: USDA, 1921; Parencia Jr, C R. "One Hundred Twenty Years of Research on Cotton Insects in the United States." In *Agriculture Handbook*, 1-17; 62-68: USDA, 1978; Haney, P B, W J Lewis, and W R Lambert. "Cotton Production and the Boll Weevil in Georgia: History, Cost of Control, and Benefits of Eradication." *Bulletin 428*, 60. Athens, GA: The Georgia Agricultural Experiment Stations, College of Agricultural and Environmental Sciences, The University of Georgia, 2009.

[63] Anonymous. "Washington Notes: Calcium Arsenate Demand." *Industrial and Engineering Chemistry* 15, no. 2 (1923): 208.

In 1921 the price of cotton collapsed, and with it the financial incentive to spread expensive poisons on cotton. Yet arsenic use increased. Take Georgia for example, where growers, heavily subsidized by taxpayers and using dosage schedules developed by the Crop Protection Institute (CPI), spread more than 3 million pounds of calcium arsenate on the cotton fields of the Peach State.[64] By 1923, US consumption of white arsenic had risen to 21,300 tons (42.6 million pounds). That same year, the rapidly developing US agro-industrial complex productively consumed 16,000 tons of this white arsenic as economic poisons to kill insects and weeds. In 1924, farmers spread more than 30,000 tons of calcium arsenate (made from 12,000 tons of arsenic trioxide – As_2O_3), or 60 million pounds, across 1.6 million acres of cotton.[65] For the 1925 cotton season, the crop-dusting airplane made its commercial debut across the South and US domestic arsenic production and its consumption by agriculture smashed all previous records.[66]

As the 1920s progressed, the US nonferrous mining and smelting industries rapidly developed, and farms and ranches of the United States began to reorganize in tandem – wrapping themselves in a blanket of cheap toxic industrial chemicals. In the interwar era, farms across the US served not only as a new market for the sudden abundance of industrial chemicals and chemical capacity following WWI, but perhaps more importantly, they also served the needs of industrial and finance capital and regulatory compliance by acting as a profitable sink for toxic smelter waste.[67]

[64] The Georgia legislature authorized the State Entomological Board to supply the insecticide to farmers at cost and went to great length to makes sure. Anonymous. "Minutes of the Crop Protection Institute Annual Meeting, December 6." In *Institutions: Association Individuals*, National Research Council. Washington DC: Archive of the National Academy of Sciences, 1920; Anonymous. "The Crop Protection Institute." *Crop Protection Digest* 1, no. 1 (1921); Coad, "Killing Boll Weevils," 1921; Anonymous. "Crop Protection Institute Discusses War on Boll Weevil." *The Journal of Industrial and Engineering Chemistry* 13, no. 1 (1921): 89; Haynes, *World War I Period*, 1945; Loftin, U. "Living with the Boll Weevil for Fifty Years." *Report of the Smithsonian. Institution 1945* (1946): 273-91; Helms, D. "Technological Methods for Boll Weevil Control." *Agricultural History* 53, no. 1 (1979): 286-99.

[65] WSJ. "Increasing Use Calcium Arsenate." *Wall Street Journal*, January 28 1924; LAT. "Arsenic in 1924." *Los Angeles Times*, June 5, 1925.

[66] Hinds, W E. "Airplane Dusting of Cotton for Boll Weevil Control." *Journal of Economic Entomology* 19, no. 4 (1926): 607-07; WSJ. "Record Arsenic Output." *Wall Street Journal*, June 5, 1925; Downs, E W, and G F Lemmer. "Origins of Aerial Crop Dusting." *Agricultural History* 39, no. 3 (1965): 123-35. In 1923 38% of Georgia farms used the wonder poison, and less than 6% of farmers across the South. Helms, "Technological Methods, 1979.

[67]McDonnell, C. "Recent Progress in Insecticides and Fungicides." *Industrial & Engineering Chemistry* 16, no. 10 (1924): 1007-12; Haynes, *Chemical Economics*, 1933. Marx, *Capital, Vol. III*, 1981; Brickman, R, S Jasanoff, and T Ilgen. *Controlling Chemicals: The Politics of Regulation in Europe and the United States*. Ithaca, New York: Cornell University Press 1985; Levine, M E, and J L Forrence. "Regulatory Capture, Public Interest, and the Public Agenda: Toward a Synthesis." *Journal of Law, Economics, & Organization* 6 (1990): 167-98; Desrochers, P. "Learning from History of from Nature or Both? Recycling Networks and Their Metaphors in Early Industrialization." *Progress in Industrial Ecology* 2, no. 1 (2005): 19-35. Romero, "From Oil Well to Farm," 2016. Cotton remains one of the two crops (chicken is the other) that still use arsenic based pesticides. These organo-arsine chemicals are fed to chicken to ward off parasites and increase weight gain and used by US cotton growers to chemically defoliate ("burn down") cotton prior to harvest. National Research Council. *The Use of Drugs in Food Animals: Benefits and Risks*. Washington DC: The National Academies Press, 1999; Garelick, H, H Jones, A Dybowska, and E Valsami-Jones. "Arsenic Pollution Sources." *Reviews of Environmental Contamination* 197 (2008): 17-60.

Great Wars, Fundamental Changes

World War I is regarded as the "chemist's war" for good reason.[68] As the first major war to take advantage of second industrial revolution technologies like electro- and organic chemistry, its participants introduced new explosives, new armors, new machines, new fertilizers, new clothing, new fuels, and industrial chemical warfare to bodies, hearts, and minds across the world.[69] This groundbreaking and breathtakingly industrial armamentarium rested upon the shoulders of massive chemical factories dotted across the landscape. Deep within the bowels of these factories, men and women transfigured masses of raw materials into the deadly substances of war.

The United States emerged from the Great War as a dominant player in industrial chemistry.[70] In particular, prior to the war, the US lacked coal-tar based organic chemical capacity and the infrastructure needed to capture the wastes of coking ovens that served as the raw materials for organic chemical synthesis.[71] US industries also lacked the knowledge of organic chemical engineering that the Germans possessed.[72] In 1914, American textile companies used almost 20% of the world's dyes, but most of these and other intermediate organic chemicals were imported from Germany.[73] As European belligerents plunged further into war, Britain's Naval Blockade of Germany interrupted the international trade in chemicals. The last (official) shipment of German dyes arrived at the Port of New York on March 19th, 1915.[74]

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[68] NYT. "Chemistry Rules War. Inventors Are Not to Blame for the Horrors Asserts Baekeland." *New York Times*, September 25 1915; NYT. "Chemical Preparedness." *New York Times*, February 25, 1917; NYT. "Chemists Gain Advantage: Americans Have Outdone Germany in Chemical Products." *New York Times*, February 17, 1918; TWP. "Destruction of Big Chemical Plant Staggering Military Blow to Kaiser " *The Washington Post*, January 6, 1918; Howe, J L. "War of Chemicals Reaches a Climax." *New York Times*, June 16, 1918. "There is little use in attempting to disguise the fact that the present war is a struggle between the industrial chemical and chemical engineering genius of the Central Powers and that of the rest of the world. Quite irrespective of the war's origins, aims, ideals or political circumstances, these are the cohorts from which each side derives its power." Withrow, J R. "The American Chemist and the War's Problems." *The Ohio Journal of Science* 16, no. 6 (1926): 219-31; Rhees, D J. "'The Chemists' War: The Impact of World War I on the American Chemical Profession." *Bulletin for the History of Chemistry*, no. 13/14 (1992): 40-47.

[69] Yerkes, R M, ed. *The New World of Science: Its Development During the War*. Freeport, NY: Books for Libraries Press, 1920; Robertson, R. "Some War Developments of Explosives." *Nature* 107 (1921): 524-27; Baruch, B M. *American Industry in the War: A Report of the War Industries Board*. New York: Prentice-Hall, Inc., 1941; Landes, D S. *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*. Cambridge University Press, 2003.

[70] WSJ. "America Manufactures Dyes on Big Scale." *Wall Street Journal*, October 7, 1918; Baruch, *American Industry in the War,* 1941. Haber, L F. *The Chemical Industry 1900-1930: International Growth and Technological Change*. Oxford, UK: Oxford University Press, 1971.

[71] LAT. "Coal Tar Basis of Defense: Its Products Needed for High Explosives." *Los Angeles Times* February 13, 1916.

[72] Clark, V S. *History of the Manufactures in the United States: 1893-1928*. Vol. III, New York: McGraw-Hill Book Company, 1929.

[73] Haynes, *World War I Period*, 1945.

[74] Haber, *Chemical Industry,* 1971. The dependence of the United States on German chemicals and Germany's need for American markets is demonstrated by the fact that two secret shipments of chemicals arrived in 1916 by way of German "Merchant" U-boats. The first U-boat arrived at the port of Baltimore, Maryland on July 9, 1916 loaded with German Naval Intelligence officers and 750 tons of concentrated synthetic dyes in all the colors of the rainbow (3042 cases of dyestuffs at ~500 pounds each). The Germans left 5 days later with 400 tons of bagged nickel, 90 tons of tin in pigs, 400 tons of crude rubber, .5 tons of jute, and possibly $4 million in gold bullion. The second U-boat arrived at New London, Connecticut on November 1, 1916, loaded to the brim with synthetic dyestuffs and pharmaceuticals. It departed 17 days later with over 1000 tons of rubber, metals, and oil,

"Force," as Marx argued, "is the midwife of every old society pregnant with a new one."[75] The threat and exercise of force is an economic power, one that hastens the ripening of technology, infrastructure, and industry. Lutz Haber, the second son of Fritz, echoed this sentiment 100 years later when he characterized the Great War as a technological "forcing house" for applied chemistry and the chemical industry.[76] Not only did the war raise chemistry to the forefront of military imaginaries, it also reshaped the landscapes of the chemical industry and thoroughly reshaped humanity's active relation to nature.[77] "For the first time chemicals became news. Strange words – benzene, phenol, Salvarsan, salicylates – flashed in the headlines."[78]

During WWI, in order to meet the demands of the first industrialized war, massive chemical plants with enormous fixed capital requirements, owned by large often highly diversified companies, emerged as the ideal type.[79] WWI also marked the general shift from batch to continuous production that dominates all but the most specialized chemical manufacture today.[80] Although chemicals entered warfare through almost every conceivable channel, chemical warfare and the manufacture of explosives were the most prominent facilitators of applied chemistry during the war.

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including 6.2 tons of silver that had been shipped by train from San Francisco. Messimer, D R. *The Merchant U-Boat: Adventures of the Deutschland 1916-1918*. Annapolis, MD: Naval Institute Press, 1988; Anonymous. "The Deutschland Eluded Foe with $10,000,000 Cargo." *New York Times*, November 2, 1916.

[75] Marx, K. *Capital: A Critique of Political Economy*. New York: Penguin Books, 1976.

[76] Haber, *Chemical Industry,* 1971. 184

[77] NYT. "Coal Tar Products Fill Daily Needs: Almost Every Luxury and Necessity Has Something Derived from the Substance That Gives Heat." *New York Times*, June 15, 1914. "Directly out of the exigencies of the World War sprang such notable chemical progress as could have hardly been accomplished in half a century of normal industrial and technical advance." Haynes, *Chemical Economics*, 1933. 225.

[78] Haynes, *World War I Period*, 1945. 36.

[79] Cochrane, R C. *The National Academy of Sciences, the First Hundred Years 1863-1963*. Washington, DC: National Academy of Sciences, 1978. 176. "American attitude toward the size of chemical works, which was, in short, to build a large plant and then find a market for the products."

[80] Aftalion, F. *A History of the International Chemical Industry*. Philadelphia, PA: The Chemical Heritage Foundation, 2001.

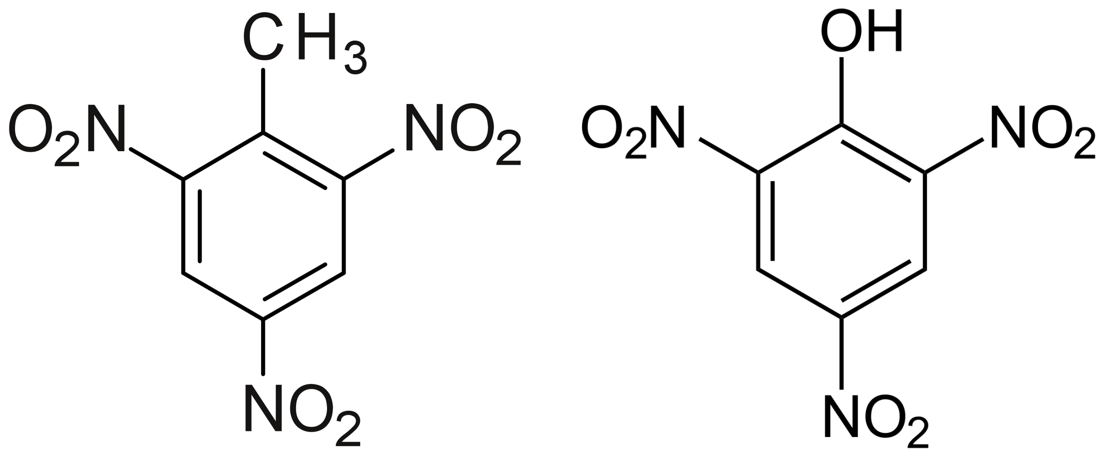

Figure 2 – a) Trinitrotoluene (TNT) and b) Trinitrophenol (TNP)[81]

Take TNT (2,4,6-trinitrotoluene), the war's primary high explosive, for example (See Figure 2a).[82] TNT was a new organic chemical that required toluene (aka benzol) as its synthetic feedstock.[83] The production of toluene required coke oven waste recovery infrastructure and separation technology.[84] Between July of 1914 and April of 1917, US toluene production surged from 700,000 pounds per month to over 6 million pounds per month as waste recovery technology spread across the coking industry. By November of 1918, US wartime output peaked at 12 million pounds per month.[85] Besides TNT, one of the other main high explosives used in WWI was TNP (2,4,6-trinitrophenol), commonly known as picric acid. It was either used pure or in its ammoniated form (See Figure 2b).[86]

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[81] Wikipedia. "Trinitrotoluene Chemical Structure." http://commons.wikimedia.org/wiki/File:Trinitrotoluene.svg.; Wikipedia. "Trinitrophenol Chemical Structure." http://commons.wikimedia.org/wiki/File:Pikrinsäure.svg.

[82] Robertson, R. "Some War Developments of Explosives." *Nature* 107 (1921): 524-27; Crowell, B. *America's Munitions 1917-1918: Report of Benedict Crowell, the Assistant Secretary of War, Director of Munitions*. Washington DC: Government Printing Office, 1919.

[83] A more accurate description would be "disruptive" rather than "high" explosive.

[84] LAT. "Coal Tar Basis of Defense: Its Products Needed for High Explosives." *Los Angeles Times* February 13, 1916.

[85] Besides the expansion of toluene recovery from coking gases, industrial chemists also sought new sources of toluene. Radical changes in the toluene manufacture first occurred in California, where two plants for toluene recovery were built in 1917 to recover toluene from the waste byproducts of recently installed high temperature thermal petroleum cracking units. The first plant was installed at an LA refinery of the General Petroleum Company, and the other at the San Francisco refinery of Standard Oil of California. These two plants had a combined capacity of 3 million pounds per month, and their capacity resolved any issues of toluene shortages for the remainder of the war. Williamson, H, R, Andreano, A Daum, and G Klose. *The American Petroleum Industry: The Age of Energy 1899-1959*. Evanston, IL: Northwestern University Press, 1963. 423; Crowell, *America's Munitions*, 1919.

[86] The French and British preferred picric acid while the American's preferred ammonium picrate due to its increased stability. Picric acid was also an intermediate in the manufacture of chloropicrin, a widely used chemical weapon during WWI after 1917, and the 4th most widely used soil fumigant in the US. It is usually applied in combination with methyl bromide, the 3rd most consumed agricultural fumigant. Together about 20 million pounds of active ingredients chloropicrin and methyl bromide are consumed by agriculture every year.

Unlike TNT, the critical ingredient in the manufacture of picric acid was phenol, which must first be synthesized from coal-tar derived benzene in a two-step chemical process.[87]

While initially caught off-guard by the war's advent, US coal-tar and chemical companies rapidly developed toluene and phenol capacity through the expansion of byproduct coking ovens and phenol production plants. Even though US industry lacked critical chemical engineering abilities at the war's outbreak, by the end of the war, US industry was producing more than 160 tons of phenol per day in highly sophisticated chemical plants.[88] But in order to synthesize large amounts of phenol, large amounts of other chemical feedstocks, like sodium hydroxide, were also needed.

Thus, besides the development of a coal-tar based organic chemical industry, one of the most lasting changes brought about by the Great War was the massive expansion of the electrolytic chlor-alkali industry.[89] The chlor-alkali industry is an entire branch of the chemical industry based on the separation of salt and the manufacture of sodium and chloride based chemicals, like sodium carbonate (Na_2CO_3), sodium hydroxide (NaOH), sodium hypochlorite (NaClO), and chlorine gas (Cl_2).[90] Although sodium chloride (NaCl) is one of the most common salts we experience, sodium and chlorine do not exist in large quantities as separate elements. They must be separated industrially using large amounts of energy. The demands of World War I and the advances of American industrial chemists upended the chlor-alkali industry across the world. By the end of the war, American industry had established itself as the most proficient in the chemical manipulation of salt.[91]

Historians of the chemical industry often label WWI as the impetus for the second chlor-alkali revolution. This claim is based on two main changes to the industry. The first development was the expansive turn toward the electrolytic method of separating sodium and chloride. By harnessing electricity as a separation reagent, sodium and chloride could be split much more efficiently than any previous method. During WWI, the US's rapid expansion of chlor-alkali production was entirely electrolytically based, which severed the longstanding reliance on the Solvay soda process as the dominant industrial process for

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[87] One of the main byproducts of picric acid manufacture was para-dichlorobenzene. While para-dichlorobenzene was experimented with as a fumigant prior to and during the war, it was only with the massive expansion of trinitrophenol production during the war that the scale of its waste products reached the necessary scalar/spatial thresholds to make it cheap enough to extensively use, along with developments in scientific understanding advanced enough so it could enter agricultural production as a protectant against the peach tree borer and for household consumption where it replaced naphthalene in moth balls.

[88] Haynes, *Chemical Economics*, 1933; Haynes, *American Chemical Industry,* 1945; Haynes, *World War I Period*, 1945. Dow chemical and the Monsanto chemical company had the most advanced chemical plants, and Dow emerged during the war as the largest phenol producer in the US. Aftalion, *International Chemical Industry*, 2001.

[89] This branch is often referred to as the heavy chemical industry. WWI also saw the critically the full-fledged industrialization of the Fridel-Crafts chemical reaction in the US. The Fridel-Crafts is a reaction that attaches halides like chlorine and bromine to aromatic compounds, and a process that German industry had industrially perfected decades earlier.

[90] The Chlor-Alkali industry is defined by the Standard Industrial Classification Manual (product code 2812) as an industry that is concerned with producing and utilizing the basic chemicals: chlorine, sodium hydroxide (caustic soda), potassium hydroxide (caustic potash), sodium carbonate (soda ash), potassium carbonate, and sodium bicarbonate.

[91] Murray, R L. "The Chlor Alkali Industry in the United States." *Industrial and Engineering Chemistry* 41, no. 10 (1949): 2157-64; Hubbard, D O. "The Chlor-Alkali Industry, 1902-1952." *Journal of the Electrochemical Society* 99, no. 11 (1952): 307C-09C.

producing soda ash (sodium carbonate) and bleaching powder (calcium hypochlorite).[92] The second change is that WWI marks the shift away from sodium-based chemicals as primary product of the chlor-alkali industry. During WWI, chlorine, formerly a waste byproduct of the soda industry, began the transformation into a chief concern of the industry. This shift would be solidified in the lead up to and following WWII as organochlorine chemicals infiltrated commodity markets, chemical synthesis, industrial production, and the environment. The need for an enlarged chlor-alkali industry, particularly for the production of chlorine, is clearly demonstrated by an experimental chemical warfare agent and in the post war manufacture of phenol.

On a Somme battlefield in the summer of 1916, the French lobbed a concoction called Vincennite at German Troops. Vincennite, made in France with American produced chemicals, was a combination of hydrogen cyanide (HCN), tin (stannous) chloride (SnCl), arsenic chloride (ArCl), and chloroform ($ChCl_3$). While the weapon was not sufficiently effective to warrant further military use, its composition is emblematic of the changing nature of the chlor-alkali industry, as each toxic component within Vincennite either contains sodium and/or chlorine or it requires the use of them in their manufacture.[93] Better known and more extensively used chemical weapons like phosgene ($COCl_2$), chloropicrin (Cl_2CNO_2), and mustard gas (ClC_2SC_2Cl) also drove the demand for chlorine. For these compounds, chlorine served as the active agent in both their manufacture and their biochemical terror.[94] Chlorine's necessity was even true of organo-arsine chemical weapons that the US developed – like Lewisite and Adamsite – that would have debuted with the return of spring in 1919.[95] On August 12, 1918, in the northwest corner of Washington, DC, the largest chlorine plant in the world came online. Built on the grounds of the Chemical Warfare Service's Edgewood Arsenal (now American University), industrial chemists of the CWS used electrified Nelson (mercury) separation cells to produce 100 tons of liquid chlorine per day.[96]

Prior to WWI, chlorine, produced in stoichiometric equivalence with sodium, was in chronic oversupply. During the war, the chlorine element took on innumerous new roles. In the interwar period the demand for chlorine exploded for direct chlorination processes, like bleaching and water treatment, and for organic chemical synthesis. It was in the interwar period that chlorine, the unruly halogenic component of synthetic contamination, was cast in its lead role.[97] While the rapid expansion of electrolytic chlor-alkali production

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[92] Haynes, *World War I Period*, 1945.

[93] Chloroform also emerged as a potent general anesthetic during WWI, with the US shipping more than 1,000,000 pounds to allies for surgical use.

[94] Crowell, *America's Munitions*, 1919. 397.

[95] Adamsite would see it first use as riot control agent during the Bonus Army Protests in Washington DC in 1932 and in other communist and union protests of the 1930s. Vilensky, J A. *Dew of Death: The Story of Lewsisite, America's World War I Weapon of Mass Destruction*. Bloomington, IN: Indiana University Press, 2005.

[96] It was actually two separate 50-ton units. The sodium-based byproducts of this plant were used to absorb toxic wastes from the manufacture of other war gases and explosives. Haber, *Chemical Industry,* 1971.

[97] Roark, R C, and R T Cotton. "Fumigation Tests with Certain Aliphatic Chlorides." *Journal of Economic Entomology* 21, no. 1

and the development of new uses for chlorine highlights the "ingenious skill of American technical men in finding uses for any available chemical," as historians have argued, it also points to a political economic threshold that chlorine must have crossed in its transmutation from waste to value.[98]

The chemicalization of United States during the war, however, could not have taken place without (autocratic) government intervention, large-scale industrial cooperation, and effective coordination of applied science and research.[99] Industrial development in the early years of the war was hesitant and haphazard, due in part to promises of a speedy war and resumption of trade with Germany. By the end of 1915, as the war ground to an attritional halt, the industrial picture had begun to recrystallize as industries responded to the wartime demands of US allies. In early 1916, as it became clear the United States was moving toward full-fledged war, the US established the Council on National Defense, legislatively burdening it with the complex task of turning the resources and industries of the United States toward the trenches of the European theatre. The Council immediately surveyed 18,000 industrial plants and munitions resources across the US.[100] Later on that year, upon the request of the Wilson Administration, the National Academy of Sciences formed the National Research Council (NRC) to function as the clearinghouse for wartime scientific activity[101].

In April of 1917, immediately following the US declaration of war, the Council on National Defense formed multiple divisions, and each limb was tasked with specific set of responsibilities. The Munitions Standards Board, for example, collaborated with the War and Navy Departments to standardize munitions manufacture across the US, while the War Industries Board became the clearinghouse for the Government's insatiable and often novel material needs. The newly minted National Research Council became the acting Department of Science and Research for the Council of National Defense.[102]

That same month the NRC convened a Committee on Noxious Gases to support the US Bureau of Mines (the forerunner to the Chemical Warfare Service) on all scientific aspects of offensive and defensive chemical warfare. Later that year the NRC became the scientific supervisor of the Army Signal Corp and the Naval Research Office. By the end of

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(1928): 135-42.

[98] Marx, *Capital, Vol. III*, 1981.

[99] "Her [America's] brilliant, if pitiless, war industry had entered the service of patriotism and had not failed it. Under the compulsion of military necessity a ruthless autocracy was at work and rightly, even in this land at which the portals of which the Statue of Liberty flashes its blinding light across the seas. They understood war." von Hindenburg, P. *Out of My Life*. Translated by F A Holt. Vol. 2, New York: Harper & Brothers Publishers, 1921.

[100] Via the Naval Consulting Board and the Kerman Board, respectively. Baruch, *American Industry in the War,* 1941.

[101] The NRC was composed of military representatives and scientific and business representatives from civilian departments, universities, research foundations, and industrial firms. Critically though, the formation of the NRC solidified the role of the applied (engineering) sciences in US scientific and industrial policy. Yerkes, *New World of Science,* 1920.

[102] "A Council of National Defense is established, for the coordination of industries and resources for the national security and welfare, to consist of the Secretary of the Army, the Secretary of the Navy, the Secretary of the Interior, the Secretary of Agriculture, the Secretary of Commerce, and the Secretary of Labor." - 50 U.S.C. § 1 : US Code - Section 1: Creation, purpose, and composition of council.

the war the NRC was occupied in every branch of applied science throughout the US – engineering, agriculture, medicine, chemistry, explosives, textiles, meteorology, optics, geography, geology, metallurgy, psychology, acoustics, photography – including direct involvement in the Chemical Warfare Service and anti-submarine research.[103]

Even so, the National Research Council's wartime influence can be hard to gauge. While the NRC was directly involved in the development of sonar and chemical warfare, most of the applied research that it coordinated took place within the confines of industrial laboratories and universities across the US. What we can say for sure is that the Great War, mediated in the US by the Council on National Defense via institutions like the National Research Council and War Industries Board, ushered in a "new world" of industrial scientific cooperation and highlighted the role of applied science in national security and economic prosperity.[104]

By virtue of a common cause, the first major industrial war brought together formerly competing companies with the anti-capitalist despotism that is government oversight. Even the empirically minded statisticians of the War Industries Board agreed with the politician's boisterous claims on the benefits of wartime cooperation. In the disinterested language of prices they embraced capitalist coordination. "[T]rust-made products" they said "seem to have steadier prices than products made under conditions of free competition."[105] Perhaps most importantly though, the war, by forcing (like a hothouse) the maturation of the US chemical industry, accelerated the "chemicalization" of industry and everyday life that proceeded so rapidly throughout the interwar years.[106]

In the late fall of 1918, just as the US's war machine was picking up speed, Germany's broke down. The United States and its industries were caught off-guard by Germany's surrender. Immediately upon armistice, US chemical capacity shifted from wartime necessity to peacetime overextension. With a few pen strokes, huge stocks of basic

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[103] TWP. "Wizardries of Modern Chemistry Shown: Remarkable Work of the National Research Council Is Presented in Nontechnical Manner." *The Washington Post*, March 20, 1921; Cochrane, *National Academy of Sciences,* 1978. The NRC's 1916 and 1917 operations were funded by private organizations such as the Rockefeller Foundation, the Carnegie Corporation, the Mellon Foundation, and the Engineering Foundation, which gives some insight into the industrially cooperative nature that framed the creation of the NRC.

[104] This cooperation with the government during the war had a two-pronged effect. The first is that it brought competing manufacturers together under a common cause, which helped to establish establishing personal relationships between rival companies and government officials. The second is that the war also galvanized new approaches to material efficiency and new possibilities for the reutilization of industrial waste. Haber, *Chemical Industry,* 1971; Anonymous. "Minutes of National Research Council, June 30," 1920; Yerkes, *New World of Science,* 1920.

[105] Mitchell et al., *History of Prices*, 1919.

[106] John Teeple, a prominent chemical engineer during WWI and the post war period, coined the term chemicalization. The chemicalization of industry is a complex phenomenon that must be distinguished from the mechanization of industry. It has proceeded socio-historically (and usually chronologically) on three related fronts: to modify materials (like tanning/dyeing), to save time or lower costs (bleaching and substitutes for natural products), and to create new synthetic products (like dyes, plastics, and pesticides), materially derived from the wastes of other industrial processes. In agriculture, for instance, processes of chemicalization and mechanization have differing effects on labor requirements. Romero, "From Oil Well to Farm," 2016. Further, these two phenomena often occurred in different orders in different places. In California, the citrus industry chemicalized more than three decades before its mechanization. Romero, A. "Commercializing Chemical Warfare: Citrus, Cyanide, and an Endless War." *Agriculture and Human Values* DOI:10.1007/s10460-015-9591-1 (2015).

chemicals that dotted US industrial geography lost their destined purpose.[107] "The war," as V. Clark put it, "left American manufactures with overgrown plants, an excess of raw materials, and an arsenal of new ideas."[108] On the 1st of January 1919, the War Production Board lifted export restrictions on most chemicals.[109] Across the US, prices of chemicals "tumbled like a spring freshet over a milldam."[110]

Industrial Collaborations, Scientific Synergisms

During the war, no other American industry grew as rapidly as the chemical industry. In only a few short years, chemical entrepreneurs backed by wartime orders had sunk more than half a trillion dollars into American chemical infrastructure.[111] Indeed, by the end of the war, the use of chemicals had increased so rapidly that almost no US industry could operate without them. US agriculture materialized from the fog of war with a new intensive form that was increasingly reliant on industrially made off-farm inputs like chemical fertilizers, specialty seeds, and economic poisons.[112] Farmers, their fields, and the industries that supplied them, emerged from the war conditioned to a set of pre-WWI economic poisons like lead arsenate, kerosene, lime-sulfur, and nicotine.

