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From Disposable Culture to Disposable People: Teaching About the Unintended Consequences of Plastics

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**From Disposable Culture to Disposable People:
Teaching About the Unintended Consequences of Plastics**

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From Disposable Culture to Disposable People:
Teaching About the Unintended Consequences of Plastics

By

Tamara "Sasha" Adkins,

DISSERTATION

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Dedication

Zendaya,
To you I dedicate not only this dissertation
but all my work to shape a world where no one is disposable.

Acknowledgments

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1

*Paper, plastic, epoxy, and ink / Am **I** BPA's ultimate sink? / Is there bisphenol-A in my tuna fillet/ And in the water I drink?* (Don't worry...I'll stick to prose.)

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I cannot resist including an anecdote about one of my earliest mentors, Sandra Steingraber, who graciously invited me to assist her with research for *The Falling Age of Puberty.* She gave the keynote address at a conference in Burlington on women's health. I paused at the door to speak to those who were protesting the conference sponsor, Planned Parenthood. I tried to explain that they belonged inside, collaborating with us, to help create a world where toxic chemicals would no longer pose a threat to healthy conception, pregnancy, and birth. I did not succeed in that endeavor, and when I turned to enter, I was curtly told that my name did not appear on the list. My registration must have been "lost." After much negotiating, I was grudgingly allowed in. After her speech, Sandra came to greet me with tremendous enthusiasm, in front of the woman who had questioned my credentials: "Oh! If they had only told me you were here, I would have introduced you from the podium. I'm so glad to see you. I do hope we can collaborate again?" Thank you, Sandra, for your great kindness, and for your continuing example of scholarly activism and integrity.

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To all those whose names I will never know, who put together the laptop I use to write, whose sacrifices bring me electricity, whose hands pick my food, to all who make my life possible, thank you.

Abstract

Plastics, the epitome of disposable culture, pose both a toxicological and a spiritual problem. This dissertation examines plastics at a molecular level using the discourse of endocrine disruption, and at a sociological level using the discourses of eco-theology and environmental justice. Adding to the literature on the adsorption of toxicants to plastic marine debris, I demonstrate that certain types of plastic -- those containing mercaptans, such as styrene butadiene block copolymer -- efficiently concentrate methyl mercury from seawater. Further, samples of polycarbonate *contributed* mercury to seawater. I propose the term *plastic-mediated magnification* to describe the phenomenon that plastics, along with their adsorbed toxicants, are being ingested directly and indirectly at each trophic level, with profound implications for quantitative risk modeling of the environmental fate and transport of persistent pollutants. I also propose an "eco-theology of zero waste," linking the habits cultivated by interacting with the natural / material world as if it were disposable and only instrumentally valuable to the mindset that people, or at least some people, are similarly disposable when not deemed useful or productive to society. I propose a framework for teaching about environmental justice issues, like plastics, by recognizing and countering defensive tactics that students may employ in order to resolve their cognitive dissonance about being a well-intentioned person in a society that treats some of us as disposable. This dissertation is available in open access at AURA, http://aura.antioch.edu/ and Ohio Link ETD Center, https://etd.ohiolink.edu/etd.

Keywords: plastic marine debris, plastic-mediated magnification, methyl mercury, environmental justice, white fragility, eco-theology, endocrine disruption, disposable culture

Table of Contents

Dedication....................i

Acknowledgments....................ii

Abstract....................viii

List of Tables....................xiii

List of Illustrations....................xiv

Introduction....................1

Rainbow Chaser, 1981....................1

Necropsy, 2008....................8

Cleaning Up the Streets, 1993....................10

Why a Dissertation on Plastics....................12

An Introduction to Plastics Themselves....................13

Common Types of Plastics Additives....................16

Teaching About Endocrine Disruption and Low Dose Toxicology Using the Story of Plastics....................20

1. Risk = Hazard x Exposure....................20

Avoiding Exposure: Case Study #1....................27

Avoiding Exposure: Case Study #2....................32

Avoiding Exposure: Case Study #3....................33

Questions for Discussion....................34

2. Risk = Hazard x Exposure....................34

Lag Time....................35

Mixture Effects....................37

Individual Variations in Susceptibility....37
Route of Exposure and Type of Dose....39
Case Study: Unanticipated Environmental Interactions....41
Case Study: Sarnia....42
Case Study: Developmental Origins of Health and Disease (DOHAD)....45
Plastic Marine Debris as a Public Health Problem....48
I. Abundance....48
II. Sources....49
III. Ingestion and Transfer of Toxicants....51
IV. More Unanticipated Problems with Marine Plastics....52
Pilot Study: Adsorption of Methyl Mercury to Plastic in Seawater....57
Abstract....57
1. Introduction....57
2. Materials and Methods....60
2.1 Phase I: Proof of Concept Testing....60
2.2 Phase II: Additional Testing....61
3. Results....63
4. Conclusions....64
Tactic #1: Denial / Universalizing....66
I. Making Environmental Privilege Visible....68
II. Developing Curiosity and Empathy....72
III. Understanding Intersectionality....72
Tactic #2: Minimizing....74

I. Taking a Long Term View..75
looking back..75
looking forward..76
II. Where Does Waste Go?...76
Tactic #3: Blame the Victim..81
I. Using Principles of Epidemiology to Understand Additive and Synergistic Effects and Variations in Individual Susceptibility...84
Tactic #4: Scapegoating / Refusing to See Patterns...85
I. Root Cause Analysis...91
II. Seeing Patterns...92
Tactic #5: Giving Up..95
I. The Precautionary Principle: Acting in the Fact of Uncertainty............................101
Conclusion: Solutions..102
Tertiary Prevention: Clean It Up..103
More Tertiary Prevention: Reduce, Reuse, Recycle...105
Bioplastics: Moving Towards Primary Prevention?..109
Policy and Regulatory Solutions: A Mixed Bag..111
Secondary Prevention: Measure the Mess..113
Using Plastics to Purify..114
Primary Prevention..115
Works Cited...120
Appendix I: Plastic Bag Bans and Fees...132
Appendix II: Permissions..134

Appendix III: "Plastics as a Spiritual Crisis"..136

List of Tables

1. Resin Codes and Monomers of the Most Common Plastics......................................14

2. Intentionally Introduced Components of PVC..17

3. FDA-Approved Polymeric Additives in Food...23

4. Concentration of Contaminants in Polypropylene Nurdles...54

5. Mercury Adsorption to Polymers in Seawater..64

6. Strategies for Responding to White Fragility Defensive Tactics................................ 66

List of Illustrations

1. Hierarchy of Controls..80
....

Introduction

Rainbow Chaser, 1981

When I turned seven, my parents sold our house and furniture and bought a sailboat. She (as ships are traditionally called) was a 37-foot custom-built Tyana. "Custom-built" in this case, meant that instead of buying a boat that was ready to move aboard, we bought the *idea* of a boat. Every six months or so, there would be a heated conversation about when she would be ready. Assurances would be made, but invariably the promises were broken and we moved from apartment to apartment, waiting.

Finally, she was ready. My parents named her "Rainbow Chaser," and the little sailing dinghy we towed, naturally, was called, "Pot of Gold."

The typical US American home is around 2,600 square feet. Below deck, we had just 340 ft^2, for three (and at one point, four) people. This was to be our home for the next seven years.

Mine was the aft cabin, which consisted of a bunk, enclosed on all sides and above, presumably to keep the occupant from falling out of bed in rough seas, and a navigation table with a bookshelf. What was a bunk on one end was the seat for the navigation table on the other, and that was that. I did not have enough room to stand up straight or stretch out my arms. The trade off was that I had a radio, a depth sounder, and charts (the nautical equivalent of maps) of the places we would visit.

My parents had the forward cabin, which had a large bunk under a hatch with a skylight. They had one tiny closet, which we all shared. I was given two hangers, and all of my clothes went on them, one outfit over another. Most of the other available storage space was devoted, by necessity, to more important provisions, such as canned food.

Many landlocked homes have shelves crowded with decorative curios, and kitchen counters with spice jars or cutting boards on them. In our case, every surface was, by necessity, bare. Anything I'd brought out to play with could not be set down for a moment without being secured. Even our chess set had magnets so that the pieces wouldn't slide off the board. When a ship is at sea, anything not properly stowed could pose a potentially lethal hazard. It could fall on someone or trip them or break and cut them. I was trained to cultivate the habit of picking things up even when we were docked, and this habit has become so inculcated in me that to this day I feel anxious when things are out of place.