After the war, however, as wartime agricultural markets withered, opinions began to crystalize among many factions of crop protection that grave problems for US agriculture lay ahead. The "insect menace," as L.O. Howard so often called the problem, never stopped waging its war against humans. It was now time, these voices chanted, to summon the spirit of the Great War to aid our counter attack.[113] Crop protection companies, scientists, salesmen, and government officials were in agreement that large-scale change was needed to avert an impending pest-induced collapse of American agriculture.[114] The prevention of massive famine and societal collapse, they argued was a task that could only be accomplished by expanding and rationalizing agricultural pesticide consumption.[115] Scientific agriculture

[107] For example: chlorine, caustic soda, soda ash, benzene, naphthalene, aniline, phenol, and acetylene.
[108] Clark, *Manufactures in the United States*, 1929. 324; Clarkson, G. B. (1923). *Industrial America in the World War: The Strategy Behind the Line, 1917-1918*. Cambridge, MA: The Riverside Press.
[109] Haynes, *World War I Period*, 1945. Chapter 27
[110] Haynes, *World War I Period*, 1945. Chapter 27
[111] In 1918 dollars. This number does not count capital invested in petroleum refining infrastructure.
[112] Cochrane, *Development of American Agriculture*, 1993; Olmstead and Rhode, *Creating Abundance,* 2008; Nelson, L B. *History of the U.S. Fertilizer Industry*. Muscle Shoals, AL: Tennessee Valley Authority, 1990.
[113] Jones, L A, and D Durand. *Mortgage Lending Experience in Agriculture*. National Bureau of Economic Research Financial Research Program. Princeton, NJ: Princeton University Press, 1954.
[114] Howard, "Two Billion Crop Loss," 1924; McWilliams, J E. "" The Horizon Opened up Very Greatly": Leland O. Howard and the Transition to Chemical Insecticides in the United States, 1894-1927." *Agricultural History* (2008): 468-95; Anonymous. "Minutes of the Conference of Plant Pathologists, Entomologists, and Manufacturers of Insecticides and Fungicides in Rochester, NY, September 28." In *Institutions: Association Individuals*, National Research Council. Washington DC: Archive of the National Academy of Sciences, 1920; Anonymous. "Minutes of National Research Council, June 30," 1920.
[115] O'Kane, W C. *Injurious Insects: How to Recognize and Control Them*. New York: The Macmillan Company, 1914; Howard, L O. "War Against Insects." *Nature* 109, no. 2725 (1922): 79-80; Howard, L O. *The Insect Menace*. New York: D. Appleton-Century

and world trade had brought many advantages to the United States. However, these advantages also made US farmers increasingly reliant on ever more powerful environmental control. Even though the war had brought intensive and extensive expansion of pesticide consumption, agrochemical advocates argued that these older methods were unsatisfactory and increasingly under the fire of government bureaucracy for their human toxicity, their labeled composition, and their efficacy. [116] Prominent government scientists and agrochemical companies agreed that more efficient and precise protection methods were necessary to deal with the insect-waste problem, make agricultural production more efficient and more profitable, and to save the human race from impending starvation.[117]

By 1920, although there were many firms directly involved in the manufacture of economic poisons, there were very few industrial concerns, especially outside California, that had dedicated research and development departments.[118] Chemical firms such as Dow, Monsanto, the Grasselli Chemical Company, and the General Chemical Company, were making standard materials like lead arsenate and lime sulfur that had been developed before the war. Many of these same companies also introduced a war synthesis waste product – paradichlorobenzene (PDB), whose distinct smell we recognize as mothballs – into agriculture and as a textile and storage fumigant. The rapid adoption of PDB as a fumigant likely had as much to do with a dramatic reduction in price as it did with efficacy, as it was known before the war to be a promising fumigant. As a waste product of explosive manufacture, both its geographical presence and capacity expanded during the war.[119]

Very few chemical companies east of the Rockies were attempting to produce pest control commodities in a modern industrial-scientific manner.[120] One obstacle to progress, NRC officials argued, was that "forward-thinking" chemical producers had no way to adequately and cost-effectively test their new materials. If a company was blessed with a

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Company, 1933; Perkins, "Insects, Food, and Hunger," 1983.

[116] Whorton, *Before Silent Spring*, 1974.

[117] McWilliams, James E. "" The Horizon Opened up Very Greatly": Leland O. Howard and the Transition to Chemical Insecticides in the United States, 1894-1927." *Agricultural History* (2008): 468-95; Yerkes, *New World of Science,* 1920.

[118] Woodworth, CW. "The Insecticide Industries in California." *Journal of Economic Entomology* 5, no. 4 (1912): 358-64; Gray, G P. "The Workings of the California Insecticide Law." *The Journal of Industrial and Engineering Chemistry* 6, no. 7 (1914): 590-94; Gray, G P. "The Consumption and Cost of Economic Poisons in California in 1916." *The Journal of Industrial and Engineering Chemistry* 10, no. 4 (1916): 301-02; Herms, WB. "An Analysis of Some of California's Major Entomological Problems." *Journal of Economic Entomology* 19, no. 2 (1926): 262-70; Gray, GP, and ER De Ong. "California Petroleum Insecticides." *Industrial & Engineering Chemistry* 18, no. 2 (1926): 175-80; Essig, E O. *A History of Entomology*. New York: Hafner Publishing Company, 1931; Fleury, A C. "Fifty Years of Plant Quarantine Activity in California." *Journal of Economic Entomology* 25, no. 3 (1932): 470-76; Stoll, *Fruits of Natural Advantage*, 1998.

[119] Erlrnbach, A. "Process of Destroying Insects." *Patent # 1,907,406*, United States Patent Office. USA: Actien Gesellschatt Für Analin Fabrikation of Berlin, Germany, 1914; Duckett, A B. "Para-Dichlorobenzene as an Insect Fumigant." In *Bulletin 167*. Washington, DC: USDA, 1915; Chandler, SC. "Some Recent Developments in the Use of Paradichlorobenzene." *Journal of Economic Entomology* 17, no. 2 (1924): 246-53; Peterson, A. "Some Soil Fumigation Experiments with Paradichlorobenzene for the Control of the Peach-Tree Borer, *Sanninoidea Exitiosa* Say." *Soil Science* 11, no. 4 (1921): 305-20; Haynes, *Chemical Economics*, 1933; Haynes, *World War I Period*, 1945; Perkins, "Insects, Food, and Hunger," 1983.

[120] Minutes of the Conference of Plant Pathologists, Entomologists, and Manufacturers of Insecticides and Fungicides at the National Academy of Sciences, Washington, DC, September 28. Multiple conference members, none of whom are from the Pacific Slope states, cited California agroindustrial R&D as an example to emulate.

substance that they believed could be a new economic poison, they had little or no access to the biological and agricultural sciences needed to determine its effectiveness, dose, method of application, and environmental longevity. Prior to the war, manufacturers who thought they had a promising new economic poison would often send them to experiment stations and private researchers in the hopes that they would field test it. Many others simply placed it on the market with grand claims and no proof of efficacy or even composition.[121]

In 1906, for instance, after Harvey Wiley, Chief Chemist of the US Bureau of Chemistry and pure food crusader sought to ban the use of sodium benzoate as a food preservative, Herbert Dow sent samples of his sodium benzoate and calcium benzoate food preservatives to hundreds of agricultural scientists, including all the US agricultural experiment stations, asking them to try it out as spray for deciduous tree pests.[122] Accompanied with personal letters from Herbert Dow, many of the scientists written tried out the new spray. But this was not typically the case, especially after WWI, when experiment stations were inundated with the largesse of the "chemist's war" – a cornucopia of novel, possibly toxic, materials, most of which had little merit in agriculture.

Companies could turn to growers and proceed by trial and error, but growers were generally risk averse, plus this approach lacked the scientific credibility that was increasingly demanded by agricultural scientists, progressive (scientific) farmers, and regulatory concerns.[123] With a unique view of post-war industrial geography, many National Research Council and National Academy of Science members believed that across the US, companies were already producing waste materials that had the potential to be modified into toxic or possibly nutritive agricultural inputs.[124] But without access to expert knowledge, these companies had no way of knowing what they possessed and thus could not recognize the agrotoxicological promise of their industrial wastes. In order to insure solutions to pressing agricultural problems and to protect the profits of American agricultural and industrial producers, these prominent NAS and NRC members called for close cooperation between the chemical industry and the biological, chemical, and agricultural sciences.

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[121] Gray, G P. "The Workings of the California Insecticide Law." *The Journal of Industrial and Engineering Chemistry* 6, no. 7 (1914): 590-94.

[122] For example: Dow, H. "Letter from Herbert Dow to Fred Snyder." In *Herbert H. Dow Papers*, Post Street Archives: Chemical Heritage Foundation, 1906; Dow, H H. "Letter from Herbert Dow to Luther Burbank." In *Herbert H. Dow Papers*, Post Street Archives. Philadelphia, PA: Chemical Heritage Foundation, 1906; Burbank, L. "Letter from Luther Burbank to Herbert Dow." In *Herbert H. Dow Papers*, by Post Street Archives. Philadelphia, PA: Chemical Heritage Foundation, 1906. Whorton, *Before Silent Spring*, 1974.

[123] Anonymous. "Minutes of the Conference of Plant Pathologists, Entomologists, and Manufacturers of Insecticides and Fungicides at The Hotel Seneca, Rochester, NY, June 30." In *Institutions: Association Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences, 1920; Essig, E O. *A History of Entomology*. New York: Hafner Publishing Company, 1931; Whorton, *Before Silent Spring*, 1974; McWilliams, *American Pests,* 2008.

[124] Some of this eventual waste reutilization would fit the definition of chemurgy, i.e. the industrial utilization of agricultural surplus/wastes. For instance, blood albumin, casein, and other byproducts of dairy and slaughter were industrially utilized as stickers/wetters/emulsifiers for pesticides in agriculture, which contributed to increased yields and overcapacity in kind of a self-reinforcing chemurgic cycle (!).

In the early summer of 1920, at the Seneca Hotel in Rochester, NY, the National Research Council's Division of Research Extension convened a very unique conference. "Created under the relentless pressure of war, [the NRC was] endeavoring to secure in times of peace, close cooperation, both in planning and execution of research, requisite to bring to the nation the largest possible rewards from scientific investigation."[125] In 1919, seeking to capitalize on its wartime accomplishments, the NRC had created the Division of Research Extension to serve as its "industrial relations" arm, whose goal was to promote, develop, and disseminate applied science across US industry.[126] To accomplish this for agricultural industry, the Division of Research Extension brought leading crop protection scientists from plant pathology, economic entomology, and chemistry together with government officials and the manufacturers of agricultural chemicals and allied equipment to discuss the pest control crisis in the United States. By the end of this noteworthy meeting, the sparks of national agrochemical reform would be born.

H.E. Howe, Vice Chairman for the Division of Research for the National Research Council opened the meeting by extolling the virtues of the NRC, highlighting its role as a clearing-house for the natural sciences, its role in advancing the technical capabilities of the US in the Great War, and the new role of the NRC in peace times. The goal of the NRC, Howe insisted, was to extend scientific research into all facets of industry for the benefit of the people of the United States. American agriculture faced grave problems, and due to the unique scalar and biological characteristics of agricultural, these problems accrue to all members involved whether or not they are the explicit cause.[127] Capitalism is about competition among firms, but as the Great War showed, competitors can also unite to attack common problems.[128] Controlling injurious insects and plants diseases, Howe challenged, is a complex problem whose solutions will benefit all crop protection interests.

Dr. Parrott spoke next on behalf of economic entomologists.[129] He outlined the key reasons why chemical pest control work is restricted in its attempts to develop a sounder scientific basis, citing lack of cooperation between experiment station workers, farmers, and industry and university scientists as the main factor in the progress of scientific agriculture. He emphasized that the prevailing policies of state experiment stations and the USDA confined the station entomologist to their home state and limited the use of private funds for experiment station research. Spatial and temporal complications that arise in economic entomology, what Parrot called "the science of industrial pest control," provide the clearest example of the need for coordinated large-scale research across diverse geographies. Without the ability to coordinate spray materials, spray schedules, and delivery methods, scientific results will continue to vary across time and space. Dr. Lyman followed Dr. Parrot

[125] Cochrane, *National Academy of Sciences,* 1978. 418.
[126] Cochrane, *National Academy of Sciences,* 1978.
[127] By nature an extensive industry based in natural processes. Mann, *Agrarian Capitalism*, 1990.
[128] Yerkes, *New World of Science,* 1920; Haynes, *World War I Period*, 1945; Haber, *Chemical Industry,* 1971.
[129] Geneva, NY experiment station.

and spoke on behalf of plant pathologists, who, he echoed, find themselves in the same situations as economic entomologists. There is a need to harmonize conflicting results in different regions "so that manufacturers can intelligently push for the sale of their product."

G.R. Cushman of the General Chemical Company spoke on behalf of chemical manufacturers. Agreeing with all the previous speakers, he argued that past antagonisms between manufacturers and government officials must be forgotten. Cooperation is necessary to attack common problems. Cooperative solutions will benefit both industry and farmers through the expansion of chemical control. He said "the problem of the manufacturers is one of tonnage. The solution of problems which will extend the use of fungicides and insecticides will make for cheaper production." Once scientists agree on the composition and strength of fungicides that are effective across different regions, it will lower the cost of marketing and make sales easier and more consistent and accompanying economies of scale will result in cheaper insecticides.[130]

Following the morning session, H.E. Howe, on behalf of the NRC, appointed industry, government, and scientific representatives to an organization committee. The meeting was then adjourned until the afternoon when they would receive the organization committee's report. After lunch the organization committee presented the conference members with the bylaws for an independent non-governmental organization known as the Plant Protection Institute, whose membership would be composed of crop protection scientists, chemical companies, and manufactures of pesticide spray and delivery equipment. Conference members agreed that the goal of the Plant Protection Institute should be to promote the general welfare of US agricultural food producers, manufacturers of insecticides, fungicides, and allied equipment, and through them, the American public. The committee proposed that the money for scientific investigation as well as for the institute's expenses would come the annual dues of member companies, fulfilling the NRC's mission to create a self-supporting non-governmental organization. Preliminary organization of the institute was proposed and the conference adjourned with the rest of the work to be done by the organization committee at the next meeting of the Biological and Agricultural Division of the National Research Council in September of 1920.

On the morning of September 28th, 1920, the Division of Research Extension of the National Research Council convened a meeting at the National Academy of Science in Washington, DC, to discuss the proposed Plant Protection Institute. Present at the meeting were members of the NRC's Division of Research Extension, various prominent crop protection scientists, representatives from select chemical companies, and the upper echelons of the USDA and its Bureaus. Dr. H. A. Bumstead, chairman of the NRC, began the meeting by outlining the three ways in which the proposed institute would be an example of activity which the NRC was anxious to foster: 1) means for conference between industry and science, 2) cooperation between different sciences interested in common

[130] The two dominant scaling functions come together - economies of scale with economies in the reuse of waste.

problems, 3) cooperation rather than competition in pursuing fundamental research. He concluded by emphasizing that since there were no existing organizations that would bring the chemical industry and agricultural science together at that time, the National Research Council would fully support the formation of the renamed Crop Protection Institute.[131]

Dr. E.D. Ball, Assistant Secretary of the USDA, spoke next. The country was faced with terrible economic problems, he argued, and agriculture occupied a fundamental position in dealing with these problems. Increased cooperation between government, industry, and crop protection scientists was needed to relieve the country of its agricultural woes.[132] Debate then ensued on the commercial and non-governmental nature of the CPI. For instance, Dr. K. F. Kellerman, director of the US Bureau of Plant Industry, questioned the institute's promoters about the constituency of the CPI.[133] "The constituency, Dr. Parrot replied, are the "millions of farmers, stockmen, fruit growers, market gardeners, and other users of these commodities and implements, who *require* [pesticides] for use in agricultural production" (emphasis added). The nature of the proposed CPI governance structure, Parrot argued, with a committee of scientists in charge of selecting studies, would prevent industry from unduly influencing scientific investigation. Dr. Vernon Kellogg, permanent secretary of the NRC and a professional entomologist added that the "sole interest and desire" of the NRC is "to promote research and science" to "win the war against pests and disease… for the benefit of the nation."

Dr. A. F. Woods, former USDA scientist and president of the University of Maryland, reiterated how current restrictions hindered USDA and state experiment station work. USDA and station scientists couldn't use funds from outside the department for research, and experiment station scientists were often limited in their ability to undertake or coordinate interstate research because of travel restrictions. The CPI's organizational structure, Dr. Woods argued would overcome these political and bureaucratic obstacles, and despite these restrictions and grumblings from within USDA Bureaus, the USDA would cooperate with the Institute to the fullest degree possible.

After lunch, H. E. Howe, submitted the proposed constitution and bylaws of the Crop Protection Institute to the organizing committee with the wording in the membership section specifically left vague. They adopted it section by section, then as a whole. Debate ensued over dues, resulting in a decision that bifurcated membership into two classes – scientific and industrial members – with different but uniform dues for each class. The meeting then turned toward what type of projects the institute should undertake. Many

[131] The name was changed between meetings to emphasize the breadth of the Institute. Plant protection denoted a commitment to investigation protecting growing plants. The protection of plants in their growth phase is just one small part of the expanding agricultural production complex. Founders of the CPI saw potential for chemicals in all arenas, including food processing, storage, and transportation. The shift from "Plant" to "Crop" helps demarcates the ideological shift from small-scale agriculture to progressive agriculture.

[132] He was thinking of the dramatic fall in farm prices since the end of WWI.

[133] He pointed out that for the most part, the knowledge that the commercial insecticidal industry uses has come in one way or another from government work done by and funded by taxes collected from all the people of the United States.

committee members stressed the importance of the standardization and simplification of spraying schedules, insecticides and fungicide labels, and spraying recommendations. Others argued for the creation of brief and simplified correspondence courses for salesman on the life history of plants, injurious insects, plant disease, and the emerging knowledge of insecticides and fungicides.[134] The meeting concluded with a general vote of the NRC's Division of Research Extension to affirm the proposed by-laws, the first Board of Governors, and the continued role of H.E. Howe as CPI secretary and NRC liaison.

The CPI's mandate inscribed in the bylaws was the following: [135]

1) To promote the efficient control of injurious insects, plant diseases, and toxic substances affecting economic and ornamental plants and their products.
2) To promote efficient control of insects and plants injurious to man, domestic animals and animal products; and for that purpose to hold patents, copyright, or to take other suitable measures
3) To support and direct research upon these and other problems of a similar nature.
4) To further cooperation between scientific workers and the producers of chemicals; the manufacturers of insecticides, fungicides and other similar materials; the manufacturers of appliances required for their use; and the manufacturers, growers, packers and shippers of the foregoing and of plant, animal, and other products.
5) To assist in the dissemination of scientifically correct information regarding the control of injurious insects, plant diseases, and toxic substances.
6) The utilization of the byproducts of industrial manufacture

In late September of 1920, at the National Academy of Sciences in Washington, DC, the National Research Council officially established the Crop Protection Institute in order to link the expertise and facilities of US agricultural experiment stations with the capital and toxic materials rapidly developing from the post-WWI agrochemical complex. With the formation of the Crop Protection Institute, the NRC started "[a] get-together movement on the part of three groups – the intelligent grower, the scientist, and the business man" – a movement that would help congeal the bonds between private capital and public agricultural science that became second nature after WWII.[136]

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[134] This would in a similar fashion to the training that salesman of the California Spray Chemical that was an obligation of the job. Woodworth, CW. "The Insecticide Industries in California." *Journal of Economic Entomology* 5, no. 4 (1912): 358-64; Stoll, *Fruits of Natural Advantage*, 1998.

[135] "Constitution and by-Laws of the Crop Protection Institute." In *Institutions: Association Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences. 1920.

[136] Van Der Bosch, *Pesticide Conspiracy*, 1978; Hightower, "Hard Tomatoes, Hard Times," 1972; Jennings, B H. "The Killing Fields: Science and Politics at Berkeley, California, USA." *Agriculture and Human Values* 14, no. 3 (1997): 259-71; Kloppenburg, J R. *First the Seed: The Political Economy of Plant Biotechnology*. Madison, WI: University of Wisconsin Press, 2004. The influence of private capital on (public) agro-food research is not as studied to the extant that private capital's influence on academic and government pharmaceutical research and testing. Boseley, S. *The Shape We're In: How Junk Food and Diets Are Shortening Our Lives*. Guardian Faber Publishing, 2014. This pattern is changing though the "rediscovery" of the role of diet and environmental chemicals in health. Ex. Bes-Rastrollo, M, M B Schulze, M Ruiz-Canela, and M Martinez-Gonzalez. "Financial Conflicts of

The first annual meeting of the Crop Protection Institute took place the following December in Washington, DC.[137] At this meeting, the CPI and NRC brought institute members and prominent USDA cotton scientists together with chemical companies and dusting machine manufacturers in order to standardize dosage and mixture recommendations for calcium arsenate on southern cotton.[138] Less than a month after the first official meeting, in response to surprising growth of its scientific and industrial member base as well as to legal advice from NRC attorneys, the Board of Governors of the CPI modified the institute's by-laws in order to allow for the expansion of industrial membership.[139] This modification changed how individual companies funded specific projects and how experiment stations would be chosen for specific projects. It also removed industrial members from the Board of Governors as part of the justification for increased funding flexibility.[140] As a result of these changes, industrial membership was spliced into separate Divisions,[141] each with its own board of financial trustees derived form the industrial members of that division. For all divisional matters and for the securing of special funds, the charge was laid with these division trustees. The ultimate say, however, in the approval, design, and direction of the project, including which experiment stations were chosen for which project, as well as any patents that arose from the research, remained with the CPI's Board of Governors.[142]

Interest and Reporting Bias Regarding the Association between Sugar-Sweetened Beverages and Weight Gain: A Systematic Review of Systematic Reviews." *PLoS medicine* 10, no. 12 (2013): e1001578; Bergman, Å, A-M Andersson, G Becher, M van den Berg, B Blumberg, P Bjerregaard, C-G Bornehag, *et al.* "Science and Policy on Endocrine Disrupters Must Not Be Mixed: A Reply to a "Common Sense" Intervention by Toxicology Journal Editors." *Environmental Health* 12, no. 1 (2013): 69.

[137] The attendance of USDA scientists like Professor Coad was critical to fulfilling the first project of the CPI, which was to produce a standardized set of recommendations and schedules for calcium arsenate on cotton. Anonymous, "Annual Meeting, December 6," 1920; Anonymous. "Crop Protection Institute Discusses War on Boll Weevil." *The Journal of Industrial and Engineering Chemistry* 13, no. 1 (1921): 89; TWP. "Organization Formed for Crop Protection." *The Washington Post*, January 4, 1925; Anonymous. "The Crop Protection Institute." *Crop Protection Digest* 1, no. 1 (1921); O'Kane, "Crop Protection Institute," 1920.

[138] These standardized dose recommendations reached southern cotton growers via a series of USDA pamphlets and publications over the next few of years For example: Hunter, W D, and B R Coad. "The Boll Weevil Problem and Methods of Reducing Damage." *Farmer's Bulletin* 1262. Washington, DC: USDA, 1922.

[139] McClung, C E. "Letter from to C. E. McClung, Chairman Division of Biology and Agriculture, NRC, to H. E. Howe, Chairman Division of Research Extension, NRC, January 29." In *Institutions, Associations, Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences, 1921; Lyman, G R. "Letter from to G R Lyman to H E Howe January 29." In *Institutions, Associations, Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Science, 1921.

[140] NRC. "Sixth Annual Report of the National Research Council." Washington, DC: National Research Council, 1922. The nine member Board of Governors changed to include three representatives from the American Association of Economic Entomologists, two representative from the American Phytopathological Society, three representatives from the Association of Official Agricultural Chemists, and one representative from the National Research Council. The Board of Governors selected the Officers, Chairman, and Secretary-Treasurer annually.

[141] For example the Division of Insecticides and Fungicides contained all insecticide and fungicide members. Divisions could be expanded and/or increased in number as other groups of manufacturers join, making possible the continuous enlargement of the institute.

[142] The CPI patent, funding, and publication structure became an issue again in 1925 when company sponsored fellowships were introduced and specifically when Standard Oil and the CPI entered a research contract for patented product named "FLIT." In the contract Standard Oil claimed exclusive rights to the knowledge produced during the research and the CPI could only publish the research "under agreement" with Standard Oil. Kellogg, V. "Letter from V. Kellogg, Permanent Secretary of the NRC, to G.

Extensive Boundaries, Intensive Frontiers

In the fall of 1920, a thick melancholy of agricultural depression descended upon US agriculture. By 1921, national farm income had dropped from a war-driven high of $16.9 billion in 1919 to less than $9 billion.[143] After the war, US farmers confronted an entirely different agricultural reality. Increasingly reliant on off-farm inputs like mortgages, fertilizers, and wage labor, they began returning home from the market each year with less money than they spent to raise their crop.

The war also spurred a shift in US demographics as people from distributed rural communities coalesced into dense urban centers.[144] In the 1920s, the majority of the US population became urban. Thus, besides struggling to feed their families, farmers suddenly found themselves numerically and politically outnumbered by city folk. Although some farmers would recover by the mid 1920s, the market generally punished US farmers for the mortal sin of chronic collective overcapacity.[145]

But even with national agricultural depression, the great war's effects reverberated across American agriculture, as new tractors, new harvesting machines, new fertilizers, new financial arrangements, new power sources, and new pesticides arrived in greater and greater quantities to the front doors of America's farms.[146] Some farmers sunk more and more capital into their operations to expand and intensify to get their costs of production below that of their market neighbors. In other words, by turning to new technologies like the tractor or pesticides, progressive and scientific famers used capital to expand their economies of scale and intensify their economies of scope. Yields continued to rise. Those who failed to get on the treadmill of agricultural production or those who slipped too far behind their neighbors passed into the annals of US agricultural history.[147] More than ever,

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Dunn, CPI Board of Governors, March 6" In *Institutions: Associations and Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Science, 1925. The wording of the contracts (and all future contracts) was changed to reflect the cooperative nature of the institute and the knowledge it produced; Kellogg, V. "Letter from V. Kellogg to G. Dunn, March 8." In *Institutions: Associations and Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences, 1925.

Kellogg, V. "Memo from P. Moore, Permanent Secretary of the NRC, to V. Kellogg, June 17." In *Institutions: Associations and Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences, 1925; Kellogg, V. "Letter from V. Kellogg to G. Dunn, June 17." In *Institutions: Associations and Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences, 1925.

[143] Perkins, *Crisis in Agriculture*, 1969.

[144] Fite, G C. *American Farmers: The New Minority*. Bloomington, IN: Indiana University Press, 1981.

[145] Wallace, "May," 1933.

[146] Gregor, H F. "Industrialized Drylot Dairying: An Overview." *Economic Geography* (1963): 299-318; Petrick, G M. "'Like Ribbons of Green and Gold': Industrializing Lettuce and the Quest for Quality in the Salinas Valley, 1920-1965." *Agricultural History* 80, no. 3 (2006): 269-95; D, Boyd, and M Watts. "Agro-Industrial Just in Time: The Chicken Industry and Postwar American Capitalism." Chap. 8 In *Globalizing Food: Agrarian Questions and Global Restructuring*, edited by D Goodman and M Watts, 139-59. New York: Routledge, 1997; Bobrow-Strain, A. *White Bread: A Social History of the Store Bought Loaf*. Boston, MA: Beacon Press, 2012; Freidberg, S. *Fresh: A Perishable History*. Cambridge, MA: The Belknap Press of Harvard University Press, 2009; Whorton, *Before Silent Spring*, 1974.

[147] Cochrane, R C. *Farm Prices: Myth and Reality*. St. Paul, MN: University of Minnesota Press, 1958; Cochrane, *Development of American Agriculture*, 1993.

those who failed to contain and direct the "anarchy of competition" into larger yields – "chasing an unattainable goal of higher lasting profits"[148] – subsidized the profits of progressive farmers with their losses.[149] In the interwar era, on-farm chemical consumption exploded as the pesticide treadmill synergized with the treadmill of agricultural production.[150]

The economic and agricultural historian William Cochrane labels the early 1920s as the second of two critical watersheds in the development of US agriculture. The first, he argues, was the US victory in the Revolutionary War, a victory that was eventually manifest as an agricultural destiny dependent on expansionary policy. The second watershed moment, echoing Turner's frontier hypothesis, is the closing of the expansionary US agricultural frontier. This closure occurred concomitantly with the shift of US population to a non-farm majority, creating what Gilbert Fite calls a "new minority" of farmers with diminishing political clout.[151] The demands of WWI and changing demographic properties set the stage for the development of the intensive technologies associated with industrial agriculture today, as farmers tuned inward, calling forth capital to drive their land to produce ever more. Hybrid seed, chemical fertilizer, the crop duster, contract labor and contracted growing, vertical integration and professional managers, and synthetic pesticides became commonplace. "Two blades of grass" and "fencerow to fencerow" became the collective mantras of the day. And yields continued to rise. But this boosterism was not done in service of US farmers who were sinking under the weight of overproduction. In the interwar era, US agrarian power devolved from the hands of farmers to the pockets (and pocketbooks) of politicians, lobbyists, food processors, subcontractors, chemical companies, and government officials.[152]

In the interwar era, the material basis of United States industry qualitatively changed due to the massive influx of chemicals. As farmers struggled to maintain profitability, as the very nature of rural life was dissolving, the chemical industries were transforming the nature of the everyday through the development of new chemicals and new commodities. These new commodities either cheaply imitated natural products or outbid nature by introducing things unknown to humanity. Stein, Vice-President of the Du Pont Chemical Company summed up this revolutionary material shift best:

"We emerged from the First World War with a wholly new concept of our possibilities. For the first time we began clearly to see that when the Creator conferred upon man freedom of choice and action, there were placed in man's hands the tools with which he could shape his destiny and modify

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[148] Levins, R A, and R C Cochrane. "The Treadmill Revisited." *Land Economics* 72, no. 4 (1996): 550-53.

[149] "In 1943 the gain in corn yield due to the use of hybrid lines was sufficient to make an extra fifty-four pounds of corn for every man, woman, and child in the country." Harding, T S. *Two Blades of Grass: A History of Scientific Development in the U.S. Department of Agriculture*. Norman, OK: University of Oklahoma Press, 1947. 100.

[150] Van Der Bosch, *Pesticide Conspiracy*, 1978.

[151] Fite, *American Farmers*, 1981.

[152] Cochrane, *Development of American Agriculture*, 1993; Olmstead and Rhode. *Creating Abundance,* 2008. Jones and Durand. *Mortgage Lending*, 1954.

his future. We learned that it was possible not only to emulate nature but even to excel her in certain fields of creation." [153]

The early 1920s saw American industry, particularly the chemical industry, quickly recovered from the post-war slump caused by overproduction and overcapacity. During the roaring twenties the twin forces of science and technology coupled to changing US consumption patterns brought the chemical industry to new heights. In the interwar era industrially made chemicals permeated the nooks and crannies of both industrial processes and everyday life. As a result of this chemicalization, the US witnessed "revolutionary" growth in chemical consumption in the interwar era.[154] For example, the vats of phenol that lost their destined purpose at the close of the war were a few years later suddenly in demand for the production of novel plastics. [155]

In the interwar era, plastics, synthetic rubbers, synthetic vitamins, new solvents, new pesticides, new medicines, new fuels, new alloys, new lubricants, new colors, new fabrics, and new refrigerants became second nature. For example, Thiokol, one of the first synthetic rubbers, introduced in 1926 and made from the wastes of oil refineries, helped spread the use of gasoline as a transportation fuel because it was resistant to gasoline. By the 1930s, Thiokol lined most of the hoses and tanks of gasoline transportation and service companies and the gasoline industry was the largest commercial user of synthetic rubber. In the interwar era, the automobile and the airplane came of age.

In the interwar era, chemistry was applied to food and foodstuffs; Henry Ford made a car from soybeans; carbohydrate chemists introduced new sugar processing techniques for both cane and sugar beets, increasing an by order or magnitude the sugar yielded from sugar beats; chemists enzymatically manipulated corn. [156] In the interwar era, the chemical industry extended to all frontiers and vast organic enterprises not based on coal sprang up. In the interwar era, both laminated safety glass and mass-produced antibiotics began saving countless lives.

At the same time as the "maelstrom of chemical development" unleashed creative destruction on US industry and mergers and acquisitions saturated the headlines, capitalists adopted some of the government's wartime roles by applying the principles of "scientific management" – aka Taylorism – to individual production processes and the principles of

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[153] Stine, C. "Molders of a Better Destiny." *Science* 96, no. 2492 (1942): 305-11.

[154] Haynes, *Chemical Economics*, 1933; Clark, *Manufactures in the United States*, 1929; Haber, *Chemical Industry,* 1971; Haynes, *World War I Period*, 1945; Haynes, W. *American Chemical Industry: 1923-1929*. Vol. IV, New York: D. Van Nostrand Company, Inc., 1948, Haynes, W. *American Chemical Industry: 1930-1939*. Vol. V, New York: D. Van Nostrand Company, Inc., 1954; Haynes, W. *This Chemical Age: The Miracle of Man-Made Materials*. London, UK: Secker and Warburg, 1946.

[155] In a similar fashion, in the 1920s the Roessler and Hasslacher Chemical Company's advertising and marketing schemes highlighted how their chemicals "play a vital role in the daily life of John Doe," from golfing, travel, and business to clothing, feeding, and sheltering his family. R&H Chemical Company. "R&H Chemicals and Service Advertisement." In *Records of the E.I. du Pont de Nemours & Co. Absorbed Companies Series II Part 1*. Wilmington, DE: Hagley Library and Museum, 1925.

[156] Hale, W. *Chemivision: From Farm to Factory and Fortune*. New York: Destiny, 1952.

coordination to industrial sectors.[157] For example, companies within similar industries developed trade associations and other organizing institutions to help stabilize prices and increase efficiency. Take the Copper and Brass Research Association (CBRA) for example. It formed in 1921 by copper producers who found themselves with too much overstock and overcapacity after the collapse of wartime contracts. The CBRA sought through multiple means – advertising, marketing, lobbying, funding of R&D – to extend the use of its member's products and its members' political interests.[158] The Copper and Brass Research Association through the CPI would fund R&D for the use of copper and copper smelting byproducts as pesticides and micronutrients nutrients (See Appendix 1).

In the interwar years, the techno-social infrastructure of the modern industrial agricultural regime was laid, not just in production, but also in changing consumption patterns, in policies and the political influence that made certain industrial forms possible, in advertising and marketing, in our conception of food and fiber, and in humanity's relation to nature. It was in the interwar years that the infrastructure necessary to generalize and support the full-fledged chemicalization of agriculture following WWII matured.[159]

By infrastructure I mean more than the physical collection of buildings, transportation networks, and personnel. By infrastructure I mean the "matter that enable[s] the movement of other matter," the built networks

> "that facilitate the flow of goods, people, or ideas and allow for their exchange over space. As physical forms they shape the nature of a network, the speed and direction of its movement, its temporalities, and its vulnerability to breakdown. They comprise the architecture for circulation, literally providing the undergirding of modern societies, and they generate the ambient environment of everyday life… Their peculiar ontology lies in the facts they are things and also relations between things."[160]

This allows us to think about how roads, railways, chemicals, or even the USDA, operate "not just [as] technical objects then but also operate on the level of fantasy and desire. They encode the dreams of individuals and societies and are the vehicles whereby those fantasies are transmitted and made emotionally real."[161]

The infrastructure of pesticides in US agriculture is thus not only pipelines, chemical plants, research laboratories, and industrial recycling networks, but also the ideologies, fantasies, and desires of war, famine, progress, nationalism, racism, dose-response, progress,

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[157] Lewis, R. "Redesigning the Workplace: The North American Factory in the Interwar Period." *Technology and Culture* 42, no. 4 (2001): 665-84; Aglietti, M. *A Theory of Capitalist Regulation: The US Experience*. New York: Verso, 1979.
[158] Clark, *Manufactures in the United States*, 1929. For a list of CPI projects see Appendix 1.
[159] Harding, Two Blades of Grass, 1947; Goodman et al., From Farming to Biotechnology, 1987; Rasmussen, W D. Taking the University to the People: Seventy Five Years of Cooperative Extension. Ames, IA: Iowa University Press, 1989.
[160] Larkin, B. "The Politics and Poetics of Infrastructure." Annual Review of Anthropology 42 (2013): 327-43. X.
[161] Larkin, "Politics and Poetics of Infrastructure, 2013. 333.

and profit that span and operate through multiple scales and levels concurrently.[162] Infrastructure takes physical form through embodied practice and embodied knowledge.[163]

The research networks established by the Crop Protection Institute were critical for the very success of the post-WWII pesticide industry and chemicalized the organizational form of post WWII agriculture. After WWII, the goal of public agricultural research (the people's land-grant universities) and private capital were aligned, and seemingly remain so to this day. In the interwar era, the ideology and fantasies of "scientific farming" came to predominate, further separating ethics and morals from the production of food.[164] The very success of the private takeover of public research system makes it less noticeable to everyday critics of the modern food system. But it doesn't make it invisible.[165]

Collectively, agricultural, economic, and science historians along with theorists of capitalist agriculture and journalists have done an excellent job in covering many aspects of the development of US agroindustrial infrastructure.[166] For example recent scholarship by McWilliams and Rasmussen illuminates how the fantasy and ideology of chemical control – bug and weed free crops – permeated and spread across the USDA in the early 1920s and 1930s.[167] Moss explores the subsumption of biological desire into food manufacturing and marketing.[168] Boyd and Watts, among others, filled in the picture of the industrial broiler chicken.[169] Kloppenburg shows us how the contemporary political economy of seed research is structured on and developed through private capital's capture of "basic" public science.[170] Hightower argued as much in *Hard Times, Hard Tomatoes*, a book in which he

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[162] "Progress is immortal." Stine, "Better Destiny," 1942. "[B]ut the killer lust is ours, and it is we who bear direct responsibility for the pesticide overuse that it engenders." Van Der Bosch, Pesticide Conspiracy, 1978. 111; Adas, M. Machines as the Measure of Men: Science, Technology, and Ideologies. Ithaca, NY: Cornell University Press, 1989; Norgaard, R B. Development Betrayed: The End of Progress and a Coevolutionary Revisioning of the Future. New York: Routledge, 1994.

[163] Bourdieu, P. *Distinction: A Social Critique of the Judgment of Taste*. Cambridge, MA: Harvard University Press, 1984; Haraway, D. *Simians, Cyborgs, and Women: The Reinvention of Nature*. London, UK: Free Association Books, 1991; Lakoff, G, and M Johnson. *Metaphors We Live By*. Chicago, IL: University of Chicago Press, 1980; Amin, A. "Lively Infrastructure." *Theory, Culture & Society* 31, no. 7 (2014): 137-61.

[164] "So the land-grant universities and its programs and policies represent another area where change is necessary if a better pest-control system is to evolve." Van Der Bosch; Moss, M. "U.S. Research Lab Lets Livestock Suffer in Quest for Profit." *New York Times*, January 19 2015, A1. McClintock, N. "Why Farm the City? Theorizing Urban Agriculture through a Lens of Metabolic Rift." *Cambridge Journal of Regions, Economy and Society* 3 (2010): 191-207; Berry, W. *The Unsettling of America*. San Francisco, CA: Sierra Club Books, 1977; Jennings, "Killing Fields," 1997.

[165] "This country is so large, and it offers so many climatic and nutritive opportunities, that the raising of fruits, vegetables, cereals, fiber crops and animals requires unrelenting warfare against insects. Modern means of rapid transport complicate the problem. The slightest relaxation of entomological control measures would result in enormous losses and often the utter destruction of entire crops and industries. The very success of the system tends to make it less noticeable to us." Harding, *Two Blades of Grass,* 1947. 79.

[166] Cochrane and Ryan. *American Farm Policy*, 1976; Walker, *Conquest of Bread*, 2004; Whorton, *Before Silent Spring*, 1974; Russell, *War and Nature*, 2001; Olmstead, A L, and P W Rhode. *Creating Abundance: Biological Innovation and American Agricultural Development*. Cambridge, UK: Cambridge University Press, 2008.

[167] McWilliams, *American Pests,* 2008; Rasmussen, N. "Plant Hormones in War and Peace: Science, Industry, and Government in the Development of Herbicides in 1940s America." *Isis* 92, no. 2 (2001): 291-316.

[168] Moss, M. *Salt, Sugar, Fat: How the Food Giants Hooked Us*. New York: Random House, 2013.

[169] Boyd and Watts. "Agro-Industrial Just in Time," 1997.

[170] Kloppenburg, *First the Seed*, 2004.

linked the development of the automated tomato picker to public research at the University of California and California labor politics. Hightower (1972) argues, like Van Der Bosch did for pesticides research a few years later, that the land grant complex failed the American public.[171]

Varietal and productivity-based research had been part of agricultural extension work prior to and since the Morrill Act, but something changed in the interwar period as the direction of research reconfigured around the profit motive.[172] By the end of WWII the social, physical, bureaucratic, and technological infrastructure that structures the division of research labor between the USDA, land-grant universities, extension scientists, and chemical companies had crystallized in place and would remain firmly so until the early 1970s, when the environmental movement began to challenge the relationship of pesticide companies to publically funded research. In other words, the current paths that enable private capital to benefit from public science were laid in the interwar era. The people of the United States did not choose these paths, but instead they were paths chosen by the pesticide industry, the federal government, land-grant universities, and agribusiness writ large in "service to the gods of profit and production."[173]

But even within all of this scholarship, the infrastructures necessary to both reutilize industrial waste in agrarian production and to link public science with the goals of the pesticide and its allied industries has not been told, perhaps because it operated behind the scenes, coordinating, mediating, and facilitating a new scientific division of labor for economic poisons. The infrastructures of chemical agriculture remain to be told. As James McWilliams has argued, "Despite the recognition of the impact of pesticides in American science, agriculture, and public health, comparatively little is known about the precise historical developments that fostered their emergence." The history of the CPI begins to fill in the institutional and infrastructural gaps of scholarship that examines agriculture's chemicalization.

Geographical Homogenizations, Poisonous Standardizations

In 1942, shortly after the US declaration of war, the National Research Council's Division of Biology and Agriculture took over and enlarged the coordinating function of the Crop

[171] Hightower, "Hard Tomatoes, Hard Times," 1972; Van Der Bosch, *Pesticide Conspiracy*, 1978; Danbom, D B. 1992. "Research and Agriculture: Challenging the Public System." *American Journal of Alternative Agriculture* 7 (3): 99-104.

[172] True, A C. "A History of Agricultural Experimentation and Research in the United States, 1607-1925." In *Miscellaneous Publications*. Washington, DC: USDA, 1937; Rasmussen et al., *The Department of Agriculture*, 1972; Knoblauch, H C, E M Law, W P Meyer, B F Beacher, R B Nestler, and B S White Jr. "Agricultural Experiment Stations: A History of Research Policy and Procedure." In *Miscellaneous Publications*, 262. Washington, DC: USDA, 1962.

[173] Carson, R. "Women's National Press Club Speech." In *Lost Woods: The Discovered Writing of Rachel Carson*, edited by L Lear. Boston, MA: Beacon Press, 1999; McWilliams, J E. "" The Horizon Opened up Very Greatly": Leland O. Howard and the Transition to Chemical Insecticides in the United States, 1894-1927." *Agricultural History* (2008): 468-95.

Protection Institute.[174] The CPI's functions, via the NRC's Committee on Crop Protection, were subsumed into the War Industries Board's wartime agricultural planning.[175] Three years later, the Crop Protection Institute dissolved just 25 years after it formed, having seen many of its goals realized. [176]

Chemical control had rationalized and generalized across the US in the interwar years, when an incredible array of toxic chemicals made their way onto US farms in increasing quantities. The use of arsenicals exploded. By 1927, nineteen companies at twenty-two chemical plants were annually producing more than 80 million pounds of arsenic based poisons for US agriculture.[177] Cryolites (sodium aluminum fluoride compounds), fluorides, and fluorosilicates became the solution to arsenic's publically imagined and institutionally acknowledged interstate toxicity.[178] Mercury chloride dusted fresh vegetables. Highly refined toxic oils appeared. New industrial gases like methyl bromide cleansed food and nursery products across the US.[179] Pesticide salesman became professional disseminators of knowledge and new growing practices.[180] Chemical companies and the USDA now viewed both basic and applied agrochemical toxicological research as a necessity. In other words, R&D in the life and death ("economic toxicology") sciences had been synergized with industrial chemistry in the race to create ever-newer and ever-more efficient economic poisons and machines to deliver them.[181]

During its tenure, the Crop Protection Institute, by coordinating more than 150 public-private partnerships of chemical companies and Agricultural Extension acted as a unique institutional link between private agrichemical industry and public agricultural science. In facilitating and forging new links between chemical companies and agricultural extension, by helping to standardize chemical formulations across varied geographies and varied crops, by aiding the productive utilization of industrial wastes, by demonstrating the necessity of agrotoxicological R&D, the CPI played a critical role in standardizing chemical control from multiple fronts. Furthermore, CPI helped foreground capital investment into agrochemical research as a method of utilizing industry's wastes.[182] R&D became an *a priori* assumption of agrochemical companies.

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[174] National Research Council. 1943. Papers of the Crop Protection Committee, Division of Biology and Agriculture of the NRC. In *Institutions: Associations and Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences.

[175] This also means that information about CPI projects post 1942 is limited.

[176] I am not sure about this, but it was sometime between 1942 and 1946. In 1942, the NRC's Division of Biology subsumed many of the CPI functions into wartime planning and research. The last CPI projects ended in 1948. (See Appendix 1).

[177] Roark, R C. "United States Insecticide Statistics for 1928." *Journal of Economic Entomology* 22, no. 4 (1929): 699-701.

[178] Carter, R H, and R C Roark. "Composition of Fluorides and Fluosilicates Sold as Insecticides." *Journal of Economic Entomology* 21, no. 5 (1928): 762-73; Roark, RC. "Insecticides and Fungicides." *Industrial & Engineering Chemistry* 27, no. 5 (1935): 530-32; Whorton, *Before Silent Spring*, 1974.

[179] Mackie, DB. "Methyl Bromide—Its Expectancy as a Fumigant." *Journal of Economic Entomology* 31, no. 1 (1938): 70-79.

[180] Sanders, J G. "The Commercial Entomologist." *Journal of Economic Entomology* 29, no. 1 (1936): 21-28.

[181] Gray, G P. "Economic Toxicology." *Science* 48, no. 12 (1918): 329-32; LAT. "New Insecticide Fog Generators Revolutionize Man's War on Pests, Vineyards Blanketed with Mist in Few Minutes at Low Cost." *Los Angeles Times*, 1945.

[182] Hale, W J. 1930. "When Agriculture Enters the Chemical Industry." *Industrial and Engineering Chemistry* 22 (12):1311-1315.

Many of the companies that utilized the Crop Protection Institute are still recognizable today: Armour and Company; Geigy Company; Minnesota Mining and Manufacturing (3M); Dow Chemical Company, Freeport Sulphur Company, General Chemical Company, General Dyestuff Corporation, Hercules Powder Company, Kay-Fries Chemical Company, The Koppers Chemical Company, Liquid Carbonic Corporation, Monsanto Chemical Company, S. B. Penick & Company, Rohm and Haas Company, Standard Chemical Products, Inc., Standard Oil Company of New Jersey, Standard Oil Company of Indiana, Stauffer Chemical Company, Tennessee Copper Company, United States Rubber Company, Quaker Oats Company – to name just a few (See Appendix 1).

And more than fifty state agricultural extensions across most US states were used: New York, West Virginia, Delaware, Iowa, Kansas, North Carolina, Missouri, Pennsylvania, Illinois, New Jersey. Wisconsin, Ohio, Florida, California, Maryland, New Hampshire, Michigan, Oklahoma, Virginia, Louisiana, Oregon, Connecticut, Massachusetts, Alabama, Colorado, Indiana, Ontario (Canada); and the private laboratories of the Boyce Thompson Institute (now affiliated with Cornell), the Miner Lab in Chicago, Missouri Botanical Garden, and Quaker Oat (See Appendix 1).

To say that the CPI caused the chemicalization of US agriculture would be vastly overstating its influence, but the CPI was critical in helping to facilitate the chemicalization of agriculture in a few important ways. One of the most important was through the geographical homogenization and standardization of applied toxicological research and pest control practices. With homogenization and standardization of toxic materials, applicator machines, and the toxicological science backing (or not) its use, the CPI met its goals of extending the consumption and rationalization of pesticide consumption in US agriculture. It also met its goal of facilitating the productive consumption of US industrial wastes in scientific agriculture.

One of the other major accomplishments was the development of an agrochemical R&D infrastructure that linked the toxic materials and capital of private companies with the facilities and expertise of US agricultural extensions. This established a political economy of industrial agriculture where public R&D labor was either captured by private companies or directed to the ideologies of profit and yield. Chemical companies now viewed agrochemical and on-farm toxicological research as a necessary part of production and sales and public agricultural extension science became a crucial node in both basic toxicological research and the commercialization and promotion of chemical control. In the interwar era, agrochemical invention, subsidized by taxpayers, became a fundamental part of agribusiness.[183]

[183] "In machinery, the appropriation of living labour by capital achieves a direct reality in this respect as well: It is, firstly, the analysis and application of mechanical and chemical laws, arising directly out of science, which enables the machine to perform the same labour as that previously performed by the worker. However, the development of machinery along this path occurs only when large industry has already reached a higher stage, and all the sciences have been pressed into the service of capital; and when, secondly, the available machinery itself already provides great capabilities. Invention then becomes a business, and the application of science to direct production itself becomes a prospect which determines and solicits it… What was once the living worker's activity becomes the activity of the machine. Thus the appropriation of labour by capital confronts the worker in a

The US emerged from the WWII with the most sophisticated agricultural complex in the world. During the war, unleashed by the constraints of peace, the American agricultural complex mobilized two decades of scientific, industrial, and ideological development into commercial practice, signaling, as T. S. Harding penned right after the war, "an absolute, irremovable, and irreversible break… with the immediate past."[184] In other words, "The nation [emerged] from [WWII] with capacities for making plastics, synthetic fibers, nitrates, hydrocarbons, high octane gasoline and literally scores of chemical and other raw materials on a scale that only [a few years ago] was beyond our comprehension."[185] For example, during the war, new synthetic organic soil fumigants made from petroleum revolutionized the organizational possibilities of industrial agriculture by severing the link between the intensive crop without rotation and the build up of destructive pests in the soil complex (See Chapter 4).[186] After the war, new industrial capacity for organic explosives like TNT and TNP and chemical armaments like nerve gases, as popularized by the likes of Rachel Carson and Michael Pollan, along with oil well and petroleum refinery waste, became a source of cheap nitrogen fertilizers and cheap pesticides.[187] Even with a large decrease in farm population caused by the draft and urban migration to fill labor requirements in the war's industries, by the end of the war, the US was producing more than 20% more agricultural goods on the same amount of land. The dramatic increase in productivity was "in essence and in reality a triumph of agricultural research such as history has never before witnessed."[188]

But a myopic lens focused on the history and impacts of particular objects like fertilizer and pesticides, or hormones that is so commonplace among historians and historical geographers (and stems from the ongoing privileging of agriculture's productive phase) obscures the critical infrastructural developments that had to occur before the inputs could be created and utilized at an industrial scale.[189] These critical infrastructural developments consisted of more than the development of industrial capacity, but also the construction and standardization of particular forms of agrochemical knowledge and the establishment of a new division of labor between agricultural extension and private enterprise.

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coarsely sensuous form; capital absorbs labour into itself – 'as though its body were by love possessed. " Marx, K. *Grundrisse*. New York: Penguin Books, 1973. 703-704. Marx quoted Goethe, *Faust*, Pt.1, Act 5.

[184] Harding, T S. 1947. *Two Blades of Grass: A History of Scientific Development in the U.S. Department of Agriculture*. Norman, OK: University of Oklahoma Press.

[185] Stine, " Better Destiny," 1942.

[186] Romero, "From Oil Well to Farm," 2016.

[187] "There seems little question after the war there will be available for use as fertilizer at least twice as much nitrogen as we have ever used at a price much less than we have even paid." (Bradfield, 1942: 1070)

[188] Carson, *Silent Spring*, 1962; Pollan, *The Omnivore's Dilemma*, 2006; Smil, V. *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production*. Boston, MA: MIT Press, 2004.

[189] "This mode of operating compromises an important part of infrastructure's political address – the way technologies come to represent the possibility of being modern, or having a future, or the foreclosing of that possibility and a resulting experience of abjection." Ferguson, J. *Expectations of Modernity: Myths and Meanings of Urban Life on the Zambian Copperbelt*. Berkeley, CA: University of California Press, 1999.

But the end of WWII is also too clean as a mark of the ascendency of agriculture's contemporary industrial iteration. Agriculture may have emerged from WWII somewhat fully formed into the modern iteration we have today, but the techno-social form of agriculture that came to be known across the world after the war as the green revolution, as I argued above, first solidified in the US in the interwar years. In other words, the prehistory of the green revolution and the stupendous yield increases it entailed were written on the agricultural, industrial, and scientific, and consumptive landscapes of the interwar era.[190]

To get into the nuts and bolts of each Crop Protection Project is beyond the scope of this chapter. Instead, I use a small handful of the projects undertaken via the CPI as a proxy to indicate the types of projects and to highlight the role that CPI played in mediating the chemicalization of US agriculture. The first project was a cooperative dusting experiment, undertaken in 1921, and covers the homogenization and standardization of pesticides, pesticide recommendations, and agrotoxicological science as related to pome and peach crops. The second looks at the control of smut from a cereal manufacturers standpoint. The third project, undertaken in 1922, was a jointly funded investigation into the toxic properties of sulfur as an insecticide. The fourth and fifth projects I cover in the most detail, because it is was from these experiments and others like them that organo-chlorines and bioselective herbicides emerged, compounds that became cosmopolitan across US agriculture and the global environment following WWII.

At the end of WWI, two of the main issues confronting pesticide companies was the dearth of standardized toxicological research and a lack of geographical homogenization in applied agro-toxicological experimentation and dosage recommendations.[191] That is why one of the first projects CPI projects tried to tackle this problem by attempting to standardize materials and for pome and peach pests (insects and fungi). In early 1921 the Board of Directors of the CPI chose Dr. N.J Geddings at the University of West Virginia Experiment Station as the primary investigator.[192] He was tasked with coordinating research across the agricultural extension of four states: Connecticut, West Virginia, New York, and Pennsylvania. While Dr. Geddings was in charge, the scientists at the individual stations were responsible for securing nearby commercial orchards in which to conduct the tests. The commercial growers and extension agents provided the labor for the tests. The CPI made sure that the industrial members supplied the participating agricultural extensions with the spraying and dusting materials at no cost. For these experiments, this included a

[190] "During the 1945 period it at last became possible for agriculture to use to the full the vast reservoir of scientific knowledge and technological know-how which had accumulated during the nineteen thirties, but which was held back from use because of drought and depression. For it was greater use of mechanization, more lavish fertilizers, lime, and soil conservation practices, the adoption of improved crop varieties and more productive strains of animals and poultry, improved control of insects and plant disease, and the social and economic know-how that enabled us to provide proper incentives to farmers to produce what was needed when it was possible which made wartime increases in production possible." Harding, T S. *Two Blades of Grass: A History of Scientific Development in the U.S. Department of Agriculture*. Norman, OK: University of Oklahoma Press, 1947. 326.

[191] In particular, screening and dose-response, or, how do you know how toxic something is in comparison with other poisons.

[192] CPI. "Cooperative Dusting and Spraying Experiment of 1921." *Crop Protection Institute Digest* 2 (1922): 1-30; Frome, F D, and F J Schneiderhan. "Cooperative Dust Spraying Experiment of 1922." *Crop Protection Institute Digest* 4 (1924): 1-36.

tremendous variety of concoctions of sulfurs, arsenates, coppers, and nicotines emulsified in various soaps, spreaders, and stickers. The companies that furnished the materials were: Sherman-Williams Company, General Chemical Company, National Sulfur Company, the Tobacco By-Products Company, and the Niagara Sprayer company, which supplied a few dusting machines.

At the end of the season, some interesting results were obtained, but environmental factors (which affected timing and extent of insect damage) and a lack of standardization of data collection (including how to determine and report foliage injury) made generalizations difficult. Furthermore, the lack of consistency between similar (or supposedly equivalent) sprays and dusts made any general conclusion impossible. The following season, the experiment was expanded to three more states – Virginia, Pennsylvania, Minnesota –and F.D. Fromme at the University of Virginia Agricultural Extension joined Dr. Geddings in coordinating the experiments and analyzing the data. But the 1922 season did not bring more concrete results.

“The lack of agreement in results obtained with dusts in different sections, especially in control of disease, is evident” Dr. Fromme concluded. “This is to be anticipated from a comparison of previous experimental work in different sections. It seems evident that such discrepancies cannot be explained satisfactorily until there is more knowledge of the action of the materials used as fungicides and insecticides on the organisms concerned and the effect of climatic conditions and other factors involved.”[193]

For many reasons, including those outlined by Fromme above, the cooperative dusting experiment failed to live up to expectations, but that did not diminish the resolve of the CPI and its members to continue forward with the standardization and homogenization of laboratory and field-based toxicological research. Those within the industry, particularly economic entomologists, continued the call for more standardized research but also rather importantly the standardization and compositional testing of commercial pesticides. They often used the early work of the CPI as an example of how to accomplish this feat.[194]

In 1922, as the cooperative dusting experiments were underway across six states, the CPI, with funding from the American Phytopathological Society and the Cereal Manufacture’s Association, launched a massive study across eleven states – Washington, Delaware, Minnesota, Pennsylvania, New York, Idaho, Ohio, North Dakota, Illinois, South Dakota along with the Canadian provinces of Quebec, Ontario, Manitoba, Saskatchewan – of the control of grain smut in wheat, oats (hulled and hulless), and barley.[195] Unlike the dusting experiments, the collective results produced from these experiments showed the superiority of copper dusts for wheat and hulled oats and formaldehyde for barley and

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[193] "Cooperative Dust Spraying Experiment of 1922." *Crop Protection Institute Digest* 4 (1924): 1-36. 2.
[194] Haseman, L. "Testing Commercial Insecticides." *Journal of Economic Entomology* 21, no. 1 (1928): 115-17.
[195] Lambert, E B, H A Rodenhiser, and H H Flor. "The Effectiveness of Various Fungicides in Controlling the Covered Smuts of Small Grains." *Phytopathology* 26, no. 6 (1926): 393-411.

hulless oats. It wasn't just the control of smuts the manufactures were after, however, but also the ability to control smuts without hindering the germination potential of the seed (a problem that all seed treatments still face).

Also in 1922, another large-scale cooperation experiment also got underway to investigate the toxic properties of sulfur. The three largest US sulfur producers funded the project: Texas Gulf Sulfur Company, Union Sulphur Company, and Freeport Sulfur Company.[196] Undertaken with more precision and deliberation than the orchard dusting experiments, this study divided the research across five experimental stations and three research labs. The field studies were conducted at the agricultural experiment stations of Michigan, Colorado, Pennsylvania, New York, and Missouri, while the laboratory studies were conducted at the Missouri Botanical Gardens, the Boyce Thompson Institute for Plant Research, and the University of New York Experiment Station. The Board of the CPI distributed the labor in this manner to try and overcome one the most critical issues facing potential facing new commercial pesticides, the bridge between the laboratory and the field.[197] These series of experiments yielded multiple publications, but the most important result came from the finding that the physical size (the fineness) of sulfur particles influenced sulfur's fungicidal toxicity, which led to new methods of manufacturing and processing sulfur for use as fungicides. This discovery was patented and assigned to the trustees of the Crop Protection Institute, meaning that in essence, the patent was available to any of the industrial members of the institute.[198]

OrganoChlorines, DinitroPhenols

After WWI, the US was awash in coal-tar products like benzene, phenol, and naphthalene, as well as an abundance of chlorine from the massive growth of the US chlor-alkali industry. Coal-tar and other chemical companies began reacting these two waste products together in the hope that they might yield fruitful compounds.[199] Naphthalene ($C_{10}H_8$), a double ringed aromatic compound, comprises on average about 10% by weight of coal tar, had been used

[196] Young, H C. "The Toxic Property of Sulphur." *Annals of Missouri Botanical Garden* 9 (1922): 403-05; Young, H C. "Colloidal Sulfur as a Spray Material." *Annals of Missouri Botanical Garden* 12 (1925): 133-43; Young, H C. "Colloidal Sulfur: Preparation and Toxicity." *Annals of Applied Biology* 12 (1925): 381-418; Young, H C, and R C Walton. "Spray Injury to Apple." *Phytopathology* 15, no. 7 (1925): 404-15; Young, H C, and R Williams. "Pentathionic Acid, the Fungicidal Factory of Sulfur." *Science* 62, no. 1723 (1928): 19-20.

[197] Salmon, ES. "Discussion on 'the Fungicidal Action of Sulphur'." *Annals of Applied Biology* 13 (1926): 308-18.

[198] Several other companies would run with this information. In California, which had a much more sophisticated network of private-public research by this time, the Pacific Gas and Electric Company (PG&E) funded the research of the UC Berkeley agricultural chemist E.R. de Ong into the use of sulfur as a pesticide. The Western Sulphur Company funded the research of J.D. Hayes at the Oregon State Agricultural College. On the East Coast, which lacked established private-public networks, the CPI continued to administer further investigation of sulfur across a great number of states with funds from the Koppers Company of Pittsburg, who was very impressed by the ability of the CPI to coordinate the project across a wide geographic and great number of local environmental conditions. Sauchelli. "Flotation Sulfur in Agriculture." *Industrial and Engineering Chemistry* 25, no. 4 (1933): 363-68.

[199] Dow Chemical Company. *Dow in the West*. Walnut Creek, CA: Dow Chemical Company, 1977.

sparingly in Europe and the US as a moth control agent and dye intermediate. Prior to WWI, most experimentation with naphthalene chemistry had been done in Germany. The German chemical industry had already been producing synthetic waxes and new materials based on chlorinated naphthalene. This research was jumpstarted in 1915 after the first offensive uses of chemicals on the battlefields of the European theater. Because chlorinated naphthalenes have very novel properties, such as resistance to physical abrasion and chemical corrosion that makes them waterproof, gas tight, rat-proof, as well as being a extremely good insulation of electrical currents, the Germans began using them for manufacture of materials that would resist chemical warfare's toxic ammunition. It was clear to the Germans early on that the materials were quite toxic, as the workers that made gas masks and gas proof clothing from impregnated materials experienced the tell tale sign of organ chlorine poisoning: chloracne.[200]

After the war, US companies, in particular the Halowax Corporation, began experimenting with polychlorinated naphthalenes as insulators and began manufacturing them for use as coatings for electrical cables.[201] During the 1920s, the scientists at Halowax found out that with new high-pressure chemical synthesis techniques introduced after the war, they could vary the degree of chlorination of the naphthalene molecule and control the physical properties of their waxes, with harder waxes produced from more highly chlorinated molecules (because they had a higher melting point). (There are 75 possible congeners of the PCN with one to eight chlorine molecules).[202] By the late 1920s, companies like Halowax were able to consistently produce a variety of PCN mixtures – halowaxes – ranging from 95% monochloronaphthalene ($C_{10}H_7Cl$) to 90% octochloronaphthlane ($C_{10}Cl_8$) and everything in between.[203]

In 1928, Monsanto Chemical Works funded a CPI study of the toxic properties of their experimental naphthalene derivatives (which was likely a mixture of mono and dichloronaphthalene). Naphthalene had been used a fumigant in mothballs in Europe and US since the turn of the century, but it was too explosive, too volatile, and not acutely toxic enough to make a good pesticide. After the war, economic entomologists, many of whom had seen the relative success of paradichlrobenzene on the southern peach orchards, began investigating the chlorinated naphthalenes as possible household fumigants. Monsanto's

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200 Good, C K, and N Pensky. "Halowax Acne ("Cable Rash"): A Cutaneous Eruption in Marine Electricians Due to Certain Chlorinated Naphthalenes and Diphenyls." *Archives of Dermatology and Syphilology* 48, no. 3 (1943): 251-57.

201 "The use of chlorinated naphthalenes and compounds of allied pharmacological possibilities is extremely wide, and [with] the steady growth of the use of electricity is certainly to expand much farther." Drinker, C, M F Warren, and G Bennett. "The Problem of Possible Systemic Effects Form Certain Chlorinated Hydrocarbons." *Journal of Industrial Hygiene* 19, no. 7 (1937): 283-99. 283.