The midships was a living room, with two bench settees that faced each other and a fold-down table in between. Below the cushions were cubbies that were filled with cans of Spam™. These provided ballast as well as incentive not to get lost at sea (I'm not a fan of Spam™.) Above the settees were built-in bookshelves, on which we had a telephone and a tiny television, both of which only worked when we were docked. While we were sailing, of course, there was no electricity. (Nowadays, many ships have generators.) The radio was our only form of communication at sea. My favorite part here was the grab rails on the ceiling that would steady adults when we were underway. For me, they were ideal for climbing and dangling.

The kitchen had a sink, a miniature alcohol-powered stovetop with two burners (for summer use), and a 16" x 18" cast-iron diesel stove, which doubled in winter as our heat source. The refrigerator and freezer could be accessed by lifting out squares of the counter top. The trick, of course, was that you had to plan ahead everything you might need from the cold storage before beginning to cook, otherwise whatever you set on the counter would block you from opening the lids again.

The head, as a bathroom on a boat is known, had a shower, sink, and toilet. A handle allowed the contents of the toilet, after use, to be pumped directly overboard. I was taught to use no more than two squares of toilet paper at a time, to keep from clogging it. Water was very precious. We had two 150-gallon tanks, which we filled with hoses when we docked. We conserved the water in our tanks by showering in the marina when that option was available. I was allowed one glass of water each evening to use for brushing my teeth and for drinking. To this day, I can't bear to see people letting a faucet run.

Looking back, I know now that drinking water from a hose is a risky proposition. Hoses tend to be made of polyvinyl chloride, and (particularly if left out in the hot sun) they leach lead and phthalates and other undesirable compounds into the water that we will return to later in our story. Even my dad admits that the water tasted bad.

Not only what goes in, but also what went out, worried us all. My mom told me after I'd grown up that when she had her period she used to have nightmares about the blood attracting sharks that could snatch her from the safety of the boat and devour her. Fortunately, these fears were unfounded. However, when I think of how many boats docked in the marinas, each discharging raw sewage, the part of me trained in public health cringes. I came across this factoid: "A single weekend boater flushing untreated sewage into our waters produces the same amount of bacterial pollution as 10,000 people whose sewage passes through a treatment plant" (Self). Fortunately, these days boats typically use "marine sanitation devices" that either treat the waste, or store it for later transfer.

Speaking of generating pollution, we stayed warm in winter by burning either diesel in the kitchen stove (from the same tank of diesel that we used to power the motor), or by burning coal in the secondary "fireplace" in the living room that vented to the deck through a small metal chimney. Needless to say, our exhaust was not filtered. One icy morning we woke up to find ourselves completely covered in soot. The stove had backdrafted. After we scrubbed the black grime off in our cold-water-only shower, my mom took me out for the day. My dad stayed below to take the fireplace chimney apart. He discovered that the creosote was so thick that it had almost entirely occluded the flue. After he cleaned up the mess, he decided we'd switch to Duraflame logs, sawed into thirds to fit our tiny fireplace.

My favorite places were above deck. We were ringed by lifelines, which gave us something to grab onto when we were underway. There were mazes of cubbies in the cockpit, some of which were large enough for me to hide in. These cubbies held ropes, which we called "lines." I practiced coiling and tying knots, many of which were taught with mnemonics like, "the rabbit comes out of the hole, around the tree, sees a fox, and goes back into the hole" (that's for a bowline).

When we were docked, my dad would hoist me up the Bosun's chair, nearly to the top of our 55' mast, and let me swing from stanchion to stanchion, pretending I was on a trapeeze. When night fell, there was a hammock tied to the boom. I loved to sleep right under the stars lashed into the hammock so I wouldn't fall out. All the way forward, there was a bowsprit. When we were at sea, I would spend hours curled up on the bag that held the jib. From this post, I could safely dangle my feet and hands out to try to touch the dolphins that teased me, jumping and racing around our bow, always just out of reach.

At this point, all my parents knew of sailing was from the warships my father had served aboard while in the Navy, and, at the other end of the size spectrum, from the sailing classes they were both taking in dinghies in the Charles River in Boston. We preserved the traditional nautical hierarchy (euphemistically known as teamwork). My father was the Captain of our ship, my mother the Admiral. I was First Mate. It was critical that crew not question orders of their superiors while underway. Lives were at stake. I often felt my parents took this a bit too far.

While my father learned to navigate with a sextant, my mother learned to cook a Thanksgiving turkey in a toaster oven (the trick is to take a measuring tape with you to the grocery store because, as she learned the hard way, you can't saw off the protruding parts while the bird is frozen). I learned not to romanticize Nature.

Survival while sailing demands a certain level of hypervigilance. To this day, subtle changes in the light in the room where I'm sleeping will wake me. These were the days before we delegated our awareness of our surroundings to computerized instrumentation. Keeping watch meant standing in the cockpit, at the helm, making sure that we stayed on course -- holding the wheel, glancing down at the compass., and compensating for any shifts in wind direction or currents. But more importantly it meant noticing any variation in the repetitive rhythm of waves against the hull, or in the sounds of the wind in the sails.

Sometimes there were strange noises in the night. My favorite was the snort of a whale coming up for a breath (when they open their blowhole they expel water before taking a breath). My mom describes standing watch one night and having the unsettling feeling that she was not alone. She turned and looked right into the eye of an orca who had surfaced to check us out. She recalls thinking, "I better be quiet, this is not my place."

My most memorable sail was a voyage to Bermuda -- one week with no land in sight. However, what was never out of sight was the garbage carelessly thrown overboard by the crews of the vessels in the Marion to Bermuda Cruising Yacht Race. My dad remarked that we didn't need to navigate - we could just follow the stream of Styrofoam plates floating by.

Unfortunately, it was also memorable because we hit a reef. A new friend who wanted to go diving was at the bow directing us. Being accustomed to power boats, he thought he was being helpful when he gave instructions like, "go right, ok..now, stop." We'll let him off the hook for not knowing his starboard from his port, but one thing he really should have known was that a 37-foot sailboat can not just stop. He learned that the hard way.

There was a dreadful crunching sound and the boat lurched onto her side. My cousin Allen grabbed me and held on to the lifelines to keep us both from falling overboard. My dinner went flying.

My father and Allen spent the rest of the afternoon underwater, inspecting the damage to our boat. At the time, I don't remember anyone worrying about the damage to the reef. They discovered that our keel, which was hollow, was punctured and was taking on water, but that the hull was intact. It was decided that the extensive repairs that would be necessary could be done stateside. They would sail her back and then put her in dry dock. I registered a vote of 'no confidence' in this plan and declared my intention to fly to my grandparents' instead of sailing back with them. And so I did.

Mammaw and Paps and I tracked a hurricane on the evening news, knowing that it was on course to intercept my parents. These were the days before satellite phones and GPS. We were completely out of communication with them for one very long week. We had only the meteorologists' predictions to fuel our fears.

One day the phone rang and we all gathered around to hear the good news. They had made it to shore. It turned out that the extra weight of the water in the keel had stabilized the boat. If they had not hit the reef, they might not have survived the storm.

I remember my parents saying the two things nearly all sailors say when they come ashore after a blue water voyage: "Never again," and, "I'm going out for a drink." Even at my age, I knew from experience that "never again" meant that in about a month they would start planning our next adventure.

Just before I started high school, we sold the boat and bought a house near Tampa Bay. Although it didn't feel like the ocean I knew -- it was as warm as bathwater and nearly as shallow -- there were still manatee and dolphins and sting rays to play with.

Every gift has a shadow. Mine is placelessness. When I try to count how many cities and towns I've lived in, I come up with somewhere between 40 and 50. Being a nomad in a culture where that is not the norm means that most conversations begin with what seems innocuous enough: "Where are you from?"

I've been working on an answer to that one for years. I'm told that in kindergarten my teacher anxiously informed my parents that I couldn't distinguish between reality and fantasy. Apparently, I had been asked to draw a picture of my home and my family. Standard kindergarten fare. I was expected to produce the requisite stick figures next to an apartment building or a little house, perhaps with a fence and a dog and flowers in the garden if I were artistically inclined, which I certainly am not. I confused them by instead drawing a sea turtle. I informed my teacher, using this metaphor, that we carried our house with us and we lived inside. I refused to recant when she insisted that I was making it up. My teacher was even more befuddled when my parents corroborated my story.