202 Brown, S. "Chlorination Apparatus." *Patent #1,566,044*, US Patent Office. USA: Halowax Corporation, 1925; Brown, S. "Process of Chlorination." *Patent #1,672, 878*, US Patent Office. USA: Halowax Corporation, 1928; Hanson, E R, and S Brown. "Light Colored Liquid Chlorinated Naphthalene and Production Thereof." *Patent #2,025,742*, US Patent Office. USA: Halowax Corporation, 1935.

203 They were also sold under the trade names: Nibren waxes, Seekay waxes, Clonacire waxes, N-Oil, N-Wax, and Cerifal materials.

chemists thought they might have a wider range of uses, particularly on soil insects, and thus they contacted the Crop Protection Institute to see if their chemical had commercial promise.[204] Monsanto funded an 18-month study of chloronaphthalene as an insecticide at the University of Illinois. Scientists tested Monsanto's compounds at a variety of concentrations and mixed with a variety of emulsifiers on a variety of available test subjects. The year of tests showed promise and they concluded that MCN could be useful in some circumstances.

In 1932, the CPI commenced a much larger study of chlorinated naphthalenes, but this time for the Halowax Corporation of Bloomfield, New Jersey. The work was split between Ohio State University, the New Hampshire Agricultural Experiment Station,[205] and the Florida Agricultural Extension. These three stations were chosen for both their expertise and perhaps more importantly, for their locations. They were places where halowaxes could be tested against a variety of insects under different environmental conditions. The exact composition of the halowaxes provided for these experiments is unknown, but it likely that they contained a mixture of three to six chlorine atoms per naphthalene molecule. This is my guess because of what we know now about the biogeochemistry of chlorinated naphthalenes.[206] The first is that these types of halowaxes would be oily liquids at room temperature, unlike mono or octochloro-naphthalene, which would be either too volatile or too firm at room temperature, respectively. The second reason is that we know from the few toxicological studies that were done of PCNs that these compounds tended to be the most acutely toxic.[207]

E.P. Breakey and A. Miller were the lead scientists at Ohio State, and they combined the halowaxes with various emulsifiers and adjuvants like white oil and soap. One of the interesting things that learned in this study was the difference between toxicity determined in the lab and the toxicity determined in the field setting. In the first series of tests, the scientists mixed the halowax emulsifiers themselves at the New Hampshire experiment station prior to the field experiments. But as they expanded the experiment to Florida, the halowaxes emulsions were made by the Halowax Corporation chemists at their New Jersey plant and the supposedly equivalent mixtures (at 0.5% Halowax and 0.5% light-medium mineral oil) were much more toxic than the ones first mixed by the extension scientists. This again highlights the difficulty in transitioning an experimentally toxic compound into a commercial product that farmers were capable of using. Overall, the experiments were a success and the Halowax Corporation continued to fund new research.[208]

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[204] Hockenyos, G L. "Monochloronaphthalenes as an Insecticide." *Crop Protection Digest* 31 (1931): 1-38. MCN may still be used as a synergistic additive to chloronicotyl (neonicotinoids). Bayer AgroSciences has multiple patents on doing this, but since active ingredients are the only ones that have to be reported, I can't really tell.

[205] Breakey, E P. "Halowax as Contact Insecticide." *Journal of Economic Entomology* 27, no. 2 (1934): 393-98.

[206] Brinkman, U A, and G M Reyer. 1976. "Polychlorinated Naphthalenes." *Journal of Chromatography* 127:203-243; Falandysz, J. 1998. "Polychlorinated Naphthalenes: An Environmental Update." *Environmental Pollution* 101:77-90.

[207] Drinker, C, M F Warren, and G Bennett. 1937. "The Problem of Possible Systemic Effects form Certain Chlorinated Hydrocarbons." *Journal of Industrial Hygiene* 19 (7):283-299.

[208] Two years later, A. M. Boyce of the UC Citrus Experiment Station would use this recommended emulsion in experiments in

In a few of the Halowax spray experiments, extension scientists found that a high percentage of the insect eggs were killed. Thus, one of the areas where the scientists thought halowaxes might be useful was as an ovicide, a chemical that specialized in killing the egg stages of insects. But before the scientists could figure out that question they had to address a dilemma that still plagued agro-toxicological research – the lack of standardization and the resulting inability to quantitatively compare toxicity between multiple studies. Breakey and Miller sought to rectify this for ovicidal research and set to work in the lab determining a quantitative method of determining ovicidal properties by comparing the Halowax emulsions with standard economic poisons such as nicotine and pyrethrum.[209] Two interesting things came from the study. The first was their decision not to use the concentration at 100% kill to standardize toxicity, but instead percent kill at various concentrations for various stages of egg development, in order to find the most efficient way to achieve the percent kill needed to achieve commercial control. Again, the research showed the potential of halowaxes, particularly when emulsified in white oil, as an ovicidal.

With more funding from the Halowax Company, Breaker and Miller expanded the project. This time they wanted to determine a testing procedure that would help bridge the gap between the laboratory and the field, one that accounted for practical and environmental considerations. They had already shown that Halowax was toxic, but they needed to determine the other factors that were needed to move toward the practical commercial application of the materials. They used the eggs of the codling moth this time and they used eggs on live foliage instead of eggs on plate glass. This was done to make the lab tests more like the field. The tests showed how the varying the concentration of the emulsifier compound (oil, soaps, casein, glue, etc.) could affect toxicity by changing the physical properties of the spray mixture. Again, the halowaxes showed promise as toxic ingredients, but limitations still persisted in making it commercially viable, most notably in the physical characteristics to make it a good practical ovicide. More research was needed to determine how to combine it with other ingredients to make it an acceptable product. The question was not whether it was toxic to the eggs of the codling moth (there are a lot of toxic chemicals), but how to make this toxic compounds into something that could be useful to agriculture.[210]

The project wound down at the end of the 1935 season without having developed a clear path to commercialization. One of the other complicating factors at the time may have been the increased occurrences (or at least reported occurrences) of health complications arising among workers who handled the novel chlorinated organic materials, including

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the control of the citrus red spider. He obtained very promising results for control, but the Halowax mixtures caused too much foliage injury to be considered a promising for use in commercial control of the red spider mite on citrus (an evergreen tree). Boyce, A M. "The Citrus Red Mite *Paratetranychus Citri* Mcg. In California, and Its Control." *Journal of Economic Entomology* 29, no. 1 (1936): 125-30.

[209] Breakey, E P, and A C Miller. "Halowax as an Ovicide." *Journal of Economic Entomology* 28, no. 2 (1935): 358-65.

[210] Breakey, E P, and A C Miller. "Halowax (Chlorinated Naphthalene) as an Ovicide for Codling Moth and Oriental Fruit Moth." *Journal of Economic Entomology* 29, no. 5 (1936): 820-26.

workers of the Halowax Corporation and electricians that worked with their products.[211] In 1936, three workers died from exposure to Halowax, likely from the fumes.[212] Even as these companies were denying the toxicity of these chemical to humans (even though they knew they were), they were having them testing them on animals for use as the active ingredient in commercially-efficient mass death.[213]

As noted above, Dow Chemical emerged from the war as a world leader in industrial phenol chemistry. After the war, Dow reconfigured its phenol synthesis and phenol chemistry around the Hale-Britton process, a process that bypassed the need for sulfur in the reaction by using chlorine instead, revolutionizing the synthesis of phenol from benzene. The success that Dow had in internalizing the waste products of the Hale-Britton process as biocides/fungicides in glues and varnishes, which they marketed as Dowicides, keyed Dow in on the potential toxicological value of many of its novel synthetic compounds (see footnote 42).

Prior to the war, dinitrophenol was used in the synthesis of sulfur black and blue dyes.[214] During the war, as a byproduct in the synthesis of TNP from phenol, its production soared and Dow became the major purveyor of DNP across the US.[215] In the late 1920s, Dow had learned that Bayer (their arch enemy) was selling a phenol derivative as an insecticide in Europe. This compound – dinitro-o-cresol (DNOC) – was likely originally a byproduct of the nitration of phenol in the production of trinitrophenol, a synthetic explosive also known as picric acid. DNOC exhibited phytotoxic effects that limited is potential, but Dow scientists at their Organic Research Laboratory in Midland, MI, particularly the visionary industrial chemist William Hale, thought that there might be derivatives of this compound that could have potential biological activity and they began using their phenolic expertise to synthesize various derivatives. One dinitrophenol derivative, in particular, they thought might have potential value as an economic poison. This novel compound conjured, from salt and coal-tar, was dinitro-ortho-cyclo-hexyl-phenol (DNOCHP). But Dow had no way to figure out its potential as an economic poison because they lacked the agro-toxicological capabilities and facilities to do so.[216]

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[211] Good, C K, and N Pensky. "Halowax Acne ("Cable Rash"): A Cutaneous Eruption in Marine Electricians Due to Certain Chlorinated Naphthalenes and Diphenyls." *Archives of Dermatology and Syphilology* 48, no. 3 (1943): 251-57.

[212] Drinker, C, M F Warren, and G Bennett. "The Problem of Possible Systemic Effects Form Certain Chlorinated Hydrocarbons." *Journal of Industrial Hygiene* 19, no. 7 (1937): 283-99.

[213] "These experiments leave no doubt as to the possibility of systemic effects of chlorinated naphthalenes and chlorinated diphenyls." Drinker, et al., p. 298.

[214] Vlies, L E. "Colouring Matters and Their Application." *Journal of the Society of Dyers and Colourists* 29, no. 11 (1913): 316-21.

[215] Smith, A W. "Letter from A.W. Smith to H. H. Dow." In *Dow Chemical Historical Collection, 1897-2006*, Dow Chemical Company. Philadelphia, PA: Chemical Heritage Foundation, 1917; Whittaker, C M. "The British Coal-Tar Industry and Its Difficulties in Time of War." *Journal of the Royal Society of Arts* 65, no. 3342 (1916): 61-72; Also because cresol, or ortho-methyl-phenol, was an impurity in the phenol used for explosive production. Allen, A H. "On the Assay of Commercial Picric Acid." *Journal of the Society of Dyers and Colourists* 4, no. 6 (1888): 84-88; King, R. "Production of Picric Acid from Sulphonic Acids of Phenol." *Journal of the Chemical Society, Transactions* (1921); Olsen, F, and J C Goldstein. "The Preparation of Picric Acid from Phenol." *Industrial and Engineering Chemistry* 16, no. 1 (1924): 66-71; Hamilton, A. "Dinitrophenol Poisoning in Munition Works in France." *Monthly Labor Review* 7, no. 3 (1918): 718-26.

[216] In 1933 multiple health companies introduced DNP (likely made by Dow) as a diet pill. Tainter, M L, W C Cutting, and

In 1931, Dow contacted the Crop Protection Institute to arrange a preliminary laboratory study to analyze the toxicity of their new dinitrophenol compounds.[217] The CPI chose Iowa State University to conduct the research. They tasked the graduate student J. F. Kagy to study and toxicologically survey Dow's new contact insecticides.[218] By developing new screening techniques for determining the biologic activity of synthetic organic chemicals, Kagy demonstrated the potential of DNOCHP in the lab for his doctoral dissertation, which he completed in 1937.[219] In 1935, however, before Kagy had completed his thesis, Dow Chemical seized on his preliminary results and provided DNOCHP to a few CPI member economic entomologists for research.[220] The potential of DNOCHP and the new techniques developed by Kagy also spurred Dow to establish a small Agricultural Experiment Station in New Haven, MI, in 1936.[221]

One of scientists provided with Dow's new concoction was the economic entomologist A. M. Boyce, Director of the University of California Citrus Experiment Station in Riverside, CA. Boyce was an expert on the control of citrus pests, and he thought the compound might have potential for use against the red spider mite. The red spider mite

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Stockton A B. "Use of Dinitrophenol in Nutritional Disorders: A Critical Survey of Clinical Results." *American Journal of Public Health* 24, no. 10 (1934): 1045-53. More recently, 2,4-Dintrophenol has been investigated for use to treat metabolic disorders such as diabetes and fatty liver disease. Perry, R J, D Zhang, X-M Zhang, J L Boyer, and G I Shulman. "Controlled-Release Mitochondrial Protonophore Reverses Diabetes and Steatohepatitis in Rats." *Science* 347, no. 6227 (2015): 1253-56.

[217] Mills, L E. "Nicotine Salts of 2,4-Dinitrophenol and Substituted Derivatives Thereof." *Patent #1,963,471*, US Patent Office. USA: Dow Chemical Company, 1934; Smith, F B, and W W Sunderland. "Esters of 2,4-Dintro-6-Cyclohexyl-Phenol." *Patent #2,097,136*, US Patent Office. USA: Dow Chemical Company, 1937; Britton, E C, and C L Moyle. "N-Substituted-2-Amino Nitro-Phenols." *Patent #2,155,356*, US Patent Office. USA, 1939; Hansen, J N, and F B Smith. "Alkylamines Salts of Dinitrophenols." *Patent #2,416,309*, US Patent Office. USA: Doe Chemical Company, 1947.

[218] Anonymous. "Personnel - Kagy, John F." In *The Dow Chemical Historical Collection, 1897 - 2006*, Dow Chemical Company. Philadelphia, PA: Chemical Heritage Foundation, Unknown; Barrons, K. "The Ag Labs." In *Dow Chemical Historical Collection, 1897-2006*, Dow Chemical Company. Philadelphia, PA: Chemical Heritage Foundation, 2000.

[219] Kagy, J F. "Toxicity of Some Nitro-Phenols as Stomach Poisons for Several Species of Insects." *Journal of Economic Entomology* 29, no. 2 (1936): 397-405; Kagy, J F. "Laboratory Method of Comparing the Toxicity of Substances to San Jose Scale." *Journal of Economic Entomology* 29, no. 2 (1936): 393-97; Kagy, J F. "Ovicidal and Scalicidal Properties of Solutions of Dinitro-O-Cyclohexylphenol in Petroleum Oil." *Journal of Economic Entomology* 29, no. 1 (1936): 52-61;

[220] Dutton, W C. "Orchard Trials of Dinitro-O-Cyclohexylphenol in Petroleum Oil for Control of Rosy Apple Aphis and San Jose Scale." *Journal of Economic Entomology* 29, no. 1 (1936): 62-65. Dutton left Michigan State to go work for Dow following the publication. Hartzell, F Z, and J B Moore. "Control of Oyster-Shell Scale on Apple by Means of Tar Oils, Tar-Lubricating Oils, and Lubricating Oils Containing Dinitro-O-Cyclohexylphenol." *Journal of Economic Entomology* 30, no. 4 (1937): 651-55; ; Hartzell, F Z, J B Moore, and D E Greenwood. "Control of Eye-Spotted Budmoth on Apple by Lubricating Oil Containing Dintro-O-Cyclohexylphenol." *Journal of Economic Entomology* 31, no. 2 (1938): 249-53; Wain, R L. "The Use of Toxic Polynitro Derivatives in Pest Control." *Annals of Applied Biology* 29, no. 3 (1942): 301-08.

[221] Britton, E C, and L E Mills. "Dinitro-Ortho-Cyclohexylphenol." *Patent #1,880,404*, US Patent Office. USA: Dow Chemical Company, 1932; Britton, E C, and R P Perkins. "Manufacture of Cyclohexlphenols." *Patent #1,862, 075*, US Patent Office. USA: Dow Chemical Company, 1932; Britton, E C, and R P Perkins. "Method for Manufacture of Cyclohexlphenols." *Patent # 1,917, 823*, US Patent Office. USA: Dow Chemical Company, 1933; Prescott, R F. "Preparation of 2,4-Dinitro-6-Cyclo-Hexyl-Phenol." *Patent #2,112,543*, US Patent Office. USA: Dow Chemical Company, 1938; Heath, S B. "Sulphur Composition." *Patent #2,145,259*, US Patent Office. USA: Dow Chemical Company, 1939; Heath, S B. "Composition of Matter." *Patent #2,146,739*, US Patent Office. USA: Dow Chemical Company, 1939; Heath, S B, and M O Keller. "Phenol Composition." *Patent #2,169,240*, US Patent Office. USA: Dow Chemical Company, 1939; Britton, E C. "Insecticidal Emulsion Composition." *Patent #2,210,894*, US Patent Office. USA: Dow Chemical Company, 1940; Mills, L E, and B L Fayerweather. "Dinitro-Alkyl-Phenol." *Patent #2,192,197*, US Patent Office. USA: Dow Chemical Company, 1940; Britton, E C, and F B Smith. "Amine Salts of Nitro-Phenols." *Patent #2,225,618*, US Patent Office. USA: Dow Chemical Company, 1940.

was a pernicious pest that began to be economically destructive to citrus growers in the early 1920s.[222] Cyanide fumigation, the common industrial practice for controlling citrus scale pests, did not control the mite. Petroleum oil did provide some control, but not enough.[223] Plus, the red spider mite was only one of many mite issues that confronted California growers.

Upon graduation in1937, Kagy, at the direction of Dow and the CPI, moved to California to join Boyce in his research.[224] Dow and Kagy recognized the potential of this new synthetic organic compound, but brining it to full commercialization still needed work, especially the issue of DNOCHP's potential phytotoxicity when diluted in standard oils. Together Boyce and Kagy (and others) developed a DNOCHP dry dust formula that proved very effective as an acaricide while causing limited citrus foliage injury.[225] In 1938, Dow commercialized DNOCHP as "DN Dust," – the "first synthetic insecticide" – and began manufacturing DN-Dust, a dry mixture with about 1% DNOCHP, at their chemical plant in Long Beach, CA.[226] In 1940, Dow erected a new plant in Seal Beach, CA with twice the capacity of the Long Beach plant, along side its iodine units, to manufacture "DN" insecticides for the California agricultural market.[227] Walnut shell flour from California grown walnuts served as the main inert ingredient in the first few years of manufacture, eventually being replaced by diatomaceous earth.

Dow was pleased with the brisk business of DN Dusts in California in 1938 and 1939 and decided to try to reformulate DN for use on other crops. Thus, in 1940, Dow contracted the University of Oregon Experiment station to determine its efficacy on hop and similar row crops.[228] In the meantime, Dow scientists had began synthesizing an amine salt of DNOCHP, which they briefly field-tested at their New Haven, MI agricultural

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[222] Boyce, "Citrus Red Mite," 1936. It likely arrived from Europe in in the early 1910s.
[223] Romero, "Commercializing Chemical Warfare," 2015.
[224] Boyce, A M, D T Prendergast, J F Kagy, and J W Hansen. "Dinitro-O-Cyclohexylphenol in the Control of Mites on Citrus and Persian Walnuts." *Journal of Economic Entomology* 32, no. 3 (1939): 450-66; Boyce, A M, J F Kagy, and J W Hansen. "Studies with Dinitro-O-Cyclohexylphenol." *Journal of Economic Entomology* 32, no. 3 (1939): 432-49; Kagy, J F. "The Relative Toxicity of Some 2,4-Dinitro-6-R-Phenols." *Journal of Economic Entomology* 34, no. 4 (1941): 660-68.
[225] Mills, L E. "Insecticidal Compositions Comprising Dinitro-Cresols." *Patent #2,121,039*, US Patent Office. USA: Dow Chemical Company, 1938; Mills, L E. "Insecticidal Compositions." *Patent #2,121,038*, US Patent Office. USA: Dow Chemical Company, 1938; Britton, J W, and F B Smith. "Insecticidal Composition." *Patent #2,225,619*, US Patent Office. USA: Dow Chemical Company, 1940; Boyce, A M. "Dusting Composition." *Patent #2,191,421*, US Patent Office. USA: Government and the People of the United States, 1940; Britton, J W, and R C Dosser. "Manufacture of 2,4-Dintro-6-Cyclohexl-Phenol." *Patent #2,384,365*, US Patent Office. USA: Dow Chemical Company, 1945.
[226] Barss, H P. "Report of the Crop Protection Institute." In *Institutions, Associations, Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences, 1940; Oman, M F. "Great Western Division, General Student and Sales Trainee Program " In *Dow Chemical Historical Collection, 1897-2006*, Educational Department Dow Chemical Company: Chemical Heritage Foundation, 1950; Dow, *Dow in the West*, 1977. In 1938 and DN-Dust was compounded at the Long Beach facility with feedstocks from around the LA basin. The walnut dust was made from the shells of local walnut trees and the emulsifiers and oils were located purchased. The active ingredient was manufactured at the Midland chemical plant.
[227] Ohman, "Great Western Division," 1950.
[228] Morrison, H E, and J D Vertrees. "Hop Pests and Their Control: A Report of the Control of the Hop Red Spider and Other Closely Related Problems During the Season of 1940." *Extension Report*, 1-71. Corvallis, OR: Oregon Agricultural Experiment Station. 1940.

experiment facility. Boyce and Kagy then did more extensive field-testing of DNOCHP in oil at the UC Citrus Experiment Station and nearby commercial fields. In the early 1940s, Dow introduced, with help from UC Citrus Experiment Station scientists like Kagy and Boyce, "DN-111," an oil-based amine salt of DNOCHP. DN-111 could be effectively and profitably used as a dormant spray for the commercial control of fruit tree pests like scales and mites.

In 1941, Kagy left his Dow funded post at the UC Citrus Experiment Station to head up Dow's just completed agricultural chemical research facility at Seal Beach, CA.[229] (In 1938, Dow had already hired D. Pendergast, S. Braucher, and B. Underhill, all of whom had studied under A.M. Boyce and Kagy at the UC Citrus Experiment Station in Riverside.)[230] DN-111, like DN-Dust was modestly successful upon introduction to the California agriculture market and it remained so throughout the agricultural production environment of WWII. In 1944, after growers commercially introduced DDT to Southern California citrus and nut orchards, the consumption of the DN compounds exploded. Because DDT was not effective as an acaricide, it killed the predators of the red spider mite (and other mites like the six-spotted mite) and not the red spider mite itself, in turn causing both mite populations and the demand for Dow's DN product to soar.[231]

DNOCHP was not the only promising dinitrophenol derivative that Kagy had identified in his graduate work at Iowa State University. Dow had presented him with a smorgasbord of synthetic novelty based around the dinitro-cresol molecule. There were a few other potential economic poisons identified by Kagy. The other main potential economic poison he identified was dinitro-o-sec-butyl-phenol (DNOSBP), which had potential not just as an insecticide, but also as an herbicide.[232] This time however, Dow bypassed the Crop protection Institute and went directly to the scientist and experiment station they needed.

Dow sought out A. S. Crafts and other scientists at the UC Davis Experiment Station for research and development. A. S. Crafts was at the time a world expert on plant physiology, and one of the few experts on the herbicidal action of synthetic compounds on plants. In the late 1930s, Crafts, Dow chemists, and other scientists at the UC Davis experiment station, built on Kagy's earlier studies and demonstrated that DNOSBP was an effective contact herbicide. Dow would eventually commercialize DNOSBP in the early 1940s as "DINOSEB," a general herbicide, and DN-289 (DOWSPRAY), as a dormant spray for orchard trees pests, both manufactured at the Seal Beach plant of Dow Chemical.[233]

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[229] Dow, *Dow in the West*, 1977.

[230] Dow, *Dow in the West*, 1977.

[231] Simpson, A C. "Control of the Red Spider Mite." *Nature* 155, no. 3930 (1945): 241; Anonymous. "Red Mite Research and the Dinitros." *Down to Earth* 1, no. 1 (1945): 6-9; Anonymous. "DN-111 Used with DDT Controls Red Mite." *Down to Earth* 2, no. 1 (1946): 5-6; Dow Chemical Company, Great Western Division. "Chemical News for Western Agriculture." In *Papers of Alden S. Crafts*, Dow Chemical. Davis, CA: UC Davis Special Collections, 1949.

[232] Meuli, L J. "Herbicides." *Patent #2,393,859*, US Patent Office. USA: Dow Chemical Company, 1946.

[233] Dow Chemical Company. "Dow Manual on Spraying and Dusting." In *Dow Chemical Historical Collection, 1897-2006*, Dow Chemical Company. Midland, MI: Chemical Heritage Foundation, 1945; Crafts, A S. "A New Herbicide, 2,4, Dinitro 6

a) b)

Figure 3 – a) Dow Contact Herbicide pamphlet and b) Dow Selective Herbicide pamphlet, ca. 1944[234]

In 1936, about the same time Crafts began working on Dow's new DINOSEB compound, the Standard Agricultural Chemical Company contracted the CPI to study their new product Sinox (DNOC) as an herbicide instead of an insecticide. The CPI chose UC Davis Agricultural Experiment Station and the New Hampshire Experiment Station as sites for a new series of experiments with Sinox.[235] This project would explore the use of dinitro compounds as selective herbicides, particularly dinitro-o-cresol (DNOC), a Bayer product

Secondary Butyl Phenol." *Science* 101, no. 2625 (1945): 417-18; Crafts, A S. "Toxicity of Ammonium Dintro-O-Sec-Butyl." *Hilgardia* 19, no. 5 (1949): 159-69; Crafts, A S. "Weed Control Research: Past, Present, and Future." *Weeds* 8, no. 4 (1960): 535-40.

[234] Dow Chemical Company, Great Western Division. "Dow Contact Herbicide Pamphlet." In *Paper of Alden S. Crafts*, Davis, CA: UC Davis Special Collections, 1944; Dow Chemical Company, Great Western Division. "Dow Selective Herbicide Pamphlet." In *Papers of Alden S. Crafts*. Davis, CA: UC Davis Special Collections, 1944.

[235] Westgate, W A, and R N Raynor. "A New Selective Spray for the Control of Certain Weeds." *Bulletin 634*, 1-36. Berkeley, CA: UC Agricultural Experiment Station, 1940.

that had never caught on in Europe because of its phytotoxic effects on dormant trees.

Sinox was initially screened and tested at the New Hampshire Experiment Station, but in 1937 the project was enlarged and shifted entirely to UC Davis. In the spring of 1938, UC Davis scientists field tested Sinox (DNOC) on some fields near the UC Davis campus and by the end of the next season, UC Davis and Dow chemists had field tested DNOC on 12,000 acres of flax and grains in the delta regions of San Joaquin and Contra Costa counties using both mechanized sprayers and airplanes (See Figure 4).[236]

It was not Standard Chemical Company that benefited from this research.[237] It was Dow Chemical. Dow scientists had been experimenting with this compound since 1930 when they got wind of Bayer's plan to sell it in Europe. It was one of the compounds originally tested by Kagy in his doctoral studies. [238] Thus, from both the CPI studies at UC Davis as well as from studies directly supported by Dow at UC Davis, Dow scientists developed the first commercial synthetic selective herbicides for the control of broad-leaf annual weeds in cereals, flax, alfalfa and corn. [239] In 1942, Dow introduced DNOC as the world's first selective herbicide to California growers.[240] It was used most extensively in the Salinas Valley on select higher value crops than flax or field crops.[241]

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[236] Westgate and Raynor, "New Selective Spray," 1940. The Caterpillar Company and the Campbell-Budlong Company furnished the tractors and hand sprayers and the Hawke Dusting Corporation and the Independent Dusting Corporation provided the airplanes.

[237] The Standard Chemical Company did commercialize Sinox in the mid 1940s and opened an office in Sacramento.

[238] Britton, E C. "Insecticide." *Patent #1,907,493*, US Patent Office. USA: Do2 Chemical Company, 1933.

[239] Dow learned a lesion from the commercialization of DN-111 that different salts of their target compounds had differing commercial toxicological potential and had A.S. Crafts look at selective the herbicidal potential or various salts of DNOC they synthesized at their facility in Midland, MI.

[240] At this time various (aromatic) fractions of oil were also beginning to be used as selective herbicides. They were used most extensively on carrots in California. Crafts, A S, and H G Reiber. "Herbicidal Properties of Oils." *Hilgardia* 18, no. 2 (1948): 77-156.

[241] Dow, *Dow in the West*, 1977.

Figure 4 – Application of Sinox to a flax field for the selective control of wild radish, San Joaquin County, CA, 1938[242]

An overview of all the CPI projects can be found in Appendix 1, although this is an incomplete record. The project record was compiled from the archives of the NRC at the National Academy of Sciences, from the published Bulletins and internal Circulars of the CPI, from the minutes of the annual meetings of the American Association of Economic Entomology, and from various other publications and patents, and in the case of the “dinitro” compounds, from the archives of UC Citrus Experiment Station at UC Riverside and the papers of A.S. Crafts at the UC Davis Special Collections. The records of the CPI become very limited after 1942.

Limited Sinks, Limitless Worlds

The US emerged from WWII as the supreme commander in both industrial chemistry and industrial agriculture. US chemical companies aided by the US War Industries Board built on their interwar petrochemical advantage and made petroleum chemistry synonymous with the US chemical industry. WWII, like WWI, acted like a forcing house of technological development and in a few short years the US mobilized the fiercest industrial armament the world had ever seen. After the war, agricultural scientists took the war’s new offensive and defensive technologies and turned them toward to the belligerent enemies on agricultural

[242] Standard Agricultural Chemicals Inc. "Pamphlet: For Selective Weed Control - Sinox." In *Papers of Alden S. Crafts*. Davis, CA: UC Davis Special Collections, 1944.

fields.[243] For example, new synthetic organic chemicals and more powerful foggers, built for chemical warfare and the deployment of destroyer-size smokescreens, were introduced to US agriculture.[244] Used in combination with the "wonder insecticide" DDT, growers could fog (poison) an entire acre in often less than a minute at minimal cost, finally achieving the economies of scale needed to begin to democratize access to economic poisons for all growers and for all crops. During and just after the war, modernity's agricultural poisons, like DD, DDT, and 2,4-D, became an ordinary part of the production of food and fiber. After WWII, in the oft cited example, chemical facilities that produced nitrates for explosives were sold at fire sale prices to chemical companies, many of whom turned that industrial capacity toward the agricultural field.[245]

US agriculture emerged from the Second World War in an enlarged state of overproduction, a state compounded by an ideology of nature's control, i.e. "the fact that throughout man's competition with Nature synthetic chemistry has never lost a battle."[246] The rapid adoption of chemical consumption in agrarian production after the war, however, cannot be laid at the feet of the industrial changes wrought by the war as is still commonly done by popular critics of industrial agriculture.[247] The US Green Revolution was not possible without the development of an industrial agrarian infrastructure that solidified in the interwar years. In other words, the Green Revolution was painted upon the canvas of interwar changes, particularly the overlapping infrastructures of modern seed varieties and the assumption that these varieties would take an input intensive form.[248] These infrastructures included chemical companies, chemical plants, the truck and train networks that transported products, scientists trained in screening for toxic compounds, the extension scientists that tested them in the field, the government officials that supported their use, and the assumptions, ideologies, and imaginaries that shaped their use. In the interwar era, there was, as Goodman et al. (1987) put it, "a new threshold of industrial appropriation" for both US agriculture and for US public agricultural research.[249]

Founded in 1920 under the aegis of the National Research Council, the Crop Protection Institute was a non-governmental organization tasked with linking private industry to public science by bringing together expertise and facilities of state, university, and extension scientists in the emerging fields of crop protection with the toxic materials and capital of a rapidly developing post WWI US chemical industry.[250] Through the

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[243] Russell, *War and Nature*, 2001.

[244] LAT. "New Insecticide Fog Generators Revolutionize Man's War on Pests, Vineyards Blanketed with Mist in Few Minutes at Low Cost." *Los Angeles Times*, May 13 1945.

[245] Smil, *Enriching the Earth*, 2004; Pollan, *The Omnivore's Dilemma*, 2006; Gorman, H S. *The Story of N: A Social History of the Nitrogen Cycle and the Challenge of Sustainability*. New Brunswick, NJ: Rutgers University Press, 2012.

[246] Hale, "Agriculture Enters the Chemical Industry," 1930.

[247] Carson, *Silent Spring*, 1962; Pollan, *The Omnivore's Dilemma*, 2006.

[248] Evenson, R E, and D Gollin. "Assessing the Impact of the Green Revolution, 1960 to 2000." *Science* 300, no. 5620 (2003): 758-62; Kloppenburg, *First the Seed*, 2004.

[249] Goodman et al., *From Farming to Biotechnology*, 1987.

[250] O'Kane, "Crop Protection Institute," 1920.

industrial, scientific, and political networks of the Crop Protection Institute, chemical manufacturers, agricultural producers, and crop protection scientists collaborated to facilitate new agricultural outlets for primary chemical products and new methods to transmute the growing masses of inorganic and organic industrial wastes from costs of production into valuable and effective pest control products. By helping standardize agricultural toxicology and geographically homogenize crop protection research and pesticide use, and through the establishment and naturalization of private-public agro-industrial research networks, the Crop Protection Institute helped shift crop protection to the forefront of capital investment and industrial R&D, laying the techno-social infrastructure necessary for the generalization of industrially produced chemicals across American agriculture following WWII.[251] Howard Barss, the Principal Botanist of the USDA Office of Experiment Stations, said as much in the last National Research Council review of the Crop Protection Institute. He wrote,

"There is a continuing trend among large organizations to establish research departments in entomology and plant pathology. Toward this the Institute has strongly contributed. After the Institute has assisted a company and carried investigation work to a certain point, development assumes such proportions that the company naturally sets up a department of its own. This is undoubtedly a significant and productive outcome of Institute activities. It extends the scope of industrial research into the fields of science represented by the Institute, and the attitude of industry toward biological research becomes more appreciative and more discerning… By establishing initial connections, the Institute has also strongly contributed on the tendency on the part of some industrial companies to work directly with experiment stations, usually those close at hand."[252]

The theoretical claim underlying this chapter is that industrial agriculture can serve as both an outlet for over production in the chemical industry and a profitable sink for industrial waste. While the historical record shows this to be the case, what is important about this chapter is that it highlights, through a brief history of the CPI, the development of the institutional capacity necessary to make that happen, in particular the links between private capital and public research. It also highlights how the chemicalization of agriculture made the farm another outlet for byproducts of the chemical industry as well as a source of raw material. William Hale, head of Dow's Organic Research Lab, described the process of what happens when an industry becomes chemicalized, when agriculture becomes an extension of the chemical plant.

"If we look upon agriculture as an organic chemical activity, which it is solely and nothing more, we shall have little difficulty in understanding the real needs of the farmer and directing his chemical

[251] Larkin, B. 2013. "The Politics and Poetics of Infrastructure." *Annual Review of Anthropology* 42:327-343.
[252] Barss, H P. "Crop Protection Institute Report for 1941." In *Institutions, Associations, Individuals*, National Research Council. Washington, DC: Archive of the National Academy of Sciences, 1942.

labors so as to bring him assured prosperity. At the outset we must recognize that prosperity has come to the organic chemical industry in this country primarily by reason of the adaptation for distinct use of every single component found to arise in the course of any of its manufacturing processes. Roughly speaking, this may be termed 'the utilization of all byproducts;' as a matter of fact, it is such control of manufacturing processes that by-products may become main products at will and to profitable turn."[253]

The history of the CPI reflects and is a good proxy for the larger changes that occurred to American agriculture in the interwar era. In the early 1920s, most CPI research was focused on the application, standardization, and homogenization of materials already being produced.[254] By the late 1930s, the situation had completely changed and "an increasing proportion of the research" that the CPI coordinated was "fundamental in nature… where the companies' research staffs actively cooperated with the Institute's research men." For instance, the Dow Chemical Company highlighted how their experience with the CPI not only taught them the importance of field based R&D, but also confirmed the benefit of maintaining close relationships with state and federal scientists. It was one thing to demonstrate efficacy in the lab, it was a whole other thing to bring a potential product to market, and Dow recognized that this sort of public-private cooperation was critical in bridging the gap between the laboratory and field.[255] Barss outlined this process as well.

"In the laboratories of the supporting companies experienced research men give their time and attention to the development of new chemical compounds designed to meet particular requirements. These are then studies by the Institute's workers from the point of view of their biological effectiveness. Results of such study then become the basis of further work in the laboratories of the supporting company, and out of this constructive program can be expected to emerge new and better materials for the control of serious plant disease and insects. Thus, agriculture becomes the ultimate beneficiary."[256]

This chapter has argued that historical investigation into the origins of today's agricultural political economy reveals a key role that broader processes of industrialization, particularly the waste products of industry, have had in producing the agriculture of today.[257] In

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[253] Hale, "Agriculture Enters the Chemical Industry," 1930.

[254] For example, Bartlett, B, and C Pershing. "Laboratory Control Studies on the Greenhouse Thrips." *Journal of Economic Entomology* 34, no. 6 (1941): 760-66.

[255] Barrons, K. "The Function of Agricultural Chemical Development " In *Dow Chemical Historical Collection 1897-2006*, Dow Chemical Company. Philadelphia, PA: Chemical Heritage Foundation, 2000.

[256] Barss, "Crop Protection Institute," 1940.

[257] Goodman et al., *From Farming to Biotechnology*, 1987. 162. "However, if there is neither a natural division of labor between agriculture and industry nor the possibility of directly organizing agriculture production along rural lines, we must look not to rural production for the secret of capitalist subordination but to the rise and development of various agro-industrial branches, both upstream and downstream. 'Agriculture' then represents the increasingly residual activities which have resisted transformation into industrial processes." pp. 152 "In widening the focus away from the 'point of production,' we risk accusations of technological determinism and of eliminating social relations from the analysis. However, it would be myopic to

expanding the focus of agro-historical investigation beyond the agricultural field and its institutions, as Goodman et al. (1987) suggested, this chapter claims that besides the production of food and fiber, industrial agriculture can also provide industrial *ecosystem* based *services* to industrial chemical development and the expanded reproduction of capital.[258] The growth of theses services, however, depended critically on the development and naturalization of public-private research networks and the geographic and compositional homogenization of pesticide consumption.

It is important to remember that it was not US farmers who were the ultimate beneficiaries of agriculture's chemicalization and the exponential yields of the post-WWII era. It was the companies themselves that produced chemicals and farm equipment as well as the food processors that benefited from cheap overabundant food. In the interwar era, in the face of chronic overproduction, pesticide use exploded, not to prevent starvation, but as a profitable sink for the mountains and lakes of industrial waste and as a sink for overproduction. In other words, industrial agriculture served a dissipative function for the wastes of US industry. After WWII, agricultural chemical use soared along with an era of massive federal crop subsidies, and again not to provide sufficient food but "in service to the gods of profit and production."[259] In the interwar years, Jefferson's dream of a nation of yeoman farmers vanished in an ideology of immortal progress and the racially hued specter of Malthus.[260]

What was the ultimate role of the CPI? The CPI scientist Farrar summed it up best in a 1948 piece on the relation of chemical research to new commercial pesticides. He wrote,

"From these programs of research [like the CPI] have come new organic insecticides and fungicides whose performance has been *so* outstanding that the field for new and better agricultural chemicals appears almost limitless" (emphasis in original).[261]

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ignore the social consequences of the transformation of agriculture orchestrated by industrial capitals from *outside* the immediate labor process" (emphasis in original).

[258] (Toxicological) dilution, (value and nutrient) recycling, (industrial) detoxification, (legal) management, (surplus) absorption, (legal) sequestration, and (profitable) treatment of wastes. Daily, G C, and K Ellison. *The New Economy of Nature*. New York: Island Press, 2002. Economists underestimate the economic and social value of the waste sink services provided by (industrial) ecosystems. Howarth, R B, and S Farber. "Accounting for the Value of Ecosystem Services." *Ecological Economics* 41, no. 3 (2002): 421-29, Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being*. Vol. 5, Washington, DC: Island Press 2005.

[259] Berry, W. *The Unsettling of America*. San Francisco, CA: Sierra Club Books, 1977.

[260] "Progress is immortal." Stine, "Better Destiny," 1942; Sauer, C. "Letter from Carl O. Sauer to Joseph H. Willits, 1952, June 13." In *Joseph H. Willits papers*, Series 1. Hillcrest, NY: The Rockefeller Archive Center, 1952; Jennings, B H. *Foundations of International Agricultural Research: Science and Politics in Mexican Agriculture*. Westview Special Studies in Agriculture Science and Policy. Boulder, Co: Westview Press, 1988; Perkins, J H. *Geopolitics and the Green Revolution: Wheat, Genes, and the Cold War*. New York: Oxford University Press, 1997.

[261] Farrar, M D. "Relation of Chemical Research Laboratories to Development of New Insecticides and Fungicides." *Industrial and Engineering Chemistry* 40, no. 4 (1948): 680-81.

Chapter 4

"From Oil Well to Farm": Industrial Waste, Shell Oil, and the Petrochemical Turn[1]

"A few years ago the ability to plow a straight furrow meant successful farming. Today, when agriculture is the world's most important industry, the straight furrow has a new meaning. It means new machines, new varieties of crops – and most important – new chemicals."

Dr. Roy Hansberry, 1946, Director of the Shell Agricultural Laboratory[2]

This chapter traces two stories of agriculture that merge in late autumn of 1944 on a lettuce field in California's Salinas Valley. On that field, two transmuted industrial waste products from California's rudimentary petroleum economy were at once injected into the soil and into agricultural production, spurring a radical transformation of crop rotation and recasting the organizational possibilities of industrial agriculture. Taken together, these two stories tell a tale of capital and chemistry overcoming an ecological contradiction of agroindustrialization. This chapter considers an earlier history of petroleum-based agrochemicals–one that is often left untold–situating their development in the interwar years and within the context of California's emerging petroleum complex. It argues that, in the late 1920s, agriculture began its transformation into a new and immensely productive agricultural regime organized around the oil industry and its waste byproducts. The petrochemicals and subterranean chemical warfare that were developed during this time became industrial agriculture's chemical salvation, providing both the soil disinfection power and the soil nutrition that made the massive yield increases in agricultural production following World War II possible. This chapter begins an excavation of this earlier history, positioning both the chemicals used in agro-industrialization and the subsoil itself as critical sites of historical inquiry.

California is often imagined as a land without seasons. For California agriculture however, those seasons arrive as distinct as the return of cold temperatures and changes in leaf color in other parts of the United States. Every fall, as the first rains return to California's parched landscapes, fumigation crews stir from their commercial slumber, dust off their gear, gather their chemicals, and mobilize for the soil fumigation season that lays ahead. Whether under the cool fogs of America's "Salad Bowl," the high clouds of the great Central Valley, or the

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[1] Shell Oil Company. *Shell… Soldier and Civilian*: Shell Union Oil Corporation and Associate Companies, 1945, unpaginated.
[2] Shell Oil Company, Agricultural Laboratory. *Better Farming Through Research*: Shell Union Oil and Associate Companies, 1946, unpaginated.

winter sun of the desert counties, these fumigation crews migrate like well-disciplined regiments from field to field across the California countryside, introducing a variety of toxic chemicals into the subsoil of much of its incredibly productive farmland, temporarily cleansing the soil of its commercially destructive pests. These toxic gases, some carcinogenic and neurotoxic, others potent greenhouse gases and ozone depleting substances, some both, move through the soil complex like an army of insidious assassins, leaving no place for soil pests to hide.[3] Without these toxic chemicals to disinfect the soil of nematodes, wireworms, and other soil dwelling pathogens on an annual or semiannual basis, the fertile valleys of California and much of the world's industrial agriculture could not be commercially productive (See Figure 1).

Figure 1 – Workers sealing tarps after applying methyl bromide to a strawberry field, Salinas Valley, CA, fall 2014. (Credit: Sam Hodgson for CIR)[4]

[3] Yagi, K, J Williams, N-Y Wang, and R J Cicerone. "Atmospheric Methyl Bromide (CH_3Br) from Agricultural Soil Fumigations." *Science* 267, no. 5206 (1995): 1979-81; Peters, H A, R L Levine, C G Matthews, S Sauter, and L Chapman. "Synergistic Neurotoxicity of Carbon Tetrachloride/Carbon Disulfide (80/20 Fumigants) and Other Pesticides in Grain Storage Workers." *Acta Pharmacologica et Toxicologica* 59, no. 7 (1986): 535-46; Reeves, Margaret, and Kristin S Schafer. "Greater Risks, Fewer Rights: US Farmworkers and Pesticides." *International Journal of Occupational and Environmental Health* 9, no. 1 (2003): 30-39; Yang, R S, K L Witt, C J Alden, and L G Cockerham. "Toxicology of Methyl Bromide." In *Reviews of Environmental Contamination and Toxicology*, 65-85: Springer, 1995.

[4] http://www.samhodgsonphotography.com/the-dark-side-of-the-strawberry-for-cir

The discovery of organic and inorganic fertilizers in the mid 19th century set in motion a metabolic fracturing of crop rotation, animal husbandry, and nutrient cycling.[5] Through industrial substitution, the development of commercial fertilizers removed the need to rotate crops for nutrient management. [6] They did not, however, overcome the need of crop rotation for pest management. Rather, the discovery of cheap and effective petroleum-based soil fumigants in the early 1940s revolutionized crop rotation—severing the link between the intensive production of a single crop without rotation and the build up of commercially destructive pests in the soil complex. This chapter examines this transformation of industrial agriculture through its particular relationship to petroleum-based chemicals. It argues that industrial waste and industrial agricultural production were inextricably entwined in the historic development of global agricultural and chemical industrial complexes.

This chapter considers the production and movement of two transmuted waste products—anhydrous ammonia and the soil fumigant DD—from California's rapidly developing petroleum and chemical complexes into agricultural production. Though industrialized chemical pest control had been used in California since the late 19th century, chemical pest management had never effectively entered the subsoil.[7] The transition to effective below ground pest management was critical to increasing productive capacity in *both* agricultural and petroleum-based industries[8]. In other words, agriculture developed in concert with California's emerging petroleum complex and its vast waste stream.

The reutilization of industrial byproducts is not unique to agriculture.[9] Since the mid 19th century, the chemical sciences have played a major role in transforming the dregs of industry into profitable elements of production.[10] In the late 19th century, for example, chemists transformed black coal tar into brilliant colors, extracting value from the detritus of Europe's coking mills, blast furnaces, and illuminating gas works.[11] Industrial chemistry

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[5] Smith, A. *The Wealth of Nations*. New York: Bantan Dell, 2003, 12. Liebig, J. *Familiar Letters on Chemistry, and Its Relation to Commerce, Physiology, and Agriculture*: Walton & Maberly, 1859, Letter XI; Marx, K. *Capital: A Critique of Political Economy*. New York: Penguin Books, 1976, 637; Foster, J B. "Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology." *American Journal of Sociology* 105, no. 2 (1999): 366-405. Naylor, R. " Losing the Links between Livestock and Land." *Science* 310, no. 5754 (2005): 1621-22.

[6] Goodman, D, S Bernardo, and J Wilkinson. *From Farming to Biotechnology: A Theory of Agro-Industrial Development*. London: Blackwell, 1987, 2-3.

[7] Coquilett, DW. "Report on the Gas Treatment for Scale Insects." *US Department of Agriculture, Report for 1887* (1888): 123-42; Stone, M W, and R E Campbell. "Chloropicrin as a Oil Insecticide for Wireworms." *Journal of Economic Entomology* 26, no. 1 (1933): 237-43; Abraham, G. "Policeman's Tear Gas Used for Fumigating the Garden." *New York Times*, 1940, D10; Romero, A. "Commercializing Chemical Warfare: Citrus, Cyanide, and an Endless War." *Agriculture and Human Values.* In Press (2015).

[8] Shell Oil Company, "Better Farming," unpaginated; Haynes, W. *Chemical Economics*. New York: D. Van Nostrand Company, Inc., 1933, Chapter 3.

[9] Marx, K. *Capital: Volume III*. New York: Penguin Books, 1981, 172-179; Haynes, *Chemical Economics*, Chapter 3; Leslie, E. *Synthetic Worlds: Nature, Art, and the Chemical Industry*. London: Reaktion Books Ltd., 2005; Desrochers, P. "Does the Invisible Hand Have a Green Thumb? Incentives, Linkages, and the Creation of Wealth out of Industrial Waste in Victorian England." *The Geographic Journal* 175, no. 1 (2009): 3-16; Cooper, T. "Peter Lund Simmonds and the Political Ecology of Waste Utilization in Victorian Britain." *Technology and Culture* 52, no. 1 (2011): 22-44.

[10] For agriculture, the first prominent reuse of industrial waste began in the early 1870s with the movement of arsenic oxides into agricultural production, via such products as Paris green, London Purple, and lead arsenate (see Chapter 1).

[11] Travis, A S. *The Rainbow Makers: The Origins of the Synthetic Dyestuffs Industry in Western Europe*. Toronto: Associated University

coaxes waste back into circulation—reshaping it, transmuting it, into its own antithesis: value.

However, while the reutilization of byproducts may be common industry practice, industrial agriculture is unique as an industry in its complementary relationship to industrial waste. What makes the reutilization of industrial byproducts different in this case is that, for the most part, it is industrial waste's *toxicity* that gives it potential use value in industrial agricultural production. Industrial waste is often both very toxic and very abundant, making it a potentially useful raw material for industrial agriculture. In this transfer of toxic chemicals from the wastebaskets to the coffers of industry, industrial agriculture has functioned as a profitable sink for the producers of petro-chemical waste.

This chapter is the first work to highlight the critical role industrial waste has played in the industrialization of agriculture.[12] Recent historical work on the "chemicalization" of agriculture is sparse, and these historical silences are exacerbated by the fact that chemicalization is often conceptually subsumed into debates around mechanization and the displacement of labor.[13] Of course, historians have done significant work in constructing a biological picture of agricultural industrialization—distancing it conceptually, chronologically, and geographically from processes of mechanization or other forms of technological or managerial change.[14] For their effort, we now have many excellent histories on the origins and movement of plants, animals, and foodstuffs around the world, the processes of their transformations into modern varieties, and their ecological, social, and political effects. However, there remain few historical accounts that give the same attention to chemicals.[15] Therefore deep engagement with the introduction and generalization of

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Press, 1993; Haber, L F. *The Chemical Industry During the Nineteenth Century: A Study of the Economic Aspects of Applied Chemistry in Europe and North America*. Oxford, UK: Oxford University Press, 1958.

[12] Many scholars have elegantly examined an analogous but inverse process – the industrial utilization of agricultural surplus (waste) – known as chemurgy. See, McMillen, W. "Chemurgy: Utilization of Farm Products in the American Way." *Industrial and Engineering Chemistry* 31, no. 5 (1939): 1-9; Finlay, M R. "The Industrial Utilization of Farm Products and By-Products: The USDA Regional Research Laboratories." *Agricultural History* (1990): 41-52. While Tarr (1975) and others have pointed to the use of rural farms as sinks for urban wastes (ex. sewage), none has yet to suggest that the production of industrial waste has been *integral* to the development of industrial agriculture. See Tarr, J A. "From City to Farm: Urban Wastes and the American Farmer." *Agricultural History* 49, no. 4 (1975): 598-612.

[13] For example, Cochrane, W W. *The Development of American Agriculture*. Minneapolis, MN: University of Minnesota Press, 1993, Chapter 7. For the best recent examples that are beginning a conversation on chemicalization, see, Stoll, S. *The Fruits of Natural Advantage: Making the Industrial Countryside in California*. Berkeley, CA: University of California Press, 1998, Chapter 4; Russell, E. *War and Nature: Fighting Humans and Insects with Chemicals from World War I to Silent Spring*: Cambridge University Press, 2001; Ceccatti, J S. "Biology in the Chemical Industry: Scientific Approaches to the Problem of Insecticide Resistance, 1920s-1960s." *Ambix* 51, no. 2 (2004): 135-47; McWilliams, J E. "The Horizon Opened up Very Greatly": Leland O. Howard and the Transition to Chemical Insecticides in the United States, 1894-1927." *Agricultural History* (2008): 468-95; McWilliams, J. *American Pests: The Losing War on Insects from Colonial Times to DDT*. New York: Columbia University Press, 2008; Ceccatti, J S. "Natural Selection in the Field: Insecticide Resistance, Economic Entomology, and the Evolutionary Synthesis, 1914-1951." *Transactions of the American Philosophical Society* 99, no. 1 (2009): 199-217.

[14] For example, Olmstead, A L, and P W Rhode. *Creating Abundance: Biological Innovation and American Agricultural Development*. Cambridge, UK: Cambridge University Press, 2008.

[15] Examples include: Carney, J A. *Black Rice: The African Origins of Rice Cultivation in the Americas*. Cambridge, MA: Harvard University Press, 2002; Sackman, D C. *Orange Empire: California and the Fruits of Eden*. Berkeley, CA: University of California Press, 2005; McCann, James. *Maize and Grace: Africa's Encounter with a New World Crop, 1500-2000*. Cambridge, MA: Harvard

chemicals in the agro-production complex remains largely absent in the agricultural history canon, especially prior to WWII.

As James McWilliams has argued, "Despite the recognition of the impact of [agrochemicals] in American science, agriculture, and public health, comparatively little is known about the precise historical developments that fostered their emergence."[16] Thus, in its close examination of agriculture's *chemicalization*, this chapter makes a critical intervention into historical scholarship on the industrialization of US agriculture. Specifically, it contends that chemicalization is a distinct and critical process of agricultural industrialization.[17]

In his book, *The Centrality of Agriculture*, Colin Duncan rightly argues that the term mechanization is often used incorrectly to mean chemicalization.[18] Duncan suggests that in distinguishing chemicalization from mechanization it is possible to see that the use of chemicals has in fact revolutionized the productivity of agriculture in equal or even greater measure than mechanization or modern varieties. While this claim is subject to debate, a recent review of green revolution yield gains lends empirical credibility to Duncan's argument.[19] He suggests that the chemicalization of agriculture resembles mechanization in its ability to act as a labor saving device, but differs in its implications for agriculture's ecological processes.

While Duncan's claims that chemicals are often ignored as a "determining" character of modern industrial agriculture and that chemicalization and mechanization have different (though interrelated) ecological effects are accurate, his characterization of chemicalization as primarily a labor saving process obscures the complexity of the labor-chemical dialectic in industrial agriculture. While the use of chemicals in agriculture may resemble a labor saving device, only parts of the agricultural chemical soup–herbicides in particular–actually reduce the amount of labor. In fact, many chemical practices can *increase* the amount of labor needed to bring a crop to market.[20] The relationship between chemicals, labor, and mechanization is more complicated than is currently theorized, and thus is ripe for new scholarship that begins to pry apart some of its historically sedimented layers.[21]

University Press, 2007; Freidberg, S. *Fresh: A Perishable History*. Cambridge, MA: The Beklnap Press of Harvard University Press, 2009; Kingsbury, Noel. *Hybrid: The History and Science of Plant Breeding*: University of Chicago Press, 2009; Bobrow-Strain, A. *White Bread: A Social History of the Store Bought Loaf*. Boston, MA: Beacon Press, 2012.

[16] McWilliams, "The Horizon Opened Up," 469

[17] John Teeple, a prominent chemical engineer during WWI and the interwar period, coined the term *chemicalization* to describe the unique changes that chemicals brought to American Industry. Haynes, *American Chemical Industry*, *Vol. III*, 353; Haynes, *Chemical Economics*, Chapter 3.

[18] Duncan, C. *The Centrality of Agriculture: Between Humankind and the Rest of Nature*: McGill-Queen's Press-MQUP, 1996, 116-117.

[19] Evenson, R E, and D S Gollin. "Assessing the Impact of the Green Revolution, 1960 to 2000." *Science* 300, no. 5620 (2003): 758-62.

[20] Romero, A. "Commercializing Chemical Warfare," 2015.

[21] See, Essig, E O. "Farm Machinery in Relation to Insect Pest Control." *Journal of Economic Entomology* 26, no. 4 (1933): 864-68; McWilliams, "The Horizon Opened Up," 469. Mechanization and chemicalization can act synergistically by reducing the amount of labor needed for chemical application or by reducing the per unit cost of chemical use. For example, by the late 1920s, "[a]n airplane [could] poison an acre of cotton thoroughly in less than two seconds," doing more, and far better work over a season

The two stories told in this chapter have a common origin in the post-WWI mind of J.B. August Kessler, head of operations for Shell Oil. Prior to the 1920s, the notion that a chemical industry could be based on petroleum was incomprehensible. It wasn't until the rapid expansion of thermal cracking programs for the production of gasoline during and following WWI that the scale of wastes from petroleum extraction and refining abutted a potential waste-value threshold.[22] Between 1920 and 1929, the production of US oil soared from 378 million barrels to well over one billion, with California producing twenty-three percent of US oil in 1920 and twenty-nine percent in 1929, respectively.[23] Oil refining, motor fuel consumption, and the production of petroleum byproducts, like the asphalts used to pave the rapidly expanding US road network, followed the same pattern.

The United States emerged from WWI as a major player in industrial chemistry.[24] During the war, no other American industry grew as rapidly as the chemical industry.[25] In only a few short years chemical entrepreneurs backed by wartime orders and guided by government coordination sunk more than $500,000,000 into fixed capital for American chemical manufacture.[26] This dramatic growth, coupled to the emergence of chemistry as a fundamental instrument of industry and warfare, began to reconfigure the geography and

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"than 4000 laborers applying lead arsenate spray by means of knapsack pumps." Hinds, W E. "Presidential Address: Some Achievements in Economic Entomology." *Journal of Economic Entomology* 27, no. 1 (1934): 37-52.

[22] In petroleum refining, cracking is the process by which the complex organic molecules of crude oil are broken down into simpler, smaller, and lighter hydrocarbons, such as gasoline, naptha, diesel, and jet fuel. Thermal cracking, which uses extreme heat and high pressure to crack oil, produced more gasoline than straight run distillation of crude oil, and it spread rapidly around the world following WWI. Thermal cracking installations, which required larger upfront capital outlays and meticulous design, brought more precision, control, and economies of scale to oil refining, and produced large amounts of refinery gases as byproducts of the process. California hosted some of the first petrochemical plants in the US to utilize the byproducts of thermal cracking units when in 1917 two plants were installed, one at an LA refinery of the General Petroleum Company, and another at the San Francisco refinery of Standard Oil of California to convert cracking byproducts into toluene for the production of TNT (trinitrotoluene). Crowell, B. *America's Munitions 1917-1918: Report of Benedict Crowell, the Assistant Secretary of War, Director of Munitions*. Washington DC: Government Printing Office, 1919; Williamson, H, R Andreano, A Daum, and G Klose. *The American Petroleum Industry: The Age of Energy 1899-1959*. Evanston, IL: Northwestern University Press, 1963. 423. Robertson, R. "Some War Developments of Explosives." *Nature* 107 (1921): 524-27. Shell Oil's Martinez, CA refinery opened in December of 1914, and was one of the first modern west coast refineries. By 1916, Shell's west coast operations had become fully integrated from well to consumer. Royal Dutch/Shell's expansion into California is considered "formidable" by economic historians and was financed through profit reinvestment and by floating Royal Dutch/Shell shares in the US. Wilkins, M. *The History of Foreign Investment in the United States, 1914-1945*. Cambridge, MA: Harvard University Press, 2004. 25-26. For thresholds and value, see Marx, K. *Capital: Volume III*. New York: Penguin Books, 1981. 172-173; Wilson, R E. "Refinery Gas: A Raw Material of Growing Importance." *Journal of the Society of Chemical Industry* 58, no. 51 (1939): 1095-1101; Brooks, B T. "Petroleum as a Chemical Raw Material." *Industrial and Engineering Chemistry* February (1924): 185-89.

[23] Williamson, *The American Petroleum Industry*, 442-462.

[24] Anonymous. "Chemists Gain Advantage: Americans Have Outdone Germany in Chemical Products." *New York Times*, February 17, 1918; Sinclair, J F. "War Brings New Industry." *Los Angeles Times*, 1930; Brooks, B T. "Synthetic Organic Chemicals from Petroleum: An American Development." *Industrial and Engineering Chemistry* 31, no. 5 (1939): 514-19; Smith Jr., J K. "The American Chemical Industry since the Petrochemical Revolution." In *The Global Chemical Industry in the Age of Petrochemical Revolution*, edited by L Galambos, T Hiikino and V Zamagni, 168-92. Cambridge, UK: Cambridge University Press, 2007.

[25] Clarkson, G B. *Industrial America in the World War: The Strategy Behind the Line, 1917-1918*. Cambridge, MA: The Riverside Press, 1923; Clark, V S. *History of the Manufactures in the United States: 1893-1928*. Vol. III, New York: McGraw-Hill Book Company, 1929.

[26] Hayes, *American Chemical Industry, Vol. 3*, 353-354. This figure does not count investments petroleum refining plants. For fixed capital investments in US oil during the war, see Williamson, *American Petroleum*, Chapter 8.

organization of the US chemical industry and retooled how chemical companies and the US government approached research and development.[27] During the interwar years, the rapid expansion of motor fuel and fuel oil demand, the emergence and spread of new refining technologies, and the materialization of the oil industry as a prime mover of the war machine, began to re-center US industrial chemistry around petroleum. But industrial chemistry needed more than a new source of raw material. New industrial sciences, new industrial apparatuses, and large amounts of capital were also required to aid chemistry's transmutation of petroleum wastes into petrochemicals.

Organic chemicals prior to the 1920s were derived from coal tar and coking byproducts, and therefore were mostly benzenoid (aromatic) compounds.[28] Although organic chemistry had significantly advanced since it origins in the late 1800s, scientific and industrial knowledge of petroleum's *aliphatic*, or open chain nature, was insubstantial. The knowledge and expertise that organic chemists had developed in reutilizing coal tar was not well suited to working with petroleum's aliphatic nature. The crude technological state of oil refining and chemical engineering in the oil industry's first few decades also inhibited the development of petroleum-based chemicals.[29] However, with the shift from distillation to thermal cracking and the emergence of chemical engineering as a discipline, better separation of crude oil's cracked constituents became possible, giving chemists the raw materials that they needed.[30]

In the autumn of 1927 at the Royal Dutch/Shell board meeting in Amsterdam, J. B. August Kessler laid out the guiding principles of the Royal Dutch/Shell Group's proposed approach to making chemicals from petroleum.[31] Beginning with an appeal to the chemical industry's revolutionary nature, Kessler described his vision for the future—imagining the transformation of Shell's petroleum extraction and refining wastes into the chemical products of tomorrow. The oil business and the chemical business were rapidly approaching each other, he said, and it was inevitable that they would one day overlap. Without an organized approach to their integration, capital and time would be wasted. Believing that the very happiness of humankind was at stake, Kessler argued that through petroleum-based chemistry, better things for better living could be made—that Shell's petroleum wastes could simultaneously enrich *both* oil companies and the human race. In his proposal to Shell's board, Kessler presciently envisioned a fertile marriage of petroleum and the chemical industries, foreseeing the establishment of entirely new industries based not on the energy content of petroleum, but its materiality.[32]

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[27] Yerkes, R M, ed. *The New World of Science: Its Development During the War*. Freeport, NY: Books for Libraries Press, 1920.

[28] Brooks, "Petroleum," 185; Brooks, E. *The Chemistry of Petroleum Derivatives*. Vol. 1. New York: The Chemical Catalog Company Inc., 1934, 9.

[29] Williamson, *American Petroleum,* Chapters 9, 17.

[30] Walker, W H. "A Master's Course in Chemical Engineering." *The Journal of Industrial and Engineering Chemistry* 8, no. 8 (1916): 746-48.

[31] Quoted in, Forbes, R J, and D R O'Beirne. *The Technical Development of Royal Dutch Shell: 1890-1940*. The Hague: Royal Dutch Petroleum Company, 1957, 456.