"We only save the places we love, we only love the places we know..." has become a mantra in the field of environmentalism. Teachers strive through "place-based learning" to cultivate a "sense of place." Without this, we are told, our prognosis is poor for developing an ethic of stewardship.

My home is the Atlantic Ocean. I am from tide pools and coral reefs. My watershed consists of more than 82 million billion gallons and touches four continents.

You may be tempted to pass judgment on my parents for recklessly exposing their child to danger, for taking risks without appreciating the consequences, and for indulging their own thirst for adventure over precaution. What I will attempt to illustrate in the chapters that follow is that these accusations are just as aptly leveled against a society that relies on disposable plastic.

Necropsy, 2008

I knew the bird was frozen. Even so, when I stroked the belly feathers of the juvenile black-footed albatross on the table in front of me, its magnificent wings reaching wider than I am tall, I held my breath. It seemed poised to fly. I knew that I would probably never see one again.

The albatross is endangered. There are many reasons for this, of course. One is that the birds become entangled in long-line fishing gear, as this unfortunate one had. Another is that they are eating plastic. Up to 40% of the chicks do not survive. Their parents are regurgitating not food but plastic garbage. The smaller pieces fill the babies' bellies so that they lose their appetite for nutritive food and starve. The pieces that are tiny enough to be digested release poisons into their bloodstream that concentrate in their fatty tissue and interfere with their metabolism and hormone function (Auman, et al.).

At Algalita Marine Research Foundation, we wondered if we could tell the story of how much plastic the birds were eating, and if we could measure the chemicals leaching from the plastic that contaminated their preen gland oil, if we might be able to advocate for source-reduction policies that would protect them.

This is how I found myself one summer day watching a scalpel slice open the belly of that beautiful albatross. This is how I found myself counting out pieces of spent ink pens and bottle caps that we pulled out of it. I contemplated the irony that it was some human child's plastic playthings that might have proven deadly to the young albatross. And I kept counting.

When it was over, I found the closest beach, hoping to find healing in the sand and the waves. Instead, I found a lot of garbage. Cigarette butts, plastic cups and forks, straws, broken bits of sand pails and toys. Much like what I'd just seen come out of the stomach of that magnificent albatross.

I went into the ice cream shop on the pier and asked if I could have a trash bag so I could collect litter. They kindly obliged. I filled up one bag so quickly that I went back for a second. And a third. I was trying to find my way out of despair by thinking, "At least this piece won't be eaten by an albatross" when I heard a mocking voice behind me call out, "Hey, bag lady, you missed one!"

I turned to face a beachgoer, who was sitting on a plastic folding chair and sipping out of a disposable plastic cup through a plastic straw. Children at his feet were using plastic shovels to scoop "sand" (which is just as likely fragments of plastic debris as it is fragments of rocks and shells these days) into plastic buckets. They were all wearing plastic flip-flops, and bathing suits made out of Lycra, which, of course, is a also plastic. The girls had plastic barrettes in their hair.

I felt myself at a turning point. If I projected my rage at him, I would never know peace. Indulging in being self-righteous and judgmental -- as I know from experience -- is like quicksand. It's nearly impossible to extricate myself once I start slipping. So I tried to mentally reframe this as an opportunity for public education. I smiled and went over to explain to him what I'd seen in the necropsy of the bird, of the fish. He listened. I don't know what was going on in his head while he was hearing all this, or if he was simply regretting calling my attention to him in the first place, but I will say that he listened patiently and respectfully. He did not offer to help. I continued pacing and sorting -- sand, shell, trash, sand, shell, seaweed, trash.

Cleaning Up The Streets, 1993

A family was set up on a sidewalk in Nairobi selling oranges. As we chatted, they handed me their baby to rock. Then, someone whistled. This was a signal that the police were coming. In a moment, the other vendors had all vanished. This family could not. Their grandmother moved slowly, and perhaps my presence complicated things. The police did arrive. Suddenly, there were strong arms restraining me and a hand over my mouth to muffle my screams. The family was thrown into the back of a truck, and the baby lay smashed on the sidewalk.

When I recounted this to my host mother later that evening, she told me that the police were under orders to clean up the streets. Homeless people were considered trash. She also told me that if I ever find myself lost and am robbed, I should ask the robber for directions home, never the police. "At least the robber is human," she mused.

Today, I live in a country where to assert that Black lives matter is considered controversial.

Hundreds of undocumented immigrants die of thirst, exposure to the elements, and violence crossing the desert that connects Sonora, Mexico and Arizona, USA each year and hundreds more disappear ("No More Deaths"). In the United States, researchers attribute at least 133,000 deaths a year to poverty ("How Many U.S. Deaths"). Three hundred eighty-five million of the world's children are living in extreme poverty, subsisting on less than $2.00 US dollars a day ("Some 385 Million Children"). Which of us is still human?

What does this have to do with plastic? It is humans who created the idea of waste. Nature has always had a circular economy, with nutrient cycles and energy flows. Some humans broke those cycles. The idea that some lives are more valuable than others arises from the same underlying notion that worth is a function of utility and productivity. In this worldview, value is instrumental rather than intrinsic. Things and people that no longer serve are discarded, or destroyed. In order to repair the cycles on which all life depends, new technology is not enough. The spiritual contradiction must be resolved. We cannot restore ecological sustainability without also restoring the intrinsic dignity of life. Just as action follows from intention, so intentions and beliefs are shaped by our actions, as many indigenous and many faith traditions teach. Cultivating a habit of the heart in which we no longer regard things as disposable may lead to actions affirming that life is not disposable.

Why A Dissertation on Plastics

When I began my exploration into plastics, they were mere molecules. I looked at them through a scientific lens and investigated their role as endocrine disruptors, as neurotoxicants, and as carcinogens. I explored their role in transferring contaminants into and out of the marine food web. Now they have become more potent to me as symbols of a culture that views both the material world and the living worlds, even people, instrumentally, as if they were disposable resources.

The following chapters parallel this learning, but this is not a story about simply following intellectual curiosity. It is also about my struggle to understand what to do with all of this information, and with the rage and pain that I feel seeing some of the consequences of disposable culture. I began to teach, both as a form of activism and as a form of healing. In the following pages, I offer a pedagogy of plastic. This is an attempt to make the connections explicit between the scientific, societal, and spiritual dimensions of plastic, used as a proxy for disposable culture.

An Introduction to Plastics Themselves

What *are* plastics? The very word *plastic* was once complimentary. According to the Oxford English Dictionary, *plastic* was synonymous with "formative, procreative, creative." Today it is often used as a pejorative, referring to that which is "artificial, unnatural; superficial, or insincere."

When referring to the material rather than the symbolic, the term *plastic* is short for *thermoplastic*, the particular type of high molecular weight polymer that is able to shape-shift. A thermoplastic can be heated and remolded any number of times. Other types of polymers include *elastomers* (which can be stretched or deformed at room temperature, but which snap back to their original shape as soon as they are released), and *thermoset* polymers, which form irreversible chemical bonds once they cool and so cannot be reshaped.

A polymer (from the Greek *polu*, meaning many and *meros*, meaning parts) is any chain comprised of repeating units. Sometimes just one unit repeats:

A-A-A-A-A-A

At other times, a pattern repeats:

AB-AB-AB-AB-AB

Each repeating unit is, quite logically, known as a monomer, which roughly translates as "one part." In the world of synthetic polymers, the basic monomers are ethylene, propylene, styrene, vinyl chloride, and bisphenol-A. We can think of these as being the building blocks of most commodity plastics. (The monomers used to make the first industrial plastic, Celluloid, were nitrocellulose and camphor; due to flammability concerns, these have fallen out of favor and are rarely used today.)

The number found in the chasing arrows symbol stamped on the bottom of many plastic containers indicates its monomer.

Table 1: Resin Codes and Monomers of the Most Common Plastics

Code	Name of the Plastic	Monomer
1	polyethylene terephthalate	bis(2-hydroxyethyl) terephthalate
2	high density polyethylene	ethylene
3	vinyl (polyvinyl chloride)	vinyl chloride
4	low density polyethylene	ethylene
5	Polypropylene	propylene
6	Polystyrene	styrene
7	other (usually polycarbonate)	bisphenol-A

Here is ethylene: $C2H4$. Ethylene occurs naturally in fruits. As they ripen, they release ethylene into the air, producing a sweet and musky fragrance. Ethylene (and propylene) that are used by industry, though, are produced synthetically by steam "cracking" (breaking apart) molecules of naphtha, natural gas liquids, or petroleum. When ethylene forms a chain:

C2H4- C2H4- C2H4- C2H4- C2H4- C2H4- C2H4- C2H4- C2H4

it becomes polyethylene, which might become a milk jug or a plastic grocery bag.

While ethylene and propylene are considered benign ("Ethylene Oxide"), the monomers styrene, vinyl chloride, and bispheol-A are not. Workers exposed to vinyl chloride suffer disproportionate rates of angiosarcoma of the liver (Vianna et al.), a cancer that is quite rare in the general population. To make matters worse, vinyl chloride exposure is also associated with a painful condition called acro-osteolysis, in which the bones at the tips of their fingers and toes are reabsorbed in a band-like pattern (Freudiger et al., Hahn et al., Preston et al.). According to the National Toxicology Program, styrene is reasonably anticipated to be a human carcinogen ("Styrene"). Exposure may also suppress the immune system (Biró, et al.), and could even accelerate hearing loss (Hoet and Lison). Studies of Chinese men working in a factory that produced bisphenol-A correlated increasing levels of BPA metabolites in their urine with declines in their fertility and libido (Li, et al.).

If plastics were just made up of repeating chains of monomers, toxicologists would have a much easier time of it. But the monomer is --literally-- only half the story. Up to half the weight of plastics may be additives, fillers, residual catalysts, or accidental byproducts of the reaction.

It can be said of additives, "the secret is in the sauce." We can identify the monomer from the chasing arrows code but the blend of additives in any particular batch is a trade secret. Manufacturers are not required to inform their customers when they change the formulation.

Common Types of Plastics Additives

- Fragrances
- Desiccants
- Oxygen scavengers
- Anti-blocking agents
- Anti-static agents
- Nucleating agents
- Anti-fogging agents
- Coupling agents
- Lubricants
- Mold release agents
- Anti-slip agents, slip agents
- UV stabilizers
- Antimicrobials, biocides
- Chemical and physical blowing agents
- Additives to control molecular weight
- Flame retardants
- Adhesives
- Fillers and reinforcements
- Impact modifiers
- Light-sensitizing additives that promote photodegredation
- Unintentional additives (residual catalysts and solvents, compounds that migrated in during the polymerization process

Table 2	**Intentionally Introduced Components of PVC**
Monomer	vinyl chloride
Stabilizers	cadmium, tin, lead, barium, calcium; alkylphenols such as trisnonylphenolphosphite
Plasticizers	diethylhexyl phthalate (DEHP), diisononyl phthalate (DINP), butylbenzyl phthalate (BBP), diisodecyl phthalate (DIDP), di (2-ethylhexyl) adipate (DEHA), organophosphates, trimellitates, epoxidised soybean oil, alkylphenols , tricresyl phosphate (TCP)
Antioxidants	bisphenol-A (BPA)
dyes, tints, and inks	azo-based dyes (diazo, pirazalone, anthraquinone, quiniphthalone, quinoline), lake pigment, carbon black, phthalocyanines, titanium dioxide, lead chromate, cadmium sulfide, hexavalent chromium, mercury
flame retardants	bisphenol-A (BPA), tetrabromobisphenol-A (TBBPA), other polybrominated compounds, tricresyl phosphate (TCP)
antimicrobials[2]	Triclosan, 2-n-octyl-4 isothiazolin-3, copper-8-quinoleate, nano-scale silver
UV stabilizers	carbon black, hydrobenzophenone, phenolic benzotriazoles (UV-320, UV-326, UV-327, UV-328)
impact modifiers	(no publicly available information readily accessible)
anti-fogging agents	ethyloxylates of nonylphenols
anti-static agents	alkyl quaternary ammonium salts, alkyl phosphonium, alkyl sulfonium salts, dithiocarbamic acid
anti-blocking agents	talc, diatomaceous earth, silica
mold release agents	(no publicly available information readily accessible)
fillers and reinforcements	clay, silica, talc, wood flour
Lubricants	metallic soaps
oxygen scavengers	copper loaded/ascorbate loaded silica

In 1987, Ana Soto and Carols Sonnenschein at Tufts University were performing

2 The monomer itself is not usually at risk of microbial attack (i.e., it does not biodegrade); however, some of the additives are. For this reason, and as a selling point for consumers who are concerned about bacterial contamination of the products stored in PVC containers and wraps, antimicrobials are introduced.

experiments on estrogen-sensitive breast cancer cells, testing under what conditions they multiplied (in the presence of estrogen), and under what conditions they did not (in the absence of estrogen). Suddenly both the control and the experimental cells began wildly proliferating. They assumed that they had made a mistake and contaminated their lab, so they absorbed the expense of throwing that batch away and starting over. Again, all of the cells proliferated as if they were in the presence of estrogen (Soto et al.).

They suspected that the problem was with the test tubes, but the manufacturer at first refused to answer their questions. After a great deal of wasted time and lab supplies, they discovered that the culprit was an estrogen-mimic, nonylphenol, that had been added to their polystyrene test tubes. Corning had been receiving complaints that their centrifuge tubes were brittle. In response, they tinkered with the chemical composition of the tubes. They did not notify their customers. This of course raised concerns for the researchers. Could nonylphenol cause the same sort of breast cancer cell proliferation in humans that it could *in vitro*?

However, nonylphenol continues to be a common additive in polystyrene and in PVC -- even in products intended for use in food-processing and food-packaging. Alkylphenols (the broad class of chemicals that includes nonylphenols) leach into water that flows through PVC tubing. Some polyethylene is also manufactured with alkylphenols. The breakdown products of the spermicide nonoxynyl-9 include nonylphenol. which it thought to be taken up by the permeable mucus membrane of the vagina ("Endocrine Disruptors"). Yet, unlike the now commonplace "BPA-free" labels, we do not see products labeled "alkylphenol-free."

History has a way of repeating itself. In 2008, while trying to develop drugs to treat Parkinson's disease, Andrew Holt and his team had been using ammonium chloride to inhibit the activity of the *c-Abl* enzyme in brain cells. However, the polypropylene tubes that they used to transfer liquids were leaching oleamide and quaternary ammonium, which, as it turns out, were not only biologically active but were toxic to the brain cells in their petri dishes (McDonald et al., Mittelstaedt, Olivieri et al.) Just like ethylene, oleamide comes in natural and synthetic forms. A natural version of oleamide is found in the cerebrospinal fluid of sleep-deprived animals, including humans. This endogenous oleamide induces sleep, part of a negative feedback loop. A synthetic version is used as an additive in polyvinyl chloride, low-density polyethylene, and polypropylene, where it is intended to function as a slip agent, a lubricant, or as a corrosion inhibitor. Quaternary amines (known as 'quats' for short) are synthetic neurotoxic biocides. Yet we continue to consume yogurt from polypropylene tubs, blissfully ignorant of whether or not these were added to each batch of polypropylene.

We are told, of course, that none of *our* exposures are dangerous, because the amounts we come into contact with are far below regulatory thresholds. However, as we will see in the following chapter, the dose does not always make the poison.

Teaching About Endocrine Disruption and Low-Dose Toxicology Using the Story of Plastics

Toxicology, as its name suggests, is the study of toxic chemicals: the effects that they may have on living organisms. This information is helpful in understanding and mitigating the risks that these substances pose. We will first examine one of the most basic tenants of the discipline, piece by piece.

1. Risk = Hazard x *Exposure*

Is exposure a choice? If so, is it a choice on the individual or on the societal level?

The first principle of toxicology is that in order for something to harm us, it must first find its way into our body. Much of risk management and quantitative risk assessment focus on estimating how much of a given substance we might come into contact with in various scenarios. These tools of analysis are much less useful when a substance is as ubiquitous as plastic.

Plastics are everywhere in the environment. Pieces of polystyrene have been found on remote ice floes in the Arctic Ocean (Doward), microplastic fibers litter seafloor sediment (Ling et al.), and tiny plastic particles are even in the air that we breathe (both indoors and outdoors) (Gasperi et al.). Even the steam rising from manhole covers may be a source of styrene particles (Teimouri Sendesi et al.). A toxicologist would not be concerned about any of this, until they were convinced that these plastics are also in our bodies.