[32] In 1932, at the annual dinner of the Institute of Petroleum Technologists in London, Kessler reiterated many of the same points

Lacking a history of small-holder or subsistence agriculture, California's productive landscapes have been imbued with the logic of capitalism since their inception.[33] By the first few decades of the 20th century, California's agrarian complex attained a degree of intensity, standardization, and specialization that existed nowhere else on earth. By the late 1920s, California agriculture had reached, as one industrial enthusiast put it, a "state of perfection."[34]

Between 1870 and 1929, growers and capitalists brought over 4.7 million irrigated acres into production and by 1929, California had emerged as a top US producer of agricultural value.[35] These impressive production yields made California attractive to industrial investors.[36] Indeed, the board of Royal Dutch/Shell saw the high input use of California's agriculture, its year round growing season and the high value of its products as a critical outlet for their future chemical commodities.[37]

Because their business and infrastructure was globally dispersed, Shell had many options for siting new industrial production. However, their key research and oil production locales, like Amsterdam and Romania, lacked access to both refinery byproducts and markets. Shell had originally planned to build a research lab in Illinois near one of their refineries, however Kessler instead selected Emeryville, CA near Shell Oil's Martinez refinery (See Figure 2).[38] This location, he believed, would provide ample exploration and refinery gases for research and development, access to markets, especially agricultural, and access to talent from UC Berkeley and other Bay Area universities.[39]

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in a vigorous defense Shell's then money-losing position. Anonymous, *The Petroleum Times* XXVIII, October 15 (1932): 371-77.

[33] Walker, R A. *The Conquest of Bread*; 13. Olmstead, A L, and P W Rhode. "The Evolution of California Agriculture 1850-2000." In *California Agriculture: Dimensions and Issues*, edited by J Siebert. Berkeley, CA: Information Series, Giannini Foundation of Agricultural Economics, UC Berkeley, 2003; Henderson, *California*, 7-11.

[34] Houser, J S. "Some Problems in Economic Entomology." *Journal of Economic Entomology* 25, no. 1 (1932): 28-39.

[35] U.S. Census Bureau. "Fifteenth Census of the United States 1930." Washington, DC: GPO, 1932.

[36] By the 1920s, the use of refined petroleum byproducts in agriculture was already the most scientifically advanced in California. Crude refining byproducts had been used in commercial control since the early 1900s as both active ingredients and as thinners or emulsifiers of sprays. The crude waste fractions were collections of hydrocarbon compounds with shared physical characteristics. Most were used as "dormant" sprays on tree crops. See, Vickery, R. "Petroleum Insecticides." *Journal of Economic Entomology* 13, no. 6 (1920): 444-47; Gray, G, and E De Ong. "California Petroleum Insecticides." *Industrial & Engineering Chemistry* 18, no. 2 (1926): 175-80.

[37] Beaton, K. *Enterprise in Oil: A History of Shell in the United States*. New York: Appleton-Century-Crofts, 1957, 464-469; Forbes and O'Beirne, *Technical Development*, 1957. 502-507; Chapman, *International Petrochemical Industry,* 55.

[38] Beaton, *Enterprise in Oil,* 519-522; Forbes and O'Beirne, *Technical Development*, 1957. 455-469; Spitz, P H. *Petrochemicals: Rise of an Industry*. New York: John Wiley & Sons, 1988. 82-89; Chapman, *International Petrochemical Industry,* 54-56

[39] Forbes and O'Beirne, *Technical Development*, 467; Chapman, *International Petrochemical Industry,* 56; Spitz, P H. *Petrochemicals: Rise of an Industry*. New York: John Wiley & Sons, 1988. 83.

Figure 2 – Shell Union Oil Company refinery, Martinez, CA, ca. 1920.[40]

In early 1928, the Shell Union Oil Company of California, a subsidiary of the Royal Dutch/Shell Group, floated $50 million in bonds to finance the development of a chemical and petrochemical research subsidiary and the construction of the world's first ammonia plant using natural gas (an oil well and refinery waste product) for its hydrogen feedstock[41]. In June of that same year, Royal Dutch/Shell and the Shell Union Oil Company of California formed the Shell Development Company, a subsidiary tasked with research and

[40] Beaton, *Enterprise in Oil*, 1957. 528.
[41] Anonymous. "Shell Union Offers $50,000,000 Bonds." *New York Times*, September 13, 1929. By the late1920s, Shell Oil had bought out part of Union Oil Company as a way to Americanize the company and protect it from the political harassment that is suffered as a "foreign" company during WWI. Priest, T. *The Offshore Imperative: Shell Oil's Search for Petroleum in Postwar America*. College Station, TX: Texas A&M University Press, 2007, Chapter 1.

development of petroleum based chemicals.[42] Less than a year later, in February of 1929, Royal Dutch/Shell and the Shell Union Oil Company formed the Shell Chemical Company to produce ammonium sulfate fertilizer for the California market.[43] By late 1928, Shell had broken ground at two California locations: an industrial research lab in Emeryville on the sunny side of San Francisco Bay and an ammonia plant on 640 acres of shoreline along the San Francisco/Sacramento River estuary near Pittsburg, CA (See Figure 2).[44]

The year before, Royal Dutch/Shell had built a pilot nitrogen fixation plant at their Amsterdam site to use for research and development into the design of the California plant.[45] Assured of a steady supply of hydrogen–the limiting ingredient in nitrogen fixation–from the refined coke oven gases of the Royal Dutch Blast Furnaces and Steel Works, Shell was still in need of a method of making ammonia. I.G. Farben held the patent on the Haber-Bosch route to fixed nitrogen, and Shell believed that I.G. Farben would never consider licensing the process in Europe. Instead, Shell turned to a German mining consortium that had funded the development of a novel lower-pressure process of ammonia synthesis in the mid 1920s, known the Mont-Cenis process.[46] Finally, in September of 1928, after months of negotiations, Royal Dutch/Shell was granted worldwide rights to the Mont-Cenis process.[47] Shell's proto-chemical engineers, known as technologists, set immediately to work – ironing out the industrial kinks that accompanied the license and remedying issues associated with poisoned catalysts, insufficient compressors, and defective heat exchangers. In fact, Shell's technologists improved and modified the process so much from the original patent that they were able to patent many new inventions and break with the German patent holders in 1934.[48]

With the kinks worked out of their nitrogen fixation process in Amsterdam, Royal Dutch Shell proceeded with the design and construction of the California plant. Shell assembled parts for two ammonia plants at their Amsterdam research site, which were then shipped to California for assembly. But unlike the plant in Amsterdam, which relied on waste gases from coke ovens, Shell had to devise a way to extract hydrogen from the

[42] When Shell Oil and Union Oil merged in the 1922, the Simplex Refining Company, and its associated patents, owned by Union Oil, was excluded from the merger. Asiatic of New York rechartered the Oakland, CA based Simplex Refining Company in 1926 as a Delaware corporation. In 1927, the Shell Union Oil Company of California acquired the research laboratories, patents, and personnel of the Simplex Refining Company, which was reformed as the Shell Development Company in 1928 with an enlarged research and capital base. Beaton, *Enterprise in Oil*, 517.

[43] Both of these companies were chartered under Delaware's generous corporate laws.

[44] Beaton, *Enterprise in Oil*, 1957. 521-523; Forbes and O'Beirne, *Technical Development*, 1957. 464-469.

[45] Beaton, *Enterprise in Oil*, 1957. 519-520; Forbes and O'Beirne, *Technical Development*, 1957. 503-505; Chapman, *International Petrochemical Industry,* 56; Travis, A S. "High Pressure Industrial Chemistry: The First Steps, 1909-1913." In *Determinants in the Evolution of the European Chemical Industry*, edited by A S Travis, H G Schröter, E Homburg and J T Morris. Boston: Kluwer Academic Publishers, 1998. 3-21.

[46] The overall chemistry is the same. The engineering and management of the ammonia plant was different. Beaton, *Enterprise in Oil*, 520; Haber, L. *The Chemical Industry 1900-1930: International Growth and Change*. Oxford: Clarendon Press, 1971. 95-97

[47] Travis, "High Pressure," 15; Beaton, *Enterprise in Oil*, 520; Forbes and O'Beirne, *Technical Development*, 503-504.

[48] Travis, "High Pressure," 15

abundance of oil field waste gases before they could start fixing atmospheric nitrogen in California.[49]

Prior to 1928, Kessler had considered using steam to reform natural gas (methane) in order to produce hydrogen and carbon dioxide. However, as this process had never been done at an industrial scale he considered it too expensive an investment at the time.[50] Instead, the plant design, an amalgam of US and European chemical technology, proceeded with a hydrogen stream derived from the direct cracking of natural gas.[51] The thermal decomposition of natural gas at extreme temperatures disintegrates methane into hydrogen and carbon black[52]. But at these extreme temperatures, hydrogen yields are low and are thus economically inefficient. By decreasing the intensity of decomposition Shell's technologists were able to substantially increase hydrogen yield, but this resulted in increased impurities in the hydrogen stream.[53] Shell then turned to what was to become one its key industrial petrochemical advantages, the efficient purification and separation of mixed hydrocarbon compounds. In conjunction with the Southern California Gas Company of Los Angeles, Shell's technologists developed a commercial scale system of high temperature reforming units that relied on purification and separation of mixed yields to cheaply produce the necessary hydrogen stream for the world's first natural gas based ammonia plant (See Figure 3).

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[49] Smith, H M. "Possible Utilization of Natural Gas for the Production of Chemical Products." 5. Washington, DC: US Department of Commerce, Bureau of Mines, 1930; Miller, H C. "Function of Natural Gas in the Production of Oil: A Report of the Bureau of Mines in Cooperation with the American Petroleum Institute." 321. Washington, DC: US Department of Commerce, Bureau of Mines, 1929.

[50] Forbes and O'Beirne, *Technical Development,* 515-516; Beaton, *Enterprise in Oil,* 522

[51] Pyzel, D. "Producing Ammonia." *Patent #1,849,357*. United States Patent Office: Shell Development Company, 1932; Pyzel, D. "Process and Apparatus for the Production of Ammonia." *Patent #1,957,849.* United States Patent Office: Shell Development Company, 1934; Pyzel, D. "Process for the Absorption and Distillation of Ammonia." United States Patent Office. *Patent #1,999,546*: Shell Development Company, 1935; Pyzel, F M. "Process for the Manufacture of Ammonium Sulphate." *Patent #1,932,974.* United States Patent Office: Shell Development Company, 1933; Pyzel, F M, and J Ruys. "Manufacture of Ammonium Sulfate." *Patent #2,026,250.* United States Patent Office: Shell Development Company, 1934; Pyzel, E D. *Patent # 1,996,257.* "Process and Apparatus for the Separation of Liquids from Gases." United States Patent Office: Shell Development Company, 1935.

[52] Carbon black is a semi-crystalline form of carbon that results from the incomplete combustion of hydrocarbons. Different hydrocarbons result in different forms of carbon black.

[53] Pyzel, F M. "Process of Producing Hydrogen." *Patent #1,896,420.* United States Patent Office: Shell Development Company, 1933; Pyzel, F M. "Process for the Thermal Decomposition of Hydrocarbons." *Patent #1,983,992.* United States Patent Office: Shell Development Company, 1934; Pyzel, D. "Process for the Removal of Acetylene." *Patent #1,985,548*. United States Patent Office: Shell Development Company, 1934. Haynes, W. *The American Chemical Industry*. Vol. VI. New York: Van Nostrand, 1955. 380-385; Forbes and O'Beirne, *Technical Development,* 515-516; Beaton*, Enterprise in Oil,* 523.

Figure 3 – First commercial scale methane reforming unit, Pittsburg, CA, ca. 1932.[54]

In April of 1931, the reforming units were installed at Shell Point in Pittsburg, CA, and on July 20th of that same year, the first ammonia dribbled from the plant though a pipeline that "had been optimistically marked with a dollar sign."[55] However, in the interim between Shell's initial decision to enter the ammonia sulfate fertilizer market in 1927 and its construction and operation of the Shell Point plant in 1931, the world economy crashed, and with it, the price of fertilizer. In 1927 ammonium sulfate was selling for $40-46 a ton. By 1931 the price had dropped as low as $16.50 per ton.[56] The world's descent into economic depression left Shell without profitable outlets for its ammonia, and most of the

[54] Forbes and O'Beirne, *Technical Development*, 1957. 513

[55] Forbes and O'Beirne, *Technical Development,* 516. The principle byproduct of the ammonia sulfate plant was carbon black. Carbon black was an important feedstock for steel and rubber manufacture. Shell Chemical Company. *Shell Carbon: Its Properties and Uses in the Rubber Industry*: Shell Chemical Company, 1939; Beaton, *Enterprise in Oil*, 528.

[56] Haynes, *American Chemical Industry*, *Vol. 3*, 380-385; Forbes and O'Beirne, *Technical Development,* 517-519; Beaton, *Enterprise in Oil,* 523-528.

10,000 tons of ammonia produced the first year was sold directly to the chemical industry where it was converted to nitric acid and used to manufacture explosives.[57] While Kessler and other senior management in California were convinced that chemicals derived from petroleum wastes would eventually be very profitable and thus would justify a loss for period of time, others were not so convinced. The need to economize inspired Shell's technologists to assess the potential for profit in waste byproducts like sulfuric acid, which was being thrown away by the ton on a daily basis and was one of the plant's main operating costs.[58] Indeed, it was the high cost of sulfuric acid, freight charges, and seasonal demand that urged Shell's technologists, in the closing months of 1931, to first seriously consider the use of anhydrous ammonia (pure NH_3) as fertilizer. Because ammonia would be much cheaper to produce per unit of fixed nitrogen and cheaper to ship and eventually store, and because so much of California agriculture is irrigated, Shell's technologists hypothesized they could simply add anhydrous ammonia directly to irrigation water instead of first converting it to ammonium sulfate.[59]

Before venturing down this road however, the chief chemist of Shell Development approached D. R Hoagland at the University of California, Davis, to ask whether the application of anhydrous ammonia to irrigation water was even possible.[60] Hoagland's reply was optimistic and he advised him contact D. D Waynick and F. H. Leavitt at the Association Laboratory in Southern California to undertake the necessary experimental work. The selection of Waynick's lab was important because he had previously worked with the Prizer brothers, who had patented the idea of fertilization via irrigation water.[61] In 1928, John and Eugene Prizer, concerned with the availability and cost of labor on large citrus groves, had built an applicator that would dissolve soluble fertilizers into irrigation water thus doing with away the labor needed to fertilize by hand or spreader. In 1932, after the idea of distributing fertilizer through irrigation water became a research and commercial agenda for Shell, the Shell Development Company secured the full rights to the patent with the help of the Association Laboratory.

In February of 1932, Waynick and Leavitt commenced their experimental work. In late 1933, after preliminary lab experiments showed no lasting deleterious effects of anhydrous ammonia on soils, and after Shell engineers worked out an effective metering

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[57] Leavitt, F H. "Agricultural Ammonia Equipment Development and History." In *Agricultural Anhydrous Ammonia: Technology and Use*, edited by M H McVickar, W P Martin, I E Miles and H H Tucker, 125-68. Memphis, TN: Agricultural Ammonia Institute, 1966.

[58] Pyzel and Ruys, "Manufacture of Ammonium Sulfate"; van der Valk, J H. "Acid Recovery Process." *Patent #2,441,521*, United States Patent Office: Shell Development Company, 1944; Forbes and O'Beirne, *Technical Development,* 479.

[59] By 1929, there were 4.7 million acres of irrigated land in the top 10 agricultural counties in California.

[60] Waynick, D D. "Anhydrous Ammonia as a Fertilizer." *The California Citrograph* XIX, no. 11 (1934): 295, 310-11; Leavitt, F H. "Agricultural Ammonia," 125-133; Warnock, R E. "Ammonia Application in Irrigation Water." In *Agricultural Anhydrous Ammonia: Technology and Use*, edited by M H McVickar, W P Martin, I E Miles and H H Tucker, 115-24. Memphis, TN: Agricultural Ammonia Institute, 1966

[61] Prizer, E L, and J A Prizer. "Method of Supplying Soluble Fertilizing Agents to Soil." Patent #1,868,913. United States Patent Office: Shell Development Company, 1932; Leavitt, "Agricultural Ammonia," 125-126.

device, they conducted the first experimental field applications in several orange groves near their Alhambra lab.[62] These experiments and subsequent analyses showed that if accurate and precise irrigation practices and ammonia flow rates were maintained, ammonia could be distributed evenly along furrows (See Figure 4). In 1934, buoyed by these and other experimental field results, Shell patented the process and moved toward commercialization.[63]

Figure 4 - Application of anhydrous ammonia (nitrogation) to furrow irrigation, ca. 1940.[64]

That same year, Shell appointed the Greening-Smith Company of Norwalk as the first commercial distributor of anhydrous ammonia for Central and Southern California. This decision was critical because the Greening-Smith Company was both a large owner of citrus groves and at the same time engaged in the sale of dairy manure to other growers.[65] The

[62] Waynick, "Anhydrous Ammonia," 295; Kortland, F. "Flow Meter." *Patent #2,038,511*, United States Patent Office: Shell Development Company, 1936; Beaumont, AB, and GJ Larsinos. "Aqua Ammonia as a Nitrogen Fertilizer." *American Fertilizer* 76 (1932): 9-10; Leavitt, "Agricultural Ammonia," 135;

[63] deBuyn, C B. "Process of Fertilizing Soil." Patent #2,020,824. United States Patent Office: Shell Development Company, 1935; Beaton, *Enterprise in Oil*, 529; Forbes and O'Beirne, *Technological Development*, 519-520; Warnock, "Ammonia Application" 115; Leavitt, "Agricultural Ammonia,"133.

[64] Shell Oil Company, "Better Farming," unpaginated

[65] Leavitt, F H. "Nitrogation, Nitrojection, and Soil Fumigation: Their Application and Their Results." *The American Fertilizer* 110, no. 2 (1949): 3; Leavitt, "Agricultural Ammonia," 132-133.

appointment of the Greening-Smith Company as distributor brought, along with its transportation and storage infrastructure, an aggressive sales company with vast knowledge of southern California growers and fertilizer sales to aid in the commercialization of ammonia fertilizer. In 1935, the James Mill Orchards Company of Hamilton City, CA was appointed as the Northern California distributor.[66]

The Greening-Smith company began commercial "nitrogation" – Shell's trademarked term for the process of introducing ammonia into irrigation water – in the fall of 1934.[67] Their first application took place on an Orange County orange grove in the western foothills of the Saddleback formation. But even with the established sales networks of the Greening-Smith Company, the growth of nitrogation in depression era California was slower than Shell would have liked.[68] One of the biggest initial unknowns was how much ammonia to use and at what concentrations for different crops. For Shell, the commercialization of nitrogation was both a profit making venture and a way to conduct the series of large-scale field experiments needed to refine the technique and began to develop dosage recommendations.[69] By 1936, Shell technologists had demonstrated nitrogation's efficacy on over twenty crops across California.[70] By 1937, sixteen percent of the ammonia that Shell produced was introduced into irrigation water in California, with the majority of this used by Southern California citrus growers. Shell faced opposition from some growers across the state who believed anhydrous ammonia was a poor fertilizer. However, with the help of extension scientists, demand for the product kept growing, and by the late 1930s commercial nitrogation had spread to numerous crops across California and Arizona.[71]

As the growing season wound down in late 1939, Shell's board and its senior technologists decided that if they wanted to expand the market for anhydrous ammonia further then they needed to determine how to apply it to soils that were not irrigated, or when irrigation and fertilization timing or methods were mismatched.[72] Earlier that year, F.H. Leavitt, now a senior agricultural technologist for Shell Chemical, conceived of injecting anhydrous ammonia directly into the soil after watching a telephone company lay underground cable in a new development outside Sacramento. What Leavitt observed was essentially an oversized subsoiler with a tube down the back attached to a trailing spool of cable that unwound as the machine moved forward, thus laying the cable at depth. But in

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[66] Leavitt, "Agricultural Ammonia," 133.
[67] Leavitt, "Nitrogation, Nitrojection" 7-8; Leavitt, "Agricultural Ammonia," 133-134
[68] Brand, C J. "Recovery in the Fertilizer Industry." *Industrial & Engineering Chemistry* 27, no. 4 (1935): 372-78; Beaton, *Enterprise in Oil*; 528; Leavitt, "Agricultural Ammonia," 135.
[69] Shell had a tendency to commercialize chemical products before they had a solid understanding of their efficacy. See *Buckley V. Shell Chemical Company*, 32 Cal.App.2d 209 (1939), for a picture into some of the issues that followed from this practice.
[70] Rosenstein, L. "Increased Yields Obtained from Shell Agricultural Ammonia (NH_3) in Irrigated Agriculture." *Shell Chemical Bulletin* 1 (1936).
[71] Adams, J R, and M S Anderson. "Liquid Nitrogen Fertilizers for Direct Applications." Washington, DC: USDA, Agricultural Research Service, 1961; 45. Leavitt, "Nitrogation, Nitrojection," 7-8; Leavitt, "Agricultural Ammonia," 135.
[72] Leavitt, "Nitrogation, Nitrojection," 7-9; Leavitt, "Agricultural Ammonia," 135-136; Forbes and O'Beirne, *Technical Development, 519-520.*

place of the trailing spool of cable, Leavitt envisioned an ammonia tank. In place of the large subsoiler shank, Leavitt pictured multiple cultivator shanks that released ammonia at their tips.

Figure 5 – Advertisement for Shell's "nitrojection" services.[73]

Shell technologists put Leavitt's vision into action in the beginning of 1940. In a Santa Paula blacksmith shop on the fertile Oxnard plain, Shell technologists forged the first injection shank by modifying a 5/8-inch John Deere spear point shank blade.[74] They then outfitted an

[73] Shell Oil Company. "Advertisement." *Western Fruit Grower* 10, no. 10 (1956): 17.
[74] Leavitt, "Nitrogation, Nitrojection," 7-9; Leavitt, "Agricultural Ammonia," 135-136.

off-the-shelf Killifer cultivator with their new injection shanks and one of their ammonia meters. That same spring, Shell Chemical started field-testing their new method of ammonia application across the Oxnard plain. Instead of laying phone cables, these new injection shanks laid cables of ammonia gas under agricultural soils. Further experimental work showed that the distribution of ammonia could be manipulated through depth, flow rate, and spacing for maximum nitrogen stimulation.

Limited commercial applications began in the spring of 1942 across a wide variety of California crops and soils, using custom modified injection shanks attached to a small rubber tired John Deere tractor.[75] Later that year, after his technique proved to be mechanically possible and commercially viable, Leavitt and others began a larger set of field and lab experiments to study the effects of anhydrous ammonia on the chemistry of different soils[76]. By 1943, full-scale commercial field applications were underway across California, and by 1944 with the development of Shell's experimental commercial applicator, the method was on its way to being fully commercialized (see Figure 5).[77] By 1945, the technique had spread to the apple orchards of eastern Washington and citrus groves of southern Arizona.[78] By the late 1940s, in collaboration with the USDA, the Tennessee Valley Authority, and scientists at the University of Mississippi experiment station, the method had spread east of the Rockies.[79]

In the spring of 1940, Walter Carter, lead scientist at the University of Hawaii's Pineapple Research Institute, conducted a series of soil fumigation experiments with a recently acquired batch of organic chemicals. The Pineapple Research Institute was affiliated with University of Hawaii's agricultural extension and Carter's work was sponsored by the three main Hawaiian Pineapple companies: the Maui Pineapple Company, Dole, and Del Monte. In these chemical trials, Carter was trying to solve a problem common to all three major companies: dramatic declines in yields as deleterious species accumulated in the soil complex. Soil pests had become so problematic that some were predicting the end of the Hawaiian pineapple industry.[80]

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75 Leavitt, "Agricultural Ammonia," 136.

76 Shell had also been gifting UC Berkeley small amounts ($500-1000) to undertake studies to determine the nitrogen requirements of various crops, particularly food trees. Anonymous. "U.C. Receives $10,000,000 Gift." *Los Angeles Times*, October 11, 1941; Anonymous. "University Berth Filled." *Los Angeles Times*, December 14, 1940.

77 Hannibal, L S. "Soil Injector." *Patent #2,598,121*, United States Patent Office: Shell Development Company, 1952; Turner, J R. "Device for Distributing Mixtures of Vapors and Liquid." *Patent #2,650,556*, United States Patent Office: Shell Development Company, 1952.

78 Forde, H I, and E L Proebsting. "Utilization of Ammonia Supplied to Peaches and Prunes at Different Seasons." *Hilgardia* 16 (1945): 411-25; Leavitt, "Nitrogation, Nitrojection" 7-9; Leavitt, "Agricultural Ammonia," 132-135.

79 Andrews, W B. "Anhydrous Ammonia as a Fertilizer." In *Advances in Agronomy*, edited by A G Norman, 62-125. New York: Academic Press Inc., 1956; Andrews, W B, F E Edwards, and J G Hammons. "Ammonia as a Source of Nitrogen." Oxford, MS: Mississippi Agricultural Experiment Station, 1947; Andrews, W B, J A Neely, and F E Edwards. "Anhydrous Ammonia as Source of Nitrogen." 39. Oxford, MS: Mississippi Agricultural Experiment Station, 1951; Beacher, RL. "Arkansas Rice Tests Prove Ammonia Successful in Mississippi River Delta." *Agr. Ammonia News* 5, no. 2 (1955): 9-ll.

80 Bartholomew, D P, R A Hawkins, and J A Lopez. "Hawaii Pineapple: The Rise and Fall of an Industry." *HortScience* 47, no. 10 (2012): 1390-1398.

It was well known that pineapples planted in virgin soil did not have the same pest issues as older plantations. Thus in the mid 1930s, Carter commenced a research agenda to see if he could do the impossible and restore the virginity of the soil.[81] In 1936, he tried ammonium thiocyanate as a soil fumigant, along with a suite of other common pre-WWII economic poisons such as sodium cyanide, sodium cyanamide, formaldehyde, paradichlorobenzene, and carbon disulfide. However he found that these compounds either caused severe growth problems or were not effective against soil dwelling pests. He then tried chloropicrin, the WWI chemical weapon cum pesticide, and was impressed by the initial results. However, while chloropicrin showed promise, Carter worried that it was too expensive for use in commercial control. In addition, it presented practical difficulties in handling and application.[82] For years, Carter continued his studies, eager to pursue any promising lead and writing numerous companies asking for samples of their toxic byproducts in the hopes than one of them would work. His requests were met with, "[b]ottles, drums, cans, and steel cylinders" that spilled in from across the US from "synthetic rubber, petroleum, coal tar, and gasoline" companies.[83] Carter and his assistants systematically tested these chemicals on infested pineapple fields near Wahiawa, in the fertile highland valley of Oahu, but none of them showed any promise.

Then, in late 1939, Carter received a shipment of 55-gallon drums filled to the brim with organic chemicals from Shell Oil's Emeryville-based petrochemical R&D subsidiary. These chemicals – allyl alcohol, allyl chloride, methallyl alcohol, methallyl chloride, and a 50:50 mixture of 1,3-dichlororopropene and 1,2-dichloropropane (DD) – were the waste products of Shell's groundbreaking industrial synthesis of glycerol from propylene, and consisted mostly of novel compounds, particularly the chlorinated ones.[84] Propylene, along

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[81] "Nematodes are least damaging in virgin soil. Evidently we must do the impossible – restore virginity." Carter quoted in Clark, B. "D-D Saves Crops from Foes." *Science News Letter* October (1946): 234; Carter, W. "A Promising New Soil Amendment and Disinfectant." *Science* 97, no. 2051 (1943a): 383-84; Carter, W. "Soil Fumigant Comprising 1,3-Dichloropropene and 1,2-Dichloropropane." United States Patent Office, 3, 1943b; Carter, W. "Soil Treatments with Special Reference to Fumigation with DD Mixture." *Journal of Economic Entomology* 38, no. 1 (1945): 35-44;

[82] Johnson, M O, and G H Godfrey. "Chloropicrin for Nematode Control." *Industrial & Engineering Chemistry* 24, no. 3 (1932): 311-13.

[83] Carter, "Promising New Soil Amendment," 383-384; Carter, "Soil Fumigant"; Carter, "Soil Treatments" 35-44; Clark, "D-D Saves," 383-384; Carter, W. "Fumigation of Soil in Hawaii." In *Yearbook of Agriculture*, 126-29. Washington, DC: USDA, 1953.

[84] While DD was the first chemical from this byproduct series to enter agricultural production, many others eventually did as well. Allyl alcohol became a weed seed killer, and methallyl chloride became a commodity and warehouse fumigant. Shell Chemical Corporation. "Specimen Labels." Agricultural Chemicals Division Shell Chemical Company, AA-1. New York: 1964. During the 1930s, Shell Development/Chemical developed the techniques to add halogens to unsaturated olefins while retaining their unsaturated and highly reactive character at economic yields, a process that came to be known as *high temperature substitution*. An olefin (alkene) is an unsaturated, straight-chain carbon compound that has at least one carbon-carbon double bond. In the early 1930s, scientists at Shell Development discovered that during the chlorination of alkenes through addition reactions the substitution of olefins could be induced in small amounts. This means that instead of chlorine adding to the molecule at the expense of losing the double bond, the chlorine is simply substituted for one of the hydrogen atoms, thus maintaining the compound's unsaturated character. By 1935, Shell's scientists had deduced that substitution, as opposed to addition, occurred predominantly at high temperatures (300-600 °C). Throughout the 1930s, Shell's technologists showed that addition and substitution are independent reactions and thus could be accelerated independently. While the distinction between the addition and substitution of halogen atoms on olefins may seem trivial to the lay reader, the ability to substitute halogens, rather than add halogens, to olefins at an industrial scale has had profound implications for the development of petroleum and polymer chemistry.

with gases like ethylene and the butylenes, make up a significant portion of the byproduct gases that occur during the cracking of crude oil. These compounds – known as *olefins* – are highly reactive and can be turned into an endless variety of products. Olefins still serve as one of the main feedstocks of the petrochemical industry.

Promising preliminary tests with Shell's byproducts in late 1939 demanded further trials, especially with the DD mixture. Carter initially tested DD on a pineapple field heavily infested with nematodes. He and his assistants punched holes every 15 inches and poured in the dark pernicious chlorinated liquid, covered the holes, and allowed the chemicals to do their work. The effects were dramatic. "[DD] spread through the soil like a lump of sugar. Fumes shot out in a circle, killing every worm they reached."[85] It was almost as if the chemicals actively sought out the microscopic worms. Encouraged by these results, Carter and his associates spread out across the Hawaiian Islands throughout the early months of 1941, and hand injected DD on 840 plots in every major pineapple-growing region. These experimental fields were replanted with pineapple.