The line of demarcation between our body and “the environment” is not as clear a boundary as we might expect. Some toxicologists make the case that plastics would pass through our digestive system, without being absorbed, and therefore would remain technically outside the body. Plastics that are tiny enough, however, that they can take the same path that nutrients do. Tiny PVC particles, between 5-100 microns, which are roughly the size of milled corn, passed easily through the gut into the bloodstream (Volkheimer). (For comparison, the threads comprising a spider’s web are 2-3 microns thick, and a human hair is roughly 600 microns.) From the digestive tract, they enter the circulatory system, and eventually may make their way into the cerebrospinal fluid, even crossing the blood-brain barrier (Mattson et al.). Nanoscale polystyrene beads cross the placenta (Wick et al.).

Most of the research along this line has been conducted by researchers in the employ of the pharmaceutical industry. This property of plastics is regularly exploited in order to deliver the active ingredients of our medications to the target organ before being metabolized (Hussain et al.). In 2004, a young man in the Boston area sought help at a fertility clinic because he and his wife were having difficulty conceiving. When his urine was tested, doctors discovered 17,000 parts per billion of dibutyl phthalate. That’s 100 times more dibutyl phthalate than has ever been recorded before in a human being, and double what the US EPA has deemed safe (Cone). The source: Asacol, an FDA-approved time-release medication that he had been taking as prescribed for an inflamed colon. The enteric coating contains dibutyl phthalate. So do the coatings of the drugs didanosine, omeprazole, and theophylline, among others (Betts).

This encapsulation technology is used not only to deliver medications, but also vitamins (Moskin). Polyethylene, polyamide (nylon), polyvinylpyrrolidone, polymethacrylate -- among other natural and synthetic materials -- may be used to manufacture "nutriceutical beadlets" that are added to food to enhance their nutritional profile.

Plastics are ubiquitous in our food as well as in our medications (Wallace et al.). Some polymers are direct additives and others indirect additives. (Table 1). Many are used in food processing in ways that are invisible to consumers and are not disclosed on food labels. For example, ion-exchange membranes consisting of polyethylene, polystyrene, and /or perfluorinated compounds are used to filter grapefruit juice and to purify water ("CFR").

Table 3: FDA-approved Polymeric Additives in Food.

Polymer	Purpose
vinyl chloride-vinylidene chloride copolymer[3]	a component of coating on fresh citrus fruits[4]
polyvinyl acetate, polyethylene, poly styrene-butadiene rubber, butyl rubber, and/or polyisobutylene.	permissible components of chewing gum[5]
polyethylene	a replacement for roughage in feedlot rations for finishing slaughter cattle[6], or as a protective coating for fresh avocados, bananas, beets, coconuts, eggplant, garlic, grapefruit, lemons, limes, mango, muskmelons, onions, oranges, papaya, peas (in pods), pineapple, plantain, pumpkin, rutabaga, squash (acorn), sweet potatoes, tangerines, turnips, watermelon, Brazil nuts, chestnuts, filberts, hazelnuts, pecans, and walnuts (all nuts in shells)[7]
polypropylene glycol, polyethylene glycol	defoaming agents used in beet sugar & yeast[8]
acrilonitrile copolymers and polyacrylamide	as a flocculent in the clarification of beet sugar juice and liquor or cane sugar juice and liquor or corn starch hydrolyzate[9]
methacrylic acid-divinyl benzene copolymer	a carrier for vitamin B12 in nutritional supplements[10]
polyacrylamide	the coating in gelatin capsules[11]
copolymer condensates of ethylene oxide and propylene oxide	as a solubilizing and stabilizing agent in flavor concentrates, in scald baths for poultry defeathering, as a foam control and rinse adjuvant in hog dehairing machine, or as a dough conditioner in yeast-leavened bakery products[12]
polyvinyl acetate	a diluent for color additive mixtures for drug use[13]

3 Note that another name for polyvinylidene chloride is Saran Wrap. In this case, however, the fruit is invisibly coated with the compound rather than being wrapped in a removable film.

4 "CFR - Code of Federal Regulations Title 21." Sec. 172.210. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=173&showFR=1&subpartNode=21:3.0.1.1.4.1%20(9/27/17). Accessed 2 Nov. 2017.

5 "CFR - Code of Federal Regulations Title 21." Sec. 172.615

6 "CFR - Code of Federal Regulations Title 21." Sec. 573.780

7 "CFR - Code of Federal Regulations Title 21." Sec. 172.260

8 "CFR - Code of Federal Regulations Title 21." Sec. 173.340

9 "CFR - Code of Federal Regulations Title 21." Sec. 173.5, Sec. 173.10

10 "CFR - Code of Federal Regulations Title 21."Sec. 172.775

11 "CFR - Code of Federal Regulations Title 21." Sec. 172.255

12 "CFR - Code of Federal Regulations Title 21." Sec. 172.808

Polyvinylpyrrolidone poly(2-vinylpyridine-co-styrene)	a coating for cattle feed[14]

Plastics used in food packaging are considered *indirect* additives. Tea bags are often made of plastic (Orci). Even bottled water that is sold in glass may be contaminated with chemicals that leached from the plastic processing equipment in the factory (Wagner and Oehlmann).

In the animal husbandry literature, we find a warning that boar semen samples packaged in a multilayer plastic bag resulted in “high levels of reproductive failure" (Nerin et al). The suspected culprit is the polyurethane adhesive between the layers of the bag. The adhesive contained octyl phthalate, 13- docosenamide (erucamide), and BADGE (bisphenol A diglycidyl ether) as well as two unknown compounds that appeared to be cyclic phthalates. The authors note that, “boar spermatozoa are frequently used as biosensors for detecting toxic substances (Andersson et al.)” This is of interest to public health because the same materials are used for packaging food for human consumption (“Cross-linked Polyurethanes”).

"Plasticulture" (the use of plastic in agriculture) may constitute another type of indirect plastic contamination. Microplastics may be added to soil to promote aeration (alternatively, earthworms could be recruited for this purpose). Some growers now use artificial soil, which may be a blend of gel-coated "foam plastic fragments" or "thermoplastic resin foamed particles." (Mankiewicz; Suzuki and Azuma) Some growers

[13] “CFR - Code of Federal Regulations Title 21.” Sec. 172.615, Sec. 73.1
[14] “CFR - Code of Federal Regulations Title 21.” Sec. 573.870

steam their soil before planting. One paper notes that this causes the polystyrene in artificial or enhanced soil to melt to 10% of its original volume and recommends that the soil be steamed prior to mixing in the plastic (Matkin). Studies demonstrate that heat accelerates the leaching of toxicants from plastics, but to my knowledge, studies have not been conducted to determine what leaches into soil from steaming polystyrene fragments[15].

Irrigation pipes, pond liners, and many other pieces of the agricultural infrastructure rely on plastics. Thin polyethylene sheets, used as mulch to prevent weeds from sprouting, cover 49 million acres of agricultural land in China (Shuping and Wills). In the United States, 130,000 tons of mulch film were used in 2004, and that number has been rising every year (Kasirajan and Ngouajio). Some of this may be reused from season to season, while other types are designed to disintegrate (Kasirajan and Ngouajio). However, the pieces are no less toxic than they were before disintegration; they are merely smaller and easier to ingest, and have an increased surface area to potentially adsorb lipophilic contaminants, such as pesticides.

Not all of the plastics in foods are there legally. In China, some unscrupulous manufacturers of baby formula and milk were found to be watering down their product and then spiking it with melamine, which served to blind the quality assurance tests to the low level of natural protein. However, melamine does not function in the body as a

[15] Endocrine disruption happens in plants as well, because hormonal signaling is conserved across species. Our estrogen receptors respond to the hormonal signals that plants send (phytoestrogens), and likewise plants are affected by the pharmaceutical and industrial estrogens that we release into their environment. BPA, for example, interferes with the communication between rhizobial bacteria and the host plant, which can inhibit their ability to fix nitrogen. This raises the question of whether this alters the plants' nutritional composition, or whether any of the contaminants are taken up into the parts of the plants that are used for food.

natural protein would. Instead, it tends to cause kidney disease.