In the closing days of 1941, as Carter walked among some of the experimental plots near Wahiawa, he noticed that the pineapples in the DD test plots had grown significantly. A few months later, in February 1942, he concluded that the pineapple plants in the DD plots were behaving as if there were no nematodes in the soil at all. By harvest time, the evidence of DD's subterranean killing power was unmistakable. The plants on untreated plots were stunted and diseased, while the "[t]reated plots were covered with healthy plants of towering broad, live-green leaves from the center of which grew giant-sized, golden

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Through the development of industrial synthesis based on the substitution of chlorine for hydrogen in olefinic compounds, Shell Development Company provided the chemical industry with critical synthesis techniques essential to the post war expansion of petrochemical products, and agriculture with an enormous variety of toxic possibilities. With Shell's cutting edge chemical synthesis came state of the art toxic waste. Deansley, R M. "Halogenation Process." *Patent #1,991,600*. Unites States Patent Office. USA: Shell Development Corporation, 1931; Deansley, R M. "Process for the Inhibition of Halogen Substitution Reactions." *Patent #1,952,122*. United States Patent Office. USA: Shell Development Company, 1931; Deansley, R M, and W Engs. "Process for the Preparation of Substantially Pure Tertiary Olefins." *Patent #2,012,785*. United States Patent Office. USA: Shell Development Company, 1935; Groll, H, and G Hearne. "Halo-Substitution of Unsaturated Organic Compounds." *Patent #2,130,084*, United States Patent Office. USA: Shell Development Company, 1938; Groll, H, and G Hearne. "Halo-Substitution of Ethylene." *Patent #2,167,927*. United States Patent Office. USA: Shell Development Company, 1938; Groll, H P A, and G Hearne. "Halogenation of Hydrocarbons: Substitution of Chlorine and Bromine into Straight Chain Olefins." *Industrial and Engineering Chemistry* December (1939): 1531-39; Groll, H P A, G Hearne, F F Rust, and W E Vaughn. "Halogenation of Hydrocarbons: Chlorination of Olefins and Olefin-Parrafin Mixtures at Moderate Temperatures; Induced Substitution." *Industrial and Engineering Chemistry* 31, no. 10 (1939): 1238-44; Rust, F F, and W E Vaughn. "The High-Temperature Chlorination of Olefin Hydrocarbons." *The Journal of Organic Chemistry* 5, no. 5 (1940): 472-503;Vaughn, W E, and F F Rust. "The High-Temperature Chlorination of Parrafin Hydrocarbons." *The Journal of Organic Chemistry* 5, no. 5 (1940): 449-71; Williams, E C. "Creating Industries, 1919-1939, Petroleum." *Chemical Industries* XLIV (1939): 495-501; Williams, E C. "Synthetic Glycerol from Petroleum: A Contribution from the Research Laboratories of Shell Development Company." *Transactions of the American Institute of Chemical Engineers* XXXVII (1942): 157-208.; Engs, W. "Stabilization of Unsaturated Halides." *Patent #2,341,140*, United States Patent Office. USA: Shell Development Company, 1944.; Engs, W , and S N Wik. "Process for Producing and Recovering Halogenated Organic Compounds." *Patent #2,321,472*. United States Patent Office. USA: Shell Development Company, 1943; Detling, K D. "Production of Organic Halogen Compound." *Patent #2,501,597*, United States Patent Office. USA: Shell Development Corporation, 1950.

[85] Clark, "D-D Saves," 234-235

yellow pineapples."[86] These infested soils where pineapple companies previously yielded 15 tons of fruit per acre, now yielded an average of 40 tons per acre.

DD had allowed Carter to do the impossible: to chemically disinfect the soil, ridding it of nematodes and other soil dwelling pests. With its toxicity derived from the unsaturated chlorinated compound 1,3-dichloropropene, and soil dispersion and penetration enhanced by 1,2-dichloropropane, DD had the potential to reshape world agriculture.[87] Not only was DD incredibly effective, as a waste product of the synthesis of glycerol from propylene, it was also commercially affordable.[88]

In an April 1943 edition of *Science Magazine*, Carter went public with his discovery. Although his results were preliminary, he felt it was necessary to communicate their revolutionary nature. DD, Carter wrote, "has such great potential usefulness for other more rapidly maturing crops in a great many agricultural areas, it seems advisable to present the preliminary results at this time so that these potentialities can be fully explored."[89] With chemical warfare invading the soil, farmers all over the world could expect bigger and better crops in areas where soil pests were causing damage.[90]

Before Carter's publication in *Science*, Shell's technologists, USDA scientists, the War Production Board, and UC agricultural experiment station scientists, had been informed of its success and were actively exploring its utility in California.[91] By the 1940s, more than sixty percent of California's arable farmland was heavily infested with nematodes, wireworms, and other soil pathogens, including key areas like the Central Coast and Central Valley.[92] This pattern was mirrored in agricultural regions across the world with histories of intensive commercial production.[93] At that time, California's pesticide industry was the most sophisticated in the world, and soil fumigants had been experimented with extensively in California, yet a commercial solution to subsoil control still remained elusive.[94]

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[86] Clark, "D-D Saves," 234.

[87] Carter, "Soil Treatments"; 35-44; Roberts, T R, and G Stoydin. "The Degradation of (Z)- and (E)-1,3-Dichloropropene and 1,2-Dichloropropane in Soil." *Pesticide Science* 7 (1976): 325-35.

[88] Carter, W. "Soil Fumigant Comprising 1,3-Dichloropropene and 1,2-Dichloropropane." *Patent# 2,502,244*, US Patent Office. USA: People of the United States of America, 1950.

[89] Carter, "Promising New Soil Amendment," 384.

[90] Anonymous. "DD Found Effective against Wireworms." *The Science News Letter* 48, no. 19 (1945): 296; Anonymous. "New Chemical Kills Nematodes, Soil Pests." *Science News Letter* 50, no. 23 (1946): 367.

[91] Pinckard, J A. "Soil Fumigant Effective against Root-Knot and Meadow Nematodes." *Seed World* 54, no. 10 (1943); USDA, ARA. "Report of the Administrator of Agricultural Research." 6, 215. Washington, DC: USDA, Agricultural Research Administration, 1944; Anonymous. "Control of Nematodes." *California Cultivator* 91, no. 21 (1944): 520; Anonymous. "Controlling Beet Nematode." *California Cultivator* 92, no. 1 (1945): 8; Tonkin, C J. "Soil Improving Method." *Patent #2,424,520.* United States Patent Office: Shell Development Company, 1947; Evans, T W. "Toxic Composition." *Patent #2,411,566.* United States Patent Office: Shell Development Company, 1946; Notes and correspondence of W. H. Lange Jr. Lange, William H. Jr. Papers, UC Davis Shields Library, Department of Special Collections, D-288, Box 1, Folders 1-10.

[92] Houser, "Some Problems," 28-39; Clark, "DD Saves" 235; Bishopp, F C. "The Insecticide Situation." *Journal of Economic Entomology* 39, no. 4 (1946): 444-59.

[93] Pinckard, J A. "Soil Fumigant Effective against Nematodes." *Food Packer* 25, no. 1 (1944): 43-44.

[94] Hyslop, JA. "Soil Fumigation." *Journal of Economic Entomology* 7, no. 4 (1914): 305-12; Herms, WB. "An Analysis of Some of California's Major Entomological Problems." *Journal of Economic Entomology* 19, no. 2 (1926): 262-70; Anonymous, 1925; Stone, M W, and R E Campbell. "Chloropicrin as a Oil Insecticide for Wireworms." *Journal of Economic Entomology* 26, no. 1 (1933):

Shell and UC Davis scientists first hand injected DD into a Central Valley bean field in the spring of 1943.[95] These preliminary trials in the heavily infested sandy soils of Merced County proved successful beyond anyone's expectations. In the treated plots, beans and tomatoes grew like there were no nematodes in the soil, as if the soil had returned to its virgin state (See Figure 6). In the fall of 1943, in conjunction with scientists at UC Davis' agricultural experiment station full-scale field tests were underway.[96] These tests were different than Walter Carter's in one important way. Since Shell had been in the process of developing equipment for the injection of anhydrous ammonia into the subsoil, they were able to quickly convert their equipment for use with DD, immediately mechanizing the process.[97]

237-43; Lehman, R S. "Laboratory Experiments with Various Fumigants against the Wireworm Limonius (Pheletes) Californicus Mann." *Journal of Economic Entomology* 26, no. 6 (1933): 1042-51; Lehman, R S. "Laboratory Tests of Organic Fumigants for Wireworms." *Journal of Economic Entomology* 35 (1942): 659-61; Lincoln, CG, HH Schwardt, and CE Palm. "Methyl Bromide-Dichloroethyl Ether Emulsion as a Soil Fumigant." *Journal of Economic Entomology* 35, no. 2 (1942): 238-39

[95] Leavitt, "Nitrogation, Nitrojection," 7-9; Leavitt, "Agricultural Ammonia." 132-137; M. Stone of the USDA undertook the first experiments with DD outside of Hawaii in a Ventura lab a few months prior to the first field tests. Stone, MW. "Dichloropropane-Dichloropropylene, a New Soil Fumigant for Wireworms." *Journal of Economic Entomology* 37, no. 2 (1944): 297-99; XXX

[96] Lange Jr, WH. "Ethylene Dibromide and Dichloropropane-Dichloropropene Mixture for Wireworm Control." *Journal of Economic Entomology* 38, no. 6 (1945): 643-45. Henry Lange Jr. played a critical role in the commercialization of soil fumigants, especially DD, ethylene dibromide, and benzene hexachloride. He graduated from Berkeley with a Ph.D. in chemistry in 1941 and worked as the UC extension agent for Monterey County until early 1943, when he took a position at UC Davis. From his new academic perch, Lange coordinated Shell's experiments, finding fields to do experiments and commercial tests on, and linking large commercial growers, like the Speckles sugar company, directly to the scientists and salesmen at Shell. Lange was implicitly thanked for his work by Shell with a $1000 donation to UC to explore the commercial use of DD. This money was used to fund Lange's travels and talks, which in turn, helped convince more growers of the promise of soil fumigation, expanding the market for Shell. Notes and correspondence of W. H. Lange Jr. Lange, William H. Jr. Papers, UC Davis Shields Library, Department of Special Collections, D-288, Box 1, Folders 1-10.

[97] Leavitt, "Nitrogation, Nitrojection" 7-9; Leavitt, "Agricultural Ammonia." 132-137; Leavitt, F H. "Method and Apparatus for Protecting Subsurface Ground Tools." *Patent # 2,306,339*, United States Patent Office: Shell Development Company, 1942.

Figure 6 – Bean roots, showing the effects of nematodes in soil (left) and effects of soil fumigation with D-D mixture[98]

Supplied with chemicals directly from Shell Development Company, UC Davis's Harry Lange Jr. continued laboratory experiments with DD over the first half of 1944. Throughout the late summer and early fall of 1944, Lange Jr. joined by Walter Balch, the Shell technologist leading the commercialization of DD, traversed the Salinas Valley, injecting DD into as many "sick" fields as possible, using growers' desperation for healing as a way to turn semi-commercial applications into field experiments. As fall turned to winter, the rapidly maturing crops planted following these soil disinfection experiments showed immediately identifiable results, encouraging further experimentation. On Dec 10, 1944, using a modified Shell experimental cultivator attached to a small John Deere tractor modified to carrying tanks of DD, Balch and Lange Jr., applied DD in simultaneous combination with anhydrous ammonia to a heavily infested Salinas Valley lettuce field (See Figure 7). On that field, in the late autumn of 1944, Shell's transmuted waste products quietly met for the first time.[99]

[98] Shell Chemical Company. "Shell D-D." *Bulletin* 3 (1944). unpaginated.
[99] They also trialed Dow Chemical's 1,2-dibromoethane (ethylene dibromide) at the same time, but it was not as effective against nematodes. EDB would also go on to be a critical soil and commodity fumigant around the world post WWII. EDB was not a novel chemical; it was one of the main components of ethyl fluid, the antiknock agent, which came into general use in the US in the late 1920s. See. Seyferth, D. "The Rise and Fall of Tetraethyllead." *Organometallics* 22 (2003): 5154-78. Throughout the

Figure 7 – Simultaneous application of D-D and anhydrous ammonia, ca. 1945.[100]

Early the next year, they did the experiment again on a larger scale, selecting fields so sick with soil pests that commercial production was no longer possible. One such experiment took place on June 4, 1945, when gaseous cables of fertilizer and fumigant were injected in continuous streams into the soil. Ten days later on June 14th, lettuce was planted. When yields were checked the following September, the fields applied with DD and anhydrous ammonia yielded eight times more trimmed lettuce than control fields. The yields were not just back to normal; they were better than they had ever been. Later that year, Lange and Balch conducted more commercial field trials in the Sacramento Valley, this time hoping to

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latter part of 1944, via the wartime channels of the US Production Board, samples of DD found their way from Emeryville, CA into many diverse hands, both in the US, and across the allied world. Experiments in allied Europe continued after the war via the Shell Refining and Marketing Co. Ltd, a European subsidiary of Royal Dutch/Shell. Shell provided the chemicals and the experimental injectors to use with large scale field trials. See, Thorne, G, and V Jensens. "A Preliminary Report on the Control of Sugar-Beet Nematode with Two Chemicals D-D and Dowfume W15." *Proceedings of the American Sugar Beet Technologists* 4 (1947): 322-29; Fletcher, HL. "Sugar Beet Nematode (*Heterodera Schachtii*) Control Studies in Ontario." Paper presented at the American Society of Sugar Beet Technologists, 1947;

[100] Shell Oil Company, "Better Farming," unpaginated

determine dosages, to test efficacy, and to study the synergistic effects of ammonia and DD.[101]

In the fall of 1945, two private companies began commercial application of DD in Los Angeles, Ventura, Monterey, Merced, and Sacramento counties.[102] On one of those sick Ventura fields, where DD was combined with anhydrous ammonia, a farmer that had been averaging about 800 pounds of sweet potatoes per acre boosted his yield to more than 13,000 pounds per acre.[103] In 1945, at the request of the War Production Board, Shell installed specialized units for the production of DD, allyl alcohol, and allyl chloride at their Houston, TX refinery complex.[104] For the 1946 growing season, extensive commercial applications were undertaken in California and Hawaii, with smaller applications in Georgia, Florida, Texas, Idaho, Oregon, New York, and Utah. Commercial use had also spread to Puerto Rico, Southern Africa, and New Zealand.

Between 1943 and 1946, due to government demand for glycerol in military use and the recognition of DD as game changing chemical by the War Production Board, Shell's production of DD went from 125 tons to over 10,000.[105] By 1947, its use spread to most of the southern United States, where two million acres of sick land were in desperate need of Shell's healing crusade. It also spread to allied Europe where its use led to a seventy-five percent increase in potato yields per acre.[106] For the 1948 growing season, southern farmers that had applied DD prior to planting heavily infested tobacco fields saw yields that were better than if the tobacco had been planted in virgin soil.[107] Now sold under multiple brands, DD is still critical for maintaining the disinfected "clean fields" needed for the industrial production of many of our most important commercial crops.[108] Without it and the other toxic gases used to *clean* the soil, the continuous production of a single crop without rotation would not be possible.

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[101] Notes and correspondence of W. H. Lange Jr. Lange, William H. Jr. Papers, UC Davis Shields Library, Department of Special Collections, D-288, Box 1, Folders 1-10.

[102] Thorne, "Preliminary Report," 322-29; Leavitt, "Nitrogation, Nitrojection," 7-9

[103] Clark, "D-D Saves," 235-236.

[104] Haynes, *American Chemical Industry*, *Vol. 3,* 382.

[105] In the late 1940s, Dow Chemical began manufacturing a version of DD as a byproduct of their process of glycerol production. Dow's route to DD allowed them to tweak the reaction to produce a byproduct mixture with a much higher concentration of 1,3-dichlroroprene, the active (toxic) ingredient in DD. That product was commercialized in the mid-1950s as Telone. Company, Dow Chemical. *Dow in the West*. Walnut Creek, CA: Dow Chemical Company, 1977; Barrons, K. "Soil Fumigants." In *Dow Chemical Company Historical Collection, 1897-2006*, edited by Post Street Archives. Philadelphia, PA: Chemical Heritage Foundation, 1999.

[106] National Archives, RG331, Supreme Commander for the Allied Powers, Scientific and Economic Section, Foreign Trade and Commerce Division, Chemical and Drug File, 1946-1950, Box No. 651, File D.D. J1-51,407.

[107] Clark, "DD- Saves" 235-236; Gilbreth, F B. "New Soil Fumigant Hailed as Farm Boon; Sponsors Say to Revolutionize Rotation." *The News and Courier*, 1948.

[108] Quote from Pollan, M. *The Botany of Desire: A Plant's Eye View of the World*. New York: Random House, 2001. 217. By 1990, DD (as the active ingredient 1,3-dichloropropene) was the 5th most used economic poison in the US and remains the second most used fumigant in the US. EPA. "2006-2007 Pesticide Market Estimates: Usage." http://www.epa.gov/opp00001/pestsales/07pestsales/usage2007_2.htm#3_6.

In 1947, Dr. R. M. Salter, Chief of the USDA's Bureau of Plant Industry, said that the "new soil fumigants bid fair to become one of the greatest boons to agriculture since the development of fertilizer."[109] If synthetic fertilizer revolutionized the organization of agricultural production, these new soil fumigants did it again by making it possible to plant every year as if it was the first time the soil had been planted. However, chemical salvation was not a one off; its acceptance was a Faustian bargain that meant that growers had to buy and apply chemicals every year to maintain commercial homeostasis. In the late fall of 1944, the confluence of two waste products of the emerging oil complex on a Salinas lettuce field not only transformed the practice of crop rotation and how industrial agriculture came to be organized, it also marked the ascendency of petroleum-based chemicals in agriculture that rapidly spread across the world following WWII.

In the fall of 1945, spurred by the outstanding success and rapid adoption of anhydrous ammonia and DD across the West, Shell broke ground on an agricultural experiment station in the heart of California's Central Valley (See Figure 8).[110] Spread across 142-acres of prime farmland just outside Modesto, Shell established its private experimental farm to extend the use of petrochemicals in agriculture by two different mechanisms. The first, and most direct, was to use the experimental farm and its laboratory as a scientific and commercial proving ground for potential economic poisons, now overflowing in abundance from Shell's cutting edge petrochemical R&D facility 80 miles to the west.

[109] Quoted in Anonymous. "Treatment of the Soil." *New York Times*, 1947.
[110] Shell Oil Company, "Better Farming," unpaginated

Figure 8 – Shell Agricultural Laboratory and Experimental Farm. Modesto, CA. 1945.[111]

DD, by opening up the subsoil to economic poisons, also opened entirely new markets for agricultural chemicals.[112] Shell and other chemical companies believed that this was just the beginning. By 1945, the red queen motif of industrial agriculture's pest-agrochemical dynamic was fully recognized, and Shell understood that ever-newer agrochemicals would always be needed. The company noted that "[t]he farmer constantly needs new chemicals to carry on his work efficiently and economically."[113] Shell was certain that the material basis of these chemicals would be petroleum refinery byproducts, "one of the largest sources of raw material" for the development of poisonous gases, sprays, and dusts.[114]

The second function of the experimental farm, one that has been equally significant to the development of modern agroindustry, was its use as a "clearinghouse of scientific knowledge."[115] This clearinghouse served to "maintain a two-way flow of information between the laboratory and the grower," a role previously reserved for state/university

[111] Shell Oil Company, "Better Farming," unpaginated
[112] Anonymous. "Headlines of the Month." *Industrial & Engineering Chemistry* 42, no. 11 (1946): 2385-86.
[113] Shell Oil Company, "Better Farming," unpaginated
[114] Shell Oil Company, "Better Farming," unpaginated
[115] Shell Oil Company, "Better Farming," unpaginated

experiment stations and the USDA.[116] Following WWII, chemical salesmen and consultants took on new roles as disseminators of agricultural knowledge, and Shell technologists led the way in this push, especially on the West Coast. The role of chemical technologists and salesman as disseminators of agricultural expertise was not new, what was new was their reach and influence.[117]

In 1912, C. W. Woodworth, the founder of the Division of Entomology at UC Berkeley, wrote, "I am sure we all appreciate the tremendous influence the manufactures and dealers of insecticides are exerting. They are in touch with hundreds of growers where an Experiment Station Entomologist reaches one. They have the last word when they furnish the goods just as they are bought to be applied. Their advice will go far to confirm or contradict our recommendations."[118] Having the last word is powerful, thus as agriculture reorganized itself around petroleum-based chemical technologies, chemical companies developed novel ways to spread their gospel and their products throughout the fields of the United States.[119] After WWII petroleum derived organic chemicals spread throughout the US as a part of agricultural industrialization, where they displaced many interwar economic poisons like lead arsenate, sodium cyanide, and paradichlorobenzene.

While the propagation of petrochemicals within agriculture since WWII has led to astonishing yields, it has also resulted in pollution and contamination on such an immense scale that it will continue to stalk humanity for so long that we might as well as think of it as forever.[120] A child born today, no matter rich or poor, even before they take their first breath, has hundreds of industrially made chemicals flowing through their blood.[121] And yet although bodily contamination is now a prerequisite of modern life, certain groups face greater burdens by sacrificing their bodies upon the altar of agricultural employment; or by living near the industries that make modern agriculture possible, in turn, subsidizing our cheap food through their bodily internalization of industrial agriculture's externalities.[122]

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[116] Shell Oil Company, "Better Farming," unpaginated

[117] Hall, D C, and R B Norgaard. "On the Timing and Application of Pesticides." *American Journal of Agricultural Economics* 55, no. 2 (1973): 198-201.

[118] Woodworth, CW. "The Insecticide Industries in California." *Journal of Economic Entomology* 5, no. 4 (1912): 358-64.

[119] For example, see Monkhouse, G R. "Business Philosophy Pursued by VP of Shell Chemical Put Its Ammonia Division on Top in West's Bitter Ammonia Market Battle." *Industrial & Engineering Chemistry* 71, no. 1: 63; Hall, "Timing and Application"; Whorton, J. *Before Silent Spring: Pesticides and Public Health in Pre-DDT America*. Princeton University Press Princeton, NJ, 1974; Daniel, P. *Toxic Drift: Pesticides and Health in the Post-War South*. Louisiana State University Press, 2005.

[120] Murphy, M. "Chemical Regimes of Living." *Environmental History* 13, no. 4 (2008): 695-703; Altman, R. "On What We Bury." *Interdisciplinary Studies in Literature and Environment* (2014): 1-11; Guillette Jr, L J, and T Iguchi. "Life in a Contaminated World." *Science* 337, no. 6102 (2012): 1614-15.

[121] Environmental Working Group. "Human Toxome Project." http://www.ewg.org/sites/humantoxome/. 2014; Feron, VJ, J P Groten, D Jonker, F R Cassee, and P J Van Bladeren. "Toxicology of Chemical Mixtures: Challenges for Today and the Future." *Toxicology* 105, no. 2 (1995): 415-27; Vandenberg, L N, T Colborn, T B Hayes, J J Heindel, D R Jacobs, D Lee, T Shioda, *et al.* "Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses." *Endocrine Reviews* 33, no. 3 (2012): 378-455.

[122] Bradman, A, Brenda Eskenazi, D B Barr, R Bravo, R Castorina, J Chevrier, K Kogut, M E Harnly, and T E McKone. "Organophosphate Urinary Metabolite Levels During Pregnancy and after Delivery in Women Living in an Agricultural Community." *Environmental Health Perspectives* 113, no. 12 (2005): 1802; Bradman, A, D Whitaker, L Quirós, R Castorina, B Henn, M Nishioka, J Morgan*, et al.* "Pesticides and Their Metabolites in the Homes and Urine of Farmworker Children Living in

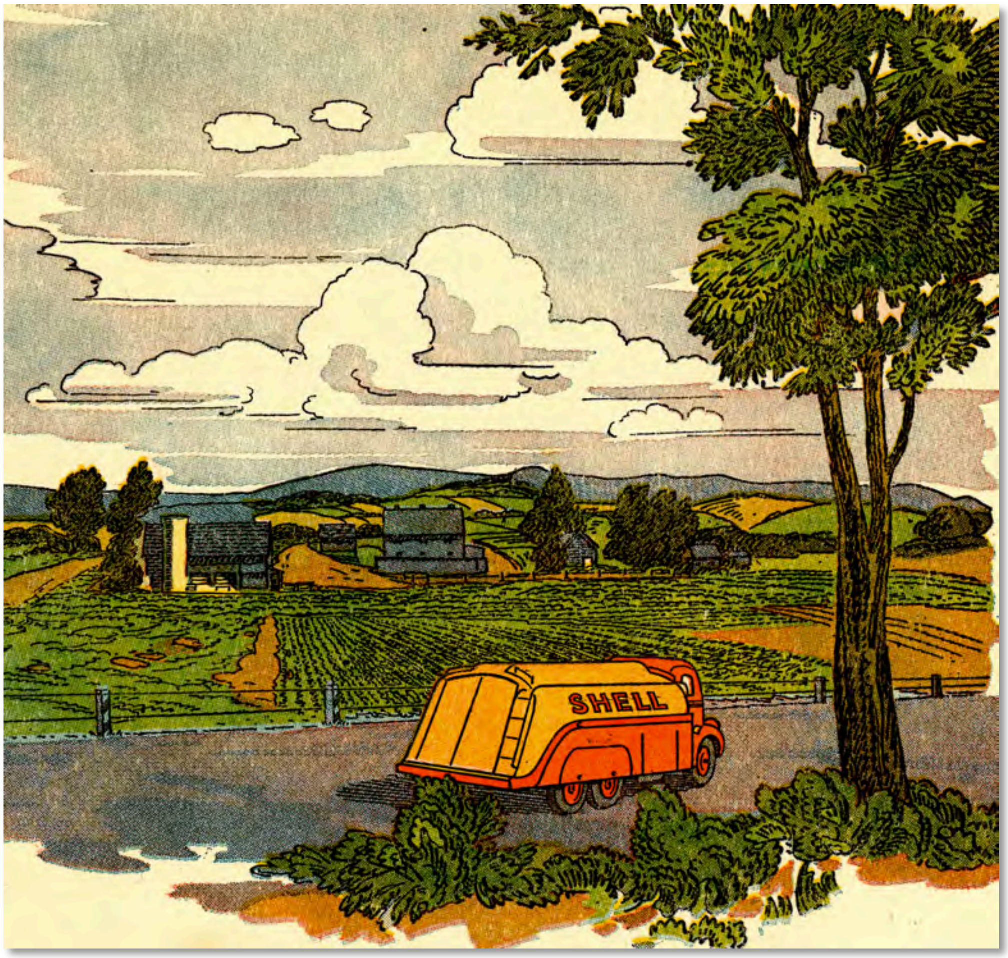

Figure 9 – "From Oil well to Farm."[123]

This chapter, through the lens of anhydrous ammonia and the soil fumigant DD, has suggested that industrial agriculture differs from other industries in its relationship to the reutilization of industrial waste. It has argued that agriculture, in its industrial form, has a uniquely reciprocal relationship with industrial waste. Although often treated as a field-based factory, agriculture is still inherently biological at its core; its functioning is not truly "akin to assembling parts in a factory to construct a machine."[124] It is this basis in natural processes that positions industrial agriculture in its complementary relationship with industrial waste. It is the *need* for toxic products that sets industrial agriculture apart. There are very few industries outside of the agroindustrial complex where toxicity is a *use value*.

the Salinas Valley, Ca." *Journal of Exposure Science and Environmental Epidemiology* 17, no. 4 (2007): 331-49; Singer, M. "Down Cancer Alley: The Lived Experience of Health and Environmental Suffering in Louisiana's Chemical Corridor." *Medical Anthropology Quarterly* 25, no. 2 (2011): 141-63; Willsher, K. "French Children Exposed to Dangerous Cocktail of Pesticides, Campaigners Say." *The Guardian*, April 29, 2014; Mascarelli, A. "Growing up with Pesticides." *Science* 341, no. 6147 (2013): 740-41.

[123] Shell Oil Company, 1945, *Shell…Soldier*, unpaginated

[124] Olmstead and Rhode, 2008, *Creating Abundance*, 14.

By viewing agriculture as a sink for industrial waste, the chemicalization of agriculture can be rethought outside the need to produce sufficient food. Through this lens, the adoption of transmuted waste products by farmers can be understood as critical to the production of other industrial goods and services – goods and services that are not critical to the survival of the population but to the survival of a particular form of political economy.[125] As long as the of production food, fiber, and other agricultural products continues in an industrial manner, newer and newer toxic chemicals will be needed, and many of them will continue to be made from the waste products of industry.[126] And as long agriculture is organized industrially, it will remain a profitable sink for industrial waste (See Figure 9).

[125] Guthman, J. 2011. *Weighing In: Obesity, Food Justice, and the Limits of Capitalism,* Berkeley, CA: University of California Press. Agricultural services to industry include the dilution, recycling, detoxification and treatment of industrial wastes and the absorption of surplus. Cf. Daily, G C, and K Ellison. *The New Economy of Nature*. New York: Island Press, 2002; Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being*. Vol. 5, Washington, DC: Island Press 2005.

[126] L, Clemens, S Jeanmart, T Luksch, and A Plant. "Current Challenges and Trends in the Discovery of Agrochemicals." *Science* 341, no. 6147 (2013): 742-46.

Conclusion:
A Fable for Today

"There was once a town in the heart of America where all life seemed to live in harmony with its surrounding… Along the roads, laurel, viburnum and alder, great ferns and wildflowers delighted the traveler's eye through much of the year… Then a strange blight crept over the area and everything began to change… There was a strange stillness… On the farms the hens brooded, but no chicks hatched… The roadsides, once so attractive, were now lined with brown and withered vegetation as though swept by fire… In the gutters under the eaves and between the shingles of the roofs, a white granular powder still showed a few patches; some weeks before it had fallen like snow upon the roofs and lawns, the fields and streams… No witchcraft, no enemy action had silenced the rebirth of new life in this stricken world… The people had done it to themselves."

Rachael Carson, *Silent Spring*, 1962[1]

What does the history of United States agricultural chemicalization mean for those of us envisioning a new agrarian future? First and foremost, it means we have to take seriously the dissipative services that industrial agriculture provides to capital and look off the farm to the industries that rely on the industrial agriculture's ecosystem services. In other words, it means that we have to change more than how we grow our food.

It means we have to change not just the institutions and the chemicalized nature of modernity, but also the stories and myths we tell about food and agriculture. Thus, in addition to new chemical regulations that put people before profit, we also have to stop believing that we have an agricultural system based on the production of food and fiber and realize that we have an agricultural system based on the production, circulation, and realization of value.

We must cleanse ourselves of the ideologies of productionism and warfare that continue to shape everyday understandings and practices of agriculture.[2] We must recognize that the end cannot justify the means, that just because there will be more people who want more meat does not mean that we have to continue in the present direction.[3] We have to come to terms with the fact that the reality of capital accumulation trumps the mythology of change through individual choice. We cannot consume our way to change. Appeals to the "free market" must stop.

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[1] Carson, R. *Silent Spring*. New York: Houghton Mifflin 1962. 1-3.

[2] Cochrane, W W. *The Curse of Agricultural Abundance: A Sustainable Solution*. Lincoln, NE: Univerisyt of Nebraska Press, 2003; Romero, A. "Commercializing Chemical Warfare: Citrus, Cyanide, and an Endless War." *Agriculture and Human Values* DOI:10.1007/s10460-015-9591-1 (2015).

[3] Moss, M. "U.S. Research Lab Lets Livestock Suffer in Quest for Profit." *New York Times*, January 19 2015, A1.

As a result of good intentioned market-based approaches to agrarian reform over the last twenty-five years, the US food system is bifurcating into one for the wealthy and one for the poor.[4] The fundamental change that food activists seek cannot rely on price as the system attractor and it cannot be accomplished by simply increasing the diversity of crops on the field.[5] In this, I echo Julie Guthman, who wrote that food and agricultural

"policy must go to an even deeper place… The systematic production of inequality has taken place not only through farm and food policy but also through trade, labor, immigration, health care, economic development, taxation, and financial policy – in other words, just about all the policies that have kept American capitalism (barely) afloat." [6]

Because the productive consumption of chemicalized agriculture provides useful ecosystem services to industry, as I have argued in this dissertation, any vision of a new US agricultural system would have to imagine simultaneous large-scale change off the agricultural field, from the food and feedstuffs processing industries and the petrochemical industries to immigration and trade policy. An entirely new agrarian system is needed, one based on care. Let's begin by putting labor first.