Some Chinese vendors describe openly how they increase their profit margin by passing off ersatz eggs (Boehler). While melted plastic is still a thick liquid, before it cools and hardens, they mix it with starch, coagulant, pigments, sodium alginate (a derivative of brown algae), paraffin wax, gypsum powder and calcium carbonate. The final product has a realistic-looking shell that cracks open to reveal what appears to be a typical yolk and egg white. The key to detection, consumers are told, is that a plastic egg yolk quickly breaks. Sadly, this is not a reliable screening tool since real egg yolks may do this too.

Rice was another target of entrepreneurial ingenuity (Ayitey). A video demonstrates the process of extruding sheets of polyethylene to resemble grains of rice. The plastic "rice" is mixed with actual rice (to make it harder to detect) and exported. The author warns that, at this time, neither government inspectors nor consumers have any way to distinguish the counterfeit from the real rice.

Unintentional contamination is yet another problem. Researchers found microplastic contamination in all of the samples of beer that they analyzed (Liebezeit and Liebezeit "Synthetic Particles"), which they speculate may have been shed from workers' synthetic clothing. Another possibility is that the process used tap water that was already contaminated. A recent study supports this, finding plastic fibers in over 80% of tap water samples taken from five continents (Tyree and Morrison). Honey (Liebezeit and Liebezeit “Non-pollen Particulates”, Mühlschlegel et al.), sea salt, lake salt, and rock salt (Yang et al.) sold in supermarkets have been found to be contaminated with microplastics, including fibers of polyethylene terephthalate (the plastic used to make disposable water bottles and fleece), polyethylene (which is used to make plastic shopping bags), and cellophane (a biobased plastic film).

Avoiding Exposure: Case Study #1

Bisphenol-A (BPA) was originally designed to be a medicinal synthetic estrogen, though it was never marketed for that purpose. Its prototype spent decades on a shelf, this history largely forgotten, until chemists polymerized it and rescued it from obscurity. The resulting polycarbonate became a popular substitute for glass, in everything from food packaging to corrective lenses to labware.

The estrogenic property of BPA was accidentally rediscovered in 1993 when researchers at Stanford University noticed that something in their plastic lab equipment was causing all of their yeast-based estrogenicity assays to come out positive -- even the negative controls. It turns out that this effect increased after they put their polycarbonate flasks in an autoclave, which exposes them to high heat and pressure (Krishnan et al.).

In 1998, Patricia Hunt was exploring the causes of meiotic aneuploidy (an incorrect number of chromosomes because of errors during meiosis) in female mice. A technician in her lab used a highly alkaline detergent to wash the cages and water bottles. The polycarbonate was damaged, and the bonds between the links in the chains of BPA weakened. Bits of free BPA broke away from the chain and into the mice's drinking water (Hunt et al.). Although at the time this was not known, BPA can also be absorbed through the skin of mammals (Zalko et al.). Perhaps some of the BPA transferred from the plastic cages into the bloodstream of the mice as they rubbed against the walls of their enclosures to scratch an itch or relieve boredom. The rates of chromosomal abnormalities in the eggs of exposed mice jumped from 1-2% to around 40% (Cohen).

After Patricia Hunt and her colleagues published their story, a flurry of research followed. Le et al. (2008) established that "Bisphenol A *is* released from polycarbonate drinking bottles and mimics the neurotoxic actions of estrogen in developing cerebellar neurons." Sandra Biedermann-Brem found that even baby bottles washed at home in the dishwasher leached BPA, though controversy ensued as to whether these amounts were high enough to warrant concern (Biedermann-Brem et al., Simoneau et al.). Oberlie (2007) found that the presence of certain microbes on the surface of polycarbonate increased the rate of leaching. Viñas (2010) looked into techniques for measuring trace levels of migration of BPA from the lining of food cans, while Mercea (2009) analyzed the physical and chemical conditions under which leaching was maximized. As expected, heat and extreme pH (as well as ozone) promoted leaching.

If BPA was leaching, how much was finding its way into people's bodies? Mariscal-Arcas et al. (2009) measured BPA in the urine of pregnant women in Spain, which correlated positively with their use of canned foods. Natalie von Goetz (2010) found that the use of canned food and polycarbonate baby bottles increased BPA levels in consumers (Bilbrey). Researchers at the Silent Spring Institute in Newton, Massachusetts decided to test this. They found five families willing to eat exclusively fresh foods without any plastic packaging for three days. The levels of BPA in the participants' urine samples decreased significantly (but did not completely disappear) during the intervention, and then returned to pre-intervention levels when the families resumed eating packaged foods (Rudell). Soon, however, another route of exposure to BPA took center stage: we are absorbing BPA each time we touch cash register receipts (Braun et al.).

BPA has since been linked to a wide variety of ill effects in both humans and in lab animals. These range from metabolic syndrome, obesity, heart and liver disease, breast cancer, early onset of puberty, ADHD, and infertility to increased susceptibility to methamphetamine addiction and diminished maternal instincts. The strength of evidence for each of these claims varies, but many consumers would like to take a precautionary approach and opt for “BPA-free.” However, often manufacturers will neither confirm nor deny that their plastic contains endocrine disrupting compounds. In other cases, information is provided, but in code.

As mentioned previously, the resin code (a number 1-7 in a chasing arrows triangle) stamped on the bottom of commodity plastic items indicates which monomer (chemical building block) was linked into long repeated chains to form that plastic. It may be vinyl chloride (#3), styrene (#6), propylene (#5), or it might be one of several ethylene-based plastics (#1,2,4). Some may wish to avoid vinyl chloride and styrene as well because of the health risks that their manufacture entails for the workers, or out of concern that the residual monomer could leach and expose them. Our hypothetical BPA-averse shopper would know that a resin code of 7, however, simply translates as “other,” a catch-all category that includes not only BPA- based polycarbonate but also bio-based plastics such as polylactic acid, or PLA. Other uses of BPA, such as thermal receipt paper and the epoxy lining of food and beverage cans and even on the underside of lids for glass jars, are not labeled. And BPA, even when not used as the monomer, might make an appearance as an additive, either in its plain form, or joined to a bromine (TBBPA, or tetrabromobisphenol-A). It is intended to act as a flame retardant in various plastics, most often in PVC. Thus, a product that is not polycarbonate may or may not contain BPA anyway, if it was used as an additive.

BPA has even been found in fresh produce grown in a greenhouse built with polycarbonate panels, that may have off-gassed BPA when exposed to direct sunlight for prolonged periods ("Blissfully Unaware"). Eight out of fourteen fresh vegetables on an Italian farm, for example, contained 250-1000 ng/g of BPA even though the food had not had any direct contact with plastic (Vivacqua et al.). One author reports, "The amount of BPA found in fresh food was...in the same range as potential migration levels from microwaving polycarbonate containers. What is significant is the indication that even fresh food that had no direct contact with BPA may still contain it."

To complicate matters further, products marked "BPA-free" may contain BPA's first cousin, bisphenol-S (BPS). BPS is not as well-studied as is BPA, but from the research that has been done, it does not appear to be any safer (Rochester and Bolden).

Consumer demand is pushing for increased transparency. As one response, George Bittner, a professor of neuroscience at the University of Texas, Austin, founded a lab that has begun screening plastics for estrogenic activity (EA) for a fee, allowing companies to label their products as "free of estrogenic activity." While this is certainly valuable information, we cannot conclude that a plastic is safe because of the absence of EA. It could still have androgenic activity (meaning that it could interfere with testosterone signaling). It could still interfere with insulin, thyroid hormones, or any number of other signaling mechanisms in the body.

Questions for Discussion

Do market-based solutions, such as Bitner's lab's services and the proliferation of BPA-free plastics that substitute one toxicant for another, adequately protect consumers, or do they provide a sense of false security (for private profit)? Could the market be better regulated in order to achieve consumer protection? Or do solutions lie outside the market?

Avoiding Exposure: Case Study #2

The late Dr. Earle Bartley of the Department of Animal Sciences at Kansas State University experimented with plastic cattle feed. His first mixture was 80-90% polyethylene and 10-20% polypropylene. One problem with the prototype was that the cows could detect it and consistently chose to eat around it. He reportedly attributed the cows' "avoidance behavior" to the slippery quality of the plastic. After he changed the shape of the pellets, he had more luck. Instead of eating four pounds of hay a day, his cows ate one-tenth of a pound of plastic, at a considerable cost savings. The indigestible but thoroughly masticated shreds of plastic floated at the top of the cows' rumen. Carbon-14 tracing did not detect any of the plastic itself in the cow’s bloodstream. At slaughter, he boasted that “about twenty pounds” of the pellet shreds could be "recovered, melted, recycled, and reintroduced into another animal (Schell). The license for this work was transferred to Ralston-Purina by Exxon, which had provided funding.

Other researchers have tried feeding livestock various forms of polyethylene pellets (Welch) and polypropylene ribbons (White and Reynolds). Some hit upon an even cheaper solution: implant regular plastic sponges and "pot scrubbers" (Loerch) directly into the cows' stomachs. As the sponges and scrubbers absorb liquid and expand, they create a feeling of fullness and save on feed costs, perhaps reducing greenhouse gas emissions as well (Christophersen et al.). Whetsell, Prigge and Nestor published a paper explaining that when they filled a cow's rumen with seventy-five tennis balls, the cow's appetite decreased (Whetsell et al.).

Although it is unclear how widespread the use of plastic in cattle feed is, ongoing use of polyethylene cattle feed was mentioned in the public health literature as recently as 2007 (Sapkota et al.), and as the article describes, this is but one example among many questionable practices in industrial feedlots.

Questions for Discussion

How would a consumer who eats meat source animals raised without plastic roughage? What constraints might limit consumers' choices?

Avoiding Exposure: Case Study #3

A two-pound premature infant receiving standard care in the NICU (neonatal intensive care unit) absorbs as much as 160,000 times more DEHP (one type of phthalate, a plasticizer used to make PVC flexible) than is considered safe for the liver

(Mallow and Fox). DEHP is known to be an endocrine disruptor and probable carcinogen ("ATSDR - ToxFAQs"). Polyvinyl chloride is used to make IV tubing, blood bags, oxygen cannulas, umbilical vessel catheters, peripherally inserted central catheter (PICC) lines, and a variety of other medical equipment ("PVC and DEHP"). It is also commonly used in homes and hospitals as flooring, shower curtains, and windows. How does health care differ from other types of consumer purchases? How would you regulate medical exposures to plastics?

Questions for Discussion

1. Given that plastics are ubiquitous and often invisible, how can consumers avoid exposure? Are public health messages such as "avoid microwaving food in plastic" and "avoid washing plastic kitchenware in hot water or in harsh detergents" helpful or harmful? (Do they give consumers who follow them a false sense of security that they can eliminate or limit their exposure through individual behavioral changes alone, without structural / regulatory changes?)

2. What regulatory measures (requiring labeling, enacting bans) are called for? Are the regulatory measures already in place working? Why or why not? Use the FDA rules on food additives as a place to start.

3. Is a focus on "consumers" sufficiently protective? Whose exposures would be unaddressed by these measures?

2. **Risk = *Hazard* x Exposure**

The potential of a substance to harm a living organism was thought to be largely a function of the dose, and of how it moves through the body (this is referred to as toxicokinetics). Substances that are persistent and bioaccumulative were thought to be more dangerous than substances that the body could quickly break down and excrete. Endocrine disruptors challenge both of these assumptions.

Hormones act as messengers. Think of Pheidippides, the courier who ran nearly 26 miles from Marathon to Athens to deliver news of the Greek victory against the Persians. The poor lad delivered his message, “Rejoice! Victory is ours!” with his last breath. Though he did not live to see it, his words set events in motion that, according to the poets, shaped the history of the Western world. Once a message has been delivered (or an alarm silenced), the story is just beginning. So with our hormones. Bispheol-A, the chemical we discussed in a case study in the last unit, has a half-life of less than six hours (*Bisphenol A Metabolism*). However, within that brief time of residency in the body, it can send messages that will have repercussions for possibly generations to come.

These messengers may impersonate or thwart natural signals to the brain, pancreas, or adrenal glands, in addition to estrogen, androgen, and thyroid hormones. These signals can disrupt reproductive development, interfere with appetite regulation, shift metabolism, and much more.

Lag Time

One of the nine principles for determining causality in public health research that epidemiologist Bradford Hill articulated in 1965 is that exposure precedes effect (Fedak et al.). The more consistently and the sooner the effect follows the cause, the easier it is for observers to make the connection. When Morgan Spurlock decided to eat nothing but McDonald's for one month, he consumed twice the recommended calories for his size and activity level, and he suffered an immediate and visible decline in his health (*Supersize Me!*).

It is well-established that certain medications, such as some anti-depressants and anti- seizure drugs, cause weight gain. When we perceive an increase in body mass soon after the patient begins taking the medication, attributing the effect to the cause is a relatively simple matter. The patient can be queried to find out if their appetite has increased, or if they are feeling lethargic and getting less exercise. Laboratory studies can be designed to determine by which pathway the drug is affecting weight, and in some cases the pharmaceutical researchers can tweak the design of their molecule to prevent this side effect.

With environmental endocrine disruptors, however, the lag time may be so long that we do not make the connection. Our metabolism seems to be most vulnerable to obesogenic insults before birth. The Developmental Origins of Health and Disease hypothesis has described how children born to women who endured starvation while pregnant during the "Hunger Winter" in Holland, though underweight at birth, tended to become obese adults (Schulz). Similarly, mice and rats exposed to a certain dose of an obesogen like DES in utero grew to be two or three times the size of their unexposed peers, despite being fed the same number of calories (Newbold et al.).

In the same way that we don't necessarily see an immediate adverse effect after an EDC exposure, we also don't necessarily see an immediate improvement in a person's health after a reduction in EDC exposure. Thus, the pseudo-scientific diet books that I have seen that encourage readers to reduce their contact with certain chemicals in order to see short-term weight loss are bound to fail. The reason for this can be understood through a metaphor. If a mail carrier delivers a letter with bad news, you won't return to your previous emotional state once the USPS truck has driven away. You might have read the letter and begun taking action to mitigate the situation. In the same way, hormones are the body's messengers. Once they have delivered their news, they set into motion a chain of events that will continue whether or not the hormone (or hormone mimic) disappears.

Mixture Effects

No one is exposed to only one toxicant at a time. Scientists now speak of the "exposome" -- the universe of physical, chemical, and biological conditions that an individual encounters[16]. To give a simple example, the obesogenic endocrine disruptor bisphenol-A can be absorbed through the skin. Touching a thermal receipt is one way that we come into contact with BPA. A person who has just applied a hand lotion is likely to absorb more BPA than someone whose skin is dry. The reason would be that the dermal penetration enhancing ingredients in the lotion not only allow the body to absorb more moisturizer, but also more BPA. Since we are, for the most part, unaware of what we are exposed to, (let alone able to quantify these exposures), we have no way to untangle the web of connections among them.

Individual Variations in Susceptibility

Scientists are trained to look for consistency. This makes sense, of course, on an

[16] https://www.cdc.gov/niosh/topics/exposome/default.html

intuitive level. We do this, too, when we look for exceptions to the rule to justify our risk-taking. I've heard people use anecdotes like, "My grandfather smoked for sixty years and he didn't get lung cancer, he lived to a ripe old age," to downplay the very real harm that smoking causes. Not only is it true that each person has a unique set of exposures, it is also true that each person responds differently.

Imagine we could create a computer program that could model not just risk for a population, but for you as an individual. Let's pretend we could make it cost-effective to type your complete genome (the genes with which you were born), epigenome (the pattern of expression of these genes), and the microbiome (the community of tiny organisms that colonize our bodies and which perform a variety of life-sustaining functions). Then, let's pretend that we know what you were exposed to from conception until this moment -- the precise doses and timing. And let's imagine that we had psychometric data on your mental and emotional health. This sort of information would be necessary to claim that you are making informed choices about your health.

Widely accepted ways to boost resilience include nutritional interventions (having an adequate calcium and iron intake, for example, reduces the amount of lead that is absorbed by the body) (Klauder and Petering). What this means is that when we are lonely and depressed, we are more vulnerable to a toxic exposure than when we are feeling connected to others and optimistic about our future. Research suggests that laughter really is medicinal (Bennett and Lengacher), and that the chemicals our bodies make after an orgasm can boost our immune function (Ellison Rodgers).