We now stand witness to a new revolution in agriculture. The influx of information and "smart" technologies are again, as in the interwar era, fundamentally remaking what it means to be a farmer. The frontier of agricultural appropriation and accumulation has moved beyond chemicals and seed companies; it is now information technology and agronomic automation.[7] With drones and fully automated tractors just on the horizon, agriculture is finally beginning to live up to the systems visions of Buckminster Fuller. In *Operating Manual for Spaceship Earth*, Fuller's utopian vision for humanity, he wrote,

"A new, physically uncompromised, metaphysical initiative of unbiased integrity could unify the world. It could and probably be provided by the utterly impersonal problem solutions of the computers. Only to their superhuman range of calculative abilities can and may all political, scientific, and religious leaders face-savingly acquiesce… Man is going to be displaced altogether as a specialist by the computer. Man himself is being forced to reestablish, employ, and enjoy his innate 'comprehensivity.' Coping with the totality of Spaceship Erath and universe is ahead for all

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[4] Guthman, J. *Agrarian Dreams: The Paradox of Organic Farming in California*. Berkeley, CA: University of California Press, 2004; Guthman, J. *Weighing In: Obesity, Food Justice, and the Limits of Capitalism*. Berkeley, CA: University of California Press, 2011.

[5] Carlisle, L, and A Miles. "Closing the Knowledge Gap: How the USDA Could Tap the Potential of Biologically Diversified Farming Systems." *Journal of Agriculture, Food Systems, and Community Development* 3, no. 4 (2013): 219-25; Kremen, C, A Iles, and C Bacon. "Diversified Farming Systems: An Agroecological, Systems-Based Alternative to Modern Industrial Agriculture." *Ecology and Society* 17, no. 4 (2012): http://dx.doi.org/10.5751/ES-05103-17044; Iles, A, and R Marsh. "Nurturing Diversified Farming Systems in Industrialized Countries: How Public Policy Can Contribute." *Ecology and Society* 17, no. 4 (2012): http://dx.doi.org/10.5751/ES-05041-170442.

[6] Guthman, *Weighing In*, 2011. 196.

[7] Upbin, B. "Monsanto Buys Climate Corp for $930 Million." *Forbes*, October 2, 2013.

of us. Evolution is apparently intent that man fulfill a much greater destiny than that of being a simple muscle and reflex machine – a slave automaton – *automation* displaces the *automatons*."[8]

New influxes of capital and technology to agriculture may mean that at long last humanity will be "free" from the drudgery of the soil that we have struggled with for the last 10,000 years. Automation is displacing the automatons. However, while the technology is living up to Fuller's vision, the comprehensive command mechanism is not. To guide spaceship earth, Fuller conjures the unifying "metaphysical initiative of unbiased integrity" as the system's captain. However, what we actually have as the comprehensive command mechanism for spaceship earth is the "metaphysical initiative" of capitalism. Thus, guiding the ship is not a computer system of unbiased integrity made for the benefit of humankind, but instead, is abstract value, capital's demon, vigilantly and incessantly steering the ship to benefit civilization's new great pirates. Automation is displacing the automatons, but at whose cost will this freedom come?

[8] Fuller, R B. *Operating Manual for Spaceship Earth*. Carbondale, Il: Southern Illinois University Press 1969. 35,44.

Appendix 1 - Projects of the Crop Protection Institute

Date	Project	Funding	Main Location(s)	Supplementary Location(s)
1920 - 1920	Boll Weevil - Calcium Arsenate Recommendations	CPI	Rochester Meeting, NY	
1921 - 1923	Cooperative Dusting Experiment	CPI and State Ag Stations, Manufactures	New York, West Virginia, Pennsylvania, Connecticut, Wisconsin, Kansas, Minnesota	Ontario, Canada
1922 - 1922	Ox Warbles	CPI		
1922 - 1924	Control of Smuts of Grains	American Phytopathological Society, CPI, Cereal manufacturers	the Ohio State University	Eleven states and Canada
1922 - 1924	Sulfur Investigations	Texas Gulf Sulphur Co., Union Sulphur Co., Freeport Sulfur Co,	Missouri Botanical Gardens (lab - chemical), Columbia, MO (field), East Lansing, MI (field), 3 places in PA, (field experiments), Boyce Thompson Institute for Plant Research and Agricultural Experiment Station, Geneva, NY (lab-insecticidal)	Oregon Agricultural College and Experiment Station
1923 - 1924	Control of European Hen Flea	Phinotas Chemical Company		
1923 - 1925	Calcium Arsenates	Riches, Pivers, and Company	Geneva, NY, Experiment Station	FL, AL
1923 - 1927	Scalecide use against borers, fire blight, aphids, mites, etc.	B.G. Pratt Company	State College, Penn State, PA	Amherst, MA, IL, WV
1924 - 1931	Causes of Cures for Crown Gall	USDA, American Association of Nurserymen, Iowa State College, University of Wisconsin, Boyce Thompson Institute	University of Wisconsin (Madison), Iowa State College (Ames)	

1924 - 1928	Furfuraldehyde as fungicide	Quaker Oats Company -	Ames Iowa, Miner Lab Chicago (Quaker Oats Lab)	Fort Collins, CO Experiment Station
1925 - 1927	Copper Compounds to develop a reversible colloid superior to Bordeaux Mix	Goldsmith Bros. Refining and Smelting Co., Nichols, Copper Co. Balach Metals Corporation	Boyce Thompson Institute, Yonkers, NY	other states
1925 - 1927	Seed Borne Parasites	Bayer Company	Boyce Thompson Institute, Yonkers, NY	
1925 - 1928	Flit possibilities and limitations in combination with various compounds	Standard Oil of New Jersey	New Jersey Experiment Station, New Brunswick	
1925 - 1935	Spraying Oils for Plants	Standard Oil of Indiana	Urbana, Illinois	Vincennes, IN, Lafayette, IN
1926 - 1927	Metal Compounds as Rodenticides and Insecticides	Bayer Company	Boyce Thompson Institute, Yonkers, NY	
1926 - 1928	Kip, household spray, Bovinol, for cattle	Standard Oil of Indiana	Lafayette, Indiana	
1927 - 1927	Organic Insecticides		New Jersey Experiment Station, New Brunswick	
1927 - 1929	Study of Volck (white oil emulsion) for animal parasites	California Spray Chemical Co.	Manhattan, Kansas	
1927 - 1929	Colloidal Sulfur	Tennessee Copper and Chemical Corporation	Urbana, Illinois Experiment Station, Madison, Wisconsin	
1927 - 1929	Physical Character of Atomized Sprays		New Jersey Experiment Station, New Brunswick	
1927 - 1929	Oxidized Oils as Insecticides		Lake Alfred Substation, Lake Alfred, Florida	
1927 - 1930	Horticultural Sprays from Petroleum Distillates	Deep Rock Oil Corporation	Connecticut Experiment Station, Iowa Experiment Station	
1927 - 1936	Pyrethrum Culture in the US	Stanco Incorporated	New Jersey Experiment Station	Pennsylvania State University
1928 - 1928		Koppers Co.		
1928 - 1928		The Interstate Chemical Company		

1928 - 1928		The Kay Laboratories		
1929 - 1929	Control of Brown Patch on Golf Greens			
1929 - 1929	New Insecticides for Mosquitos and Flies			
1929 - 1929	Insecticidal and Fungicidal Possibilities from Tanning By-products			
1929 - 1931	Pyrethrum Extraction Methods	Deep Rock Oil Corporation	Iowa Experiment Station	Massachusetts
1929 - 1931	Incorporation of fungicides in Saturated Oils		New Jersey Experiment Station, New Brunswick	
1929 - 1931	Incorporation of a Fungicide in Oxidized Oil		New Jersey Experiment Station, New Brunswick	
1929 - 1932	Industrial Impregnated Adhesive/Tape for Grafts	Johnson & Johnson, Bureau of Plant Industry, USDA, American Association of Nurserymen	Wisconsin Agricultural Experiment Station	
1929 - 1932	A Study of Coconut Emulsions		Maryland	
1929 - 1932	Control of Oriental Fruit Moth with Oil Sprays	California Spray Chemical Corporation	Delaware Experiment Station	
1929 - 1934	Plant Introduction and Improvement	Standard Oil of New Jersey	New Jersey Experiment Station	
1929 - 1929	Experiments with Naphthalene Derivatives	Monsanto Chemical Company	Illinois Experiment Station	
1930 - 1930	Utilization of Rotenone			
1930 - 1930	Accumulation of Oil in Plant Tissues			
1930 - 1933	Oils sprays for Codling Moth in Washington and Control of Codling Moth in California	California Spray Chemical Co.	Washington Experiment Station, Pullman, WA, and Berkeley, CA	

1930 - 1933	Utilization of Flotation Sulfur	Koppers Co. of Pittsburg, Standard Oil of Indiana	Urbana, Illinois Experiment Station, State Natural History Survey	New Jersey Experiment Station
1931 - 1933	Iodine Salts	Iodine Educational Bureau	New Jersey Experiment Station	
1931 - 1935	Use of CO2 in fumigation and spray materials (Proxate)	Liquid Carbonic Corporation	Iowa Experiment Station	others, Chicago
1932 - 1932	Survey of the Total Volume of Spray Materials Use in the US		New Hampshire Experiment Station	
1932 - 1932	New Synthetic Organic Compounds as Insecticides and Fungicides		Ohio Experiment Station	
1931 - 1932	New Types of Colloidal Sulfur/ Copper Sulfate as a Plant Nutrient	Nichols Copper Co., The Copper & Brass Research Association	Delaware Experiment Station	
1932 - 1932	New Synthetic Organic Compounds as Insecticides and Fungicides		Iowa Experiment Station	
1932 - 1933	New Contact Insecticides	Sharples Solvent Co.	Ohio Experiment Station	Philadelphia, PA
1931 - 1934	Pyrethrum Extract and Dusts, Improvement of Pyrethrum Sprays	J.C. Makepeace	Massachusetts substation, Wareham, MA, Virginia Truck Experiment Station, Ohio Experiment Station	FL, NH
1932 - 1934	Fungicides in combination with spray Oils	California Spray Chemical Co.	New Jersey Experiment Station	
1932 - 1934, 1936 - 1939	New Contact Insecticides and New Fungicides	National Aniline and Chemical Co.	Delaware (Fungicides), New Hampshire Experiment Station,	FL, MS, NJ Experiment Station
1932 - 1935	New Insecticides from chlorinated Compounds in oil sprays	Halowax Co.	Ohio State University	Florida
1932 - 1937	New Copper Fungicides (copper zeolites)	Nichols Copper Co., The Copper & Brass Research Association	Delaware Experiment Station	

1932 - 1937	Cooper Salts in Relation to Plant Stimulation and Nutrition	Nichols Copper Co., The Copper & Brass Research Association	Delaware Experiment Station	
1932 - 1939	New Organic Contact Insecticides	Dow Chemical	Iowa Experiment Station, UC Riverside Experiment Station	others, California, Michigan
1933 - 1933	New Copper Compounds	Shepard Chemical Company		
1933 - 1934	Sulfur as Fungicide, Physical Properties of Sulfur/ Sulfur and Pyrethrum Combinations	Freeport Sulfur Co.	Ohio Experiment Station, Delaware Experiment Station	
1933 - 1934	Combination of Various Organic Chemicals with Penetrol	A. G. Kay	Ohio Experiment Station	New Hampshire Experiment Station
1933 - 1935	Extracts of Pyrethrum and Derris	S. B. Penick and Co.	New Hampshire Experiment Station	southern states
1933 - 1935	Exploration of Organic Compounds as New Insecticides and Fungicides	Monsanto Chemical Company	Delaware Experiment Station, New Hampshire Experiment Station	
1933 - 1935	Sulfuric Acid in Weed Control	Freeport Sulfur Co., California State Department of Agriculture	UC Davis substation of CA Experiment Station	
1933 - 1935	Carbon Disulfide in Insecticide and Fungicide Sprays	Stauffer Chemical Company	New Haven Connecticut Experiment Station, Massachusetts Experiment Station	Colorado
1934 - 1935	New Spray Materials and New Means for their Application	Mergenthaler Linotype Company	New Hampshire Experiment Station	
1934 - 1935	Oil in Cattle Sprays (Pine)	Hercules Powder Company	Delaware Experiment Station	
1934 - 1937	Addition of Toxicants to DX (Pyrethrum sprays)	JC Makepeace, A G Kay	New Hampshire Experiment Station, Durham, NH	MD Experiment Station, IN Experiment Station, CO Experiment Station

1934 - 1938	Codling Moth Sprays	General Chemical Company	Indiana Experiment Station, Delaware Experiment Station	WA, VA, MO, MA, MD, MI, CO, OR, CN
1935 - 1937	Nicotine, or nicotine compounds (synthetic) in oil sprays	Monsanto Chemical Company	Illinois Experiment Station	
1935 - 1942	Fungicidal Properties of Cuprous Oxide (Cuprocide),	Rohm and Haas Company, Metals Refining Co., Merck and Co., Nichols Copper Co.	Geneva, NY, Experiment Station	
1936 - 1937	Misc. Insecticides and Fungicide Sprays	General Chemical Company	various states	
1936 - 1937	Control of disease on Seedling	Metals Refining Company		
1936 - 1937	Spreading and Wetting Agents	General Dyestuff Corporation		
1936 - 1937	Iodine Compounds	Amino Products Co.		
1936 - 1937	Control of Coccidiosis (Azamine)	Rare Chemicals Inc.		
1936 - 1938	Calcium Arsenate Investigations (Safer)	General Chemical Company	Louisiana Experiment Station, Baton Rouge	College Park, MD, State College, MS, State College, TX, Norfolk, VA, Riverhead, NY, Riverside, CA, New Haven, CN
1936 - 1939	New Insecticides from France - Sinox, Investigation of Nitro compounds as herbicides	Standard Chemical Products Inc., Standard Agricultural Chemicals, Inc.	New Hampshire Experiment Station, Durham, NH, UC Davis Experiment Station	
1937 - 1938	Ultawet, for use in combination with various insecticides	Atlantic Refining Company	New Haven Connecticut Experiment Station	Colorado Experiment Station, UC Riverside Experiment Station
1938 - 1938	Copper Rotenone Dusts	General Chemical Company	Long Island, NY	

1938 - 1938	Fungicidal Activity of New Compounds	Benzol Products Company		
1938 - 1938	Experimental Colloids	W. J. Craven and Co. LTD, England		
1938 - 1938	Copper Oxychloride as Fungicide	Hooker Electrical Company		
1938 - 1938	Various Napthenates	Nicodex Products Co. Inc.		
1938 - 1938	Casein combined with various toxicants	Casein Company of America	Geneva, NY, Experiment Station	Baton Rouge, LA, Durham, NH
1938 - 1939	Modified Bordeaux Mix	General Chemical Company	Louisiana Experiment Station, Baton Rouge	
1938 - 1939	Improvement and Stabilization of Derris	US Rubber Company	Southern State	
1938 - 1940	Proprietary Insect Repellent	Shell Petroleum Corporation		
1938 - 1940	Stomach Poisons and Repellents	US Rubber Company	Ohio State University	
1938 - 1940	Contact Insecticides	US Rubber Company	New Hampshire Experiment Station, Indiana Experiment Station	Florida (field), New Jersey, New England
1938 - 1940	Fumigants	US Rubber Company	New Hampshire Experiment Station, Durham, NH	
1938 - 1940	Fungicides	US Rubber Company	Geneva, NY, Experiment Station	
1938 - 1940	Mothproofing	US Rubber Company	New Hampshire Experiment Station, Durham, NH	
1939 - 1939	Control of Potato Diseases with Basic Copper Arsenate		Maine Experiment Station	
1939 - 1940	Genicide - xanthone as substitute for lead arsenate	General Chemical Company	Oklahoma Experiment Station, Missouri Experiment Station	NC, LA, NH, Ohio State, Boyce Thompson Institute
1939 - 1940		Sherman-Williams		
1939 - 1947	Fungicide Investigation of New Organic Compounds	Carbide and Carbon Chemicals Corporation	Boyce Thompsons Research Institute	Field Experiments in Pennsylvania
1939 - 1947	Insecticide Investigations of New Organic Compounds	Carbide and Carbon Chemicals Corporation	Indiana Experiment Station, Pennsylvania Experiment Station, Boyce Thompson Research Institute	

1939 - 1948	Investigations of Fungicides and Insecticides (Sulfur Compounds)	General Chemical Company	CO (field), Ohio State University (lab), NH (lab), AK (field), MS (field), NC (field)	NC, Boyce Thompson Research Institute
1940 - 1940	Accumulation of Facts on Plant Based Pesticide	Research Corporation with CPI Funds		
1940 - 1941	Copper Fungicides (dusts)	Rohm and Haas	New Haven Experiment Station,	
1940 - 1941	Insecticide Investigations of New Organic Compounds	Mathieson Alkali Works, Inc.	New Hampshire Experiment Station	
1940 - 1943	Organic Fungicides	Rohm and Haas	New Haven Experiment Station	
1940 - 1946	Fungicide Investigation of New Organic Compounds	Mathieson Alkali Works, Inc.	Boyce Thompsons Research Institute, Field Studies at Pennsylvania State College	other states
1940 - 1948	New organic copper fungicides	Rohm and Haas Company	New Haven Connecticut Experiment Station	Pennsylvania State University
1941 - 1948	Investigation of Blood Albumin and Related Products for Plant Sprays	Armour and Company	New Hampshire Experiment Station	Purdue, Indiana
1942 - 1942	Mildew Proofing Fabrics with Copper Compound	Albi Chemical Company		
1942 - 1942	Fungicidal Activity of New Detergents	Solvay Process Company	Boyce Thompsons Research Institute, New Hampshire Experiment Station	
1942 - 1943	Fullers Earth as carrier of Active Toxicants	Floridian Company	New Hampshire Experiment Station	
1942 - 1946	Growth Promoting Activities of Molasses By-products	US Industrial Chemicals, Inc.	New Jersey Experiment Station, Boyce Thompson Research Institute	central, western, southern states - field trials
1943 - 1943	Piperdine as substitute for pyrethrums	S. B. Penick and Co.	Boyce Thompsons Research Institute	
1943 - 1943	General Purpose Garden Spray and Cattle Spray Formulas	Socony-Vacuum Oil Company, Inc.	Indiana Experiment Station	
1943 - 1944	Study of New Compound Dichlo Diphenyl Trichloroethane	Geigy Company	New Hampshire Experiment Station	

1945 - 1946	Baits for Ants	Animal Trap Company of America
1945 - 1946		The Texas Company
1945 - 1947		Battelle Memorial Institute
1945 - 1948		Johns-Manville Corporation
1945 - 1948		J. T. Baker Chemical Company
1946 - 1946		Edco Corporation
1946 - 1946		New Jersey Zinc Company
1946 - 1946		Vick Chemical Company
1946 - 1947		Mallinckrodt Chemical Works
1946 - 1947		Minnesota Mining and Manufacturing Company
1946 - 1947		S. B. Penick and Co.
1946 - 1947		Pennsylvania Engineering Company
1946 - 1948		Boliden Mining Company
1946 - 1948		Davidson Chemical Company
1946 - 1948		Ethyl Corporation
1947 - 1947		Bridgeport Brass Company
1947 - 1947		J. N. Huber Corporation
1947 - 1947		H. H. Robertson Company
1947 - 1948		Hercules Powder Company
1947 - 1948		Standard Oil Company of Indiana
1948 - 1948		Attapulgus Clay Company
1948 - 1948		The Mathieson Chemical Corporation
1948 - 1948		Niagara Sprayer and Chemical Company

1948 - 1948

Sunoco Products Company

Appendix 2 - Official Bulletins of the Crop Protection Institute

Year	#	Title	Author	
1921	1	The Crop Protection Institute	CPI	Crop Protection Institute Digest No. 1:1-28
1922	2	Cooperative Dusting and Spraying Experiment of 1921	CPI	Crop Protection Institute Digest No. 2:1-30
1923	3	The Toxic Property of Sulfur	H. C. Young	Annals of Missouri Botanical Gardens, vol. 9:403-435
1924	4	Cooperative Dusting and Spraying Experiment of 1922	F. D. Frome, F. J. Schneiderhan	Crop Protection Digest no. 4:1-36
1925	5	An Investigation of Sulfur as An Insecticide	A. Hartzell, F. H. Lathrop	Journal of Economic Entomology 18 (2):267-279
1925	6	Spray Injury to Apple	H. C. Young, R. C. Walton	Phytopathology, Vol. XV (7):405-415
1925	7	Colloidal Sulfur as a Spray Material	H. C. Young	Annals of Missouri Botanical Gardens, vol. 12: 133-143
1925	8	Colloidal Sulfur: Preparation and Toxicity	L. E. Tisdale, H. Shaw	Annals of Missouri Botanical Gardens, vol. 12:381-418
1926	9	Suggestions on the Preparation of Apple Grafts	A. J. Riker, J. H. Muncie	Pamphlet for Nurserymen
1926	10	The Effectiveness of Various Fungicides in Controlling the Covered Smuts of Small Grains	E. B. Lambert	Phytopathology, Vol. XVI (6)
1926	11	A Summary of the Results of the Cooperative Investigation of Crown Gall in Relation to Apple Nursery Stock	I. E. Melhus	Crop Protection Digest no. 11:1-3
1926		Crown Gall of Apple Nursery Stock	I. E. Melhus	Journal of Economic Entomology 19 (2):356-366
1926		A Study of Crown Gall Caused by Pseudomonas Tumefaciens on Rosaceous Hosts	J. H. Muncie	Iowa State Journal of Science vol. 1:67-117
1926		Studies of Crown Gall and Wound Overgrowths on Apple Nursery Stock	A. J. Ricker, G. W. Keitt	Phytopathology, Vol. XVI (11):765-808
1926	12	The Penetration of a Contact Oil Spray into the Breathing System of an Insect	F. C. Nelson	Journal of Economic Entomology 20:632-635

1927	13	Fungicidal Activity of Furfural	H. H. Flor	Iowa State College Journal of Science vol. 1:201-223
1927	14	A Means of Control of the European Hen Flea (Ceratophyllus Gallinae Schrank)	M. A. Stewart	Journal of Economic Entomology 20 (1):132-134
1928	15	Organic Mercury Compounds for the Control of Insects in Stored Seeds	J. L. Horsfall	Journal of Economic Entomology 21 (1):147-150
1928	16	A Study of Pathogenic and Non-Pathogenic Strains of Pseudomonas Tumefaciens Sm. & Town	M. K. Pateli	Phytopathology, Vol. XVIII (4):331-343
1928	17	The Use od Volck Against External Parasites of Domestic Animals	W. G. Bruce	Journal of the Kansas Entomological Society 1 (4):74-79
1929	18	Viability of Certain Plant Pathogens in Soils	M. K. Pateli	Phytopathology, XIX (3):295-300
1929	19	An Inexpensive and Quickly Made Instrument for Testing Relative Humidity	W. B. Shippy	Botanical Gazette 87: 152-156
1929	20	A Progress Report on the Control of Crown Gall, Hairy Root, and other Malformations at the Unions of Grafted Apple Trees	A. K. Riker, G. W. Keitt, W. M. Banfield	Phytopathology, XIX (51):483-486
1929	21	Biological Studies of Psedomonas Tumefaciens Sm. & Town, and Fifteen Related Non-Pathogenic Organisms	M. K. Patel	Iowa State College Journal of Science 3 (3):271-298
1929	22	Volck Oil, Special Emulsion Number Two, As an Animal Insecticide	D. G. Hall	Journal of the Kansas Entomological Society 2 (4):74-85
1929	23	A Progress Report on the Testing of Sulfonated Oxidation Products of Petroleum for their Insecticidal Properties	J. L. Hoerner	University of Maryland Agricultural Experiment Station Bulletin 310:449-465
1930	24	Fungicidal Efficiency of Chemical Dusts Containing Furfural Derivatives	C. S. Reddy	Phytopathology, XX (2):147-168
	25	Studies upon a Bacteriophage Specific for Psedomonas tumefaciens	J. H. Muncie, M. K. Patel	
1930	26	Crowngall of Rumox crispus L and Rheum raponticum L.	J. H. Muncie	Iowa State College Journal of Science IV (3):315-321
1930	27	Fasciation of Sweet Peas	J. H. Muncie, M. K. Patel	American Journal of Botany, XXVII:218-230
1930	28	The Control of Certain Fruit Diseases with Flotation Sulphurs	M. A. Smith	Phytopathology, XX (7):535-553

1930	29	Studies of Growngall Overgrowth and Hairyroot on Apple Nursery Stock	J. H. Muncie, R. F. Suit	Iowa State College Journal of Science IV (2):263-313
1930	30	Influence of Environment on the Callusing of Apple Cuttings and Grafts	W. B. Shippy	American Journal of Botany, XVII:290-327
1931	31	Monochloronaphthalene as an Insecticide	G. L. Hockenyos	Crop Protection Digest no. 31:1-38
1931	32	An Insecticidal Method for the Estimation of Kerosene Extracts of Pyrethrum	H. H Richardson	Journal of Economic Entomology 24:97-105
1930	33	Some Physical Properties of Certain Dormant Oil Emulsion-Sulfur Combinations	M. D. Farrar, M. A. Smith	Journal of Economic Entomology 23 (6):979-984
1931	34	The Pyrethrin I Content of Pyrethrum Powders as an Index of Insecticidal Power	H. H. Richardson	Journal of Economic Entomology 24 (5):1098-1106
1931	35	Volck Oil, Special Emulsion Number Two, As an a Control for External Parasites of Animals	H. L. Coler	Journal of the Kansas Entomological Society IV (4):77-98
1932	36	Insecticidal Value of Certain Pyrethrum Extracts	H. G. Walker	Virginia Truck Experiment Station Bulletin 75:943-970
1932	37	Insecticidal Studies of Midcontinent Distillates as Bases for Pyrethrum Extracts-Household Sprays	H. H. Richardson	Industrial and Engineering Chemistry 24:1394-1402
1932	38	Notes on Rotenone as an Insecticide	N. Turner	Journal of Economic Entomology 25 (6):1228-1237
1932	39	Formation of Callus Knots on Apple Grafts as Related to Histology of the Graft Union	J. E. Sass	Botanical Gazette XCIV (2):364-380
1933	40	Reducing Inflammability of Fumigants with Carbon Dioxide	R. M. Jones	Industrial and Engineering Chemistry 25:394-402
1933	41	The Efficiency of Certain Proprietary Oils Emulsions, Volck and Orthol-K for Control of the Oriental Fruit Moth	D. MacCreary	University of Delaware Agricultural Experiment Station Bulletin, 184:1-43
1933	42	A Precise Method of Determining the Toxicity of Mixed Gases to Insects	R. M. Jones	Journal of Economic Entomology 26:895-902
1933	43	The Value of Copper Sulphate as a Plant Nutrient	R. Russel, T. F. Manns	Transactions of Peninsula Horticultural Society, Bulletin of the State Board of Agriculture, Delaware, 23 (5)
1934	44	Experiments with Sulphur and Pyrethrum	D. DeLong	Crop Protection Institute Digest No. 44:1-6

1934	45	Halowax as a Contact Insecticide	E. P. Breakey	Journal of Economic Entomology 27 (2):393-397
1935	46	Antiseptic Solutions and Antiseptic Adhesive Tape in Relation to Control of Hairy Root, Crown Gall, and other Overgrowths in Nursery Trees	A. J. Riker, S. S. Ivanoff, F. B. Kilmer	Phytopathology, XXV (2):192-207
1934	47	The Crop Protection Institute, Summary of Progress	W. C. O'Kane	Phytopathology, XXIV (9):1048-1053
1935	48	Copper Sulfate as a Plant Nutrient, 1934 Work on Tobacco, Cotton, and Corn	R. Russel, T. F. Manns	Transactions of Peninsula Horticultural Society, Bulletin of the State Board of Agriculture, Delaware, 24 (5):97-129
1935	49	The Toxicity of Carbon Dioxide-Methyl Formate Mixtures to the Confused Flour Beetle (Tribolium Confusum Duv.)	R. M. Jones	Journal of Economic Entomology 28 (2):476-485
1935	50	A Method for Comparing the Ovicidal Properties of Contact Insecticides	E. P. Breakey, A. C. Miller	Journal of Economic Entomology 28 (2):476-485
1935	51	Halowax as an Ovicide	E. P. Breakey, A. C. Miller	Journal of Economic Entomology 28 (2):353-358
1935	52	Sulfuric Acid for Control of Weeds	W. E. Ball, O. C. French	UC Agricultural Experiment Station Bulletin, 596: 1-29
1935	53			
1935	54	The Role of Pine Oils in Cattle Sprays	A. M. Pearson	University of Delaware Agricultural Experiment Station Bulletin, 196:1-63
1936	55	Copper Sulfate as a Plant Nutrient and Soil Amendment	W.L. Churchman, R. R. Russel, T.F. Manns	Crop Protection Institute Digest No. 55:1-16
1936	56	The Crop Protection Institute, Its Organization, Plan of Procedure, and Work Accomplished	W. C. O'Kane	Crop Protection Institute Digest No. 56:1-15
1936	57	Ovicidal and Scalicidal Properties of Solutions of Dinitro-o-cyclohexylphenol in Petroleum Oil	J. F. Kagy, C H Richardson	Journal of Economic Entomology 29 (1):52-61
1936	58	Toxicity of Some Nitro-Phenols as Stomach Poisons for Several Species of Insects	J. F. Kagy	Journal of Economic Entomology 29 (2):397-405
1936	59	Laboratory Method of Comparing the Toxicity of Substances to San Jose Scale	J. F. Kagy	Journal of Economic Entomology 29 (2):393-397

1936	60	Halowax (Chlorinated Naphthalene) as an Ovicide for Codling Moth and Oriental Fruit Moth	E. P. Breakey, A. C. Miller	Journal of Economic Entomology 29 (5):820-826
1937	61	Contact Insecticidal Properties of Various Derivatives of Cyclohexylamines	C. W. Kearns, W.P. Flint	Journal of Economic Entomology 30 (1):158-166
1937	62	Evaluation of Cuprous Oxides Recommended as Seed Treatments for the Control of Damping-Off	H. W. Anderson, K.J. Kadow, S. L. Hopperstead	Phytopathology, XXVII (4):575-587
1937	63	Copper Sulfate as a Plant Nutrient and Soil Amendment	W.L. Churchman, M.M. Manns, T.F. Manns	Crop Protection Institute Digest No. 63:1-26
1938	64	New Wetting and Spreading Agent for Spray Materials	G. L. Walker	Journal of Economic Entomology 30 (6):962-967
1939	65	Relation of Particle Size and Color to Fungicidal and Protective Value of Cuprous Oxide	J. W. Heuberger, J G. Horsfall	Phytopathology, XXIX (3):303-321
1940	66	A New Selective Spray for the Control of Certain Weeds	W. A. Westgate, R.N. Raynor	UC Agricultural Experiment Station Bulletin, 634: 1-36
1941	67	The Spore Germination Method of Evaluating Fungicides	P. D. Peterson	Phytopathology, XXXI (12):1108-1116
1942	68	A Greenhouse Method of Evaluating Fungicides by Means of Tomato Foliage Diseases	S. E. A. McCallan, R. H. Wellman	Contributions from the Boyce Thompson Institute Vol. 13:93-134
1942		Cumulative Error Terms for Comparing Fungicides by Established Laboratory and Greenhouse Methods	S. E. A. McCallan, R. H. Wellman	Contributions from the Boyce Thompson Institute Vol. 13:135-141
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