Individual variations in susceptibility mean not only that risk varies from person to person, but that even the risk for a given individual changes over time. Vulnerability is at its peak during prenatal development and in early childhood, falls after adolescence, and then rises again somewhat in the twilight years. Even over the course of a day, the impact an exposure has will vary. The same dose of a medicine, for example, given in the morning, might have very different effects on the body than it would if the same dose were taken at night. We are learning that interrupting the light-dark cycles (particularly with exposure to blue light at night) adversely affects our body's metabolism, even altering the detoxification enzymes that our liver produces (Sharma et al.). Disruption of the circadian rhythm has been linked to an increased risk of diabetes, obesity, and certain types of cancer, among other problems.

Route of Exposure and Type of Dose

Dose is not just about how much of a substance the body takes in, but to the timing of the delivery. For example, the medicine Lupron, given once a month, halts puberty that has begun too soon. The chemical composition of the drug, however, is nearly identical to the natural hormones that the body secretes in hourly pulses to *start* puberty.

For some substances, the route of exposure matters. Mercury, an example we will come back to in much more detail in the Pilot Study section, provides a great illustration of this principle. Elemental mercury -- the silver goo that children used to play with when an old-fashioned thermometer broke -- is unlikely to cause serious acute harm when touched or even when swallowed. However, if it is inhaled, it is quite dangerous.

It isn't always obvious how a particular chemical is entering our body. I remember a real estate agent responding dismissively to my questions about lead paint, "Well, you aren't planning to eat it, are you?" There are adults who eat paint chips (*pica* is the term for a craving for substances that are not generally considered food, such as dirt or chalk or ice). What is in the dust that we unwittingly eat all the time? Researchers from the Silent Spring Institute tested household dust and found up to forty-five toxic chemicals, ten of which were present in at least 90% of their samples (Mitro et al.). What is known as hand-to-mouth behavior (a behavior at which toddlers excel)?

A chemical spill in West Virginia contaminated a river with crude 4-methylcyclohexanemethanol. Risk assessments showed that people should be safe at the levels at which they were exposed by drinking their tap water. However, many people were reporting symptoms. They mystery was solved when the risk assessors realized that they had forgotten to account for the fact that people were also *breathing* a volatilized form of the chemical, and absorbing it through their skin, when they showered.

When dieticians evaluate food intake, they do not account for the polyfluoroalkyl phosphate esters from the wrapping "paper" that migrates into food or the bisphenol-A that leaches into soft drinks from the lining of the cans, depending on the pH of the foodstuff, on the temperature at which it was packaged and stored, exposure to sunlight, time, and so many other factors. Our risk assessments are incomplete.

Case Study: Unanticipated Environmental Interactions

Trenbolone acetate, a synthetic anabolic steroid, is used to make cattle gain weight more quickly. Though banned in the EU, this drug is administered to over 20 million cattle a year in the United States. They metabolize and excrete it as 17α-trenbolone. Because 17α-trenbolone can harm fish at very low doses, scientists wanted to understand what happens when the manure of treated cows enters streams. When they sampled the streams during the day, they found that the 17α-trenbolone quickly broke down in sunlight. They thought that was the end of the story, packed up, and went home. In 2013, however, researchers from the University of Iowa accidentally discovered that at night, the molecular pieces were reassembling themselves (Peplow). It turns out that other chemicals with a similar structure can perform the same trick, with the rate of reassembly determined in part by the pH and temperature of the water.

Other unanticipated environmental interactions can lead to unexpected risk. For example, when ozone touches human skin, it reacts with squalene (an oily antioxidant that protects our skin from chemical damage) to form volatile compounds, one of which is 4-oxopentanal (Biello). 4- Oxopentanal bears an unfortunate structural similarity to diacetyl. -- a component of artificial butter flavor. It doesn't seem to be a problem when we eat it, but inhaling enough of its seductive, buttery aroma can cause irreversible lung damage. The condition, bronchiolitis obliterans, is commonly referred to now as "popcorn lung," named for the highly exposed workers in the flavor mixing room of a Jasper, Missouri, popcorn plant whose misfortune lead to its discovery.[17]

Even the most sophisticated computers could not begin to predict all of the possible interactions of even one compound with all of the other natural and synthetic substances it could encounter in the environment, and the "uncertainty factors"

[17] https://www.cdc.gov/niosh/topics/flavorings/

assigned in quantitative risk assessments underestimate our knowledge gaps.

Case Study: Chemical Mixtures in Sarnia

The 12-km^2 (4.6 $mile^2$) Sarnia 45 Indian Reserve, home of the Aamjiwnaang (Chippewa) First Nation, is located on the banks of the St. Clair River, near Lake Huron in the province of Ontario. The area was designated by treaty as a reservation in 1827 ("Aamjiwnaang First Nation"). In 1858, settlers realized that the substance that the Aamjiwnaang people had long been using to waterproof their canoes was oil. First the settlers eagerly exploited the gum beds, and then thirty-eight kilometers (twenty-five miles) southeast, drilled North America's first oil wells. Towns with names like Petrolia and Oil City grew rapidly. Soon after, companies that use oil as a feedstock moved in, and Sarnia and the surrounding land became known as Chemical Valley. Today, approximately 40% of Canada's chemical industry, including over sixty plastics and pesticide manufacturers and petrochemical refineries surround the Aamjiwnaang (Hoover et al.).

All of these processes generate solid, liquid, and airborne toxic waste, much of which remains in Sarnia. A company with the anodyne name Clean Harbors Environmental Services currently incinerates and landfills hazardous waste on site. In 1958, Imperial Oil began using Sarnia's salt caverns to store their chemical-laden "brine" (also known as "produced water," this is the fluid left over after the oil has been extracted) (Kent et al). Later, manufacturers began injecting other industrial wastes into the caverns. However, the waste has a proclivity to seep back up to the surface. In 2012, for example, Sarnia's Centennial Park was forced to close when park users noticed "a black, tar-like substance of unknown origin[18]" on the ground. Environmental tests documented unsafe levels of lead, asbestos, and hydrocarbons in the park's soil and grass, which necessitated the demolition of some of the park's infrastructure.

Another site where the toxic byproducts of the petrochemical economy are sequestered is in the bodies of the Aamjiwnaang residents. Biomonitoring studies conducted in 2006 by Environmental Defense Canada found in the blood and urine of the one Aamjiwnaang resident 61 of the 68 toxic chemicals of concern. Her body burden was the highest measured anywhere in Canada.

The true toll that this is taking on the health of the Aamjiwnaang nation is impossible to tally. The government demurs that the necessary studies would be expensive and time-consuming, and that the tools of science are blunt. It is nearly impossible to prove that any given illness is caused by a given exposure. However, health disparities have been documented:

- Women in Chemical Valley were 3.11 times more likely to be hospitalized than other Ontario residents. Men were 2.83 times more likely to require hospitalization. (1996) Cardiovascular and respiratory complaints, which are thought to be pollution related, accounted for many hospital admissions (Fung et al.).
- About 40% of Aamjiwnaang residents use an inhaler. The prevalence of asthma is 17% among adults and 22% among children (MacDonald and Rang). (In the rest of Canada, the rate is 8.5% for adults [Garner and Kohen] and 13% for children [Millar and Gerry])

[18] the environmental assessment (direct quote)

- The ratio of male births declined over the period 1984–1992 from > 0.5 to about 0.3 (Mackenzie et al.)
- Thirty-nine percent of Aamjiwnaang women experience miscarriages or stillbirths, compared to the Canadian average of 25 percent
- Twenty-three percent of Aamjiwnaang children have learning disabilities compared to 4 percent of the general Canadian population ("Aamjiwnaang First Nation").

The surface water in Sarnia is so contaminated that residents are warned not to even touch it, let alone drink it, fish, or swim. The salt caverns leach industrial waste and brine into the groundwater, seeping into many of the wells that had been used for drinking water. The salt caverns are leaking, it's hard to predict just when and how much and in what direction the plume will flow. Just like the gooey tar balls that surfaced suddenly at the park, a drinking well might test potable one day and then be ruined the next.

Case Study: Developmental Origins of Health and Disease (DOHAD)

Consumer advocacy groups have lobbied strenuously for limits on certain plastics (particularly those containing BPA and phthalates) in products designed for babies. While infancy and early childhood *are* vulnerable periods, intervening after birth may already be too late. As the thalidomide tragedy demonstrated, it is very challenging to design tests to assure the safety of chemical exposures in pregnant women. Some children born to mothers who had taken thalidomide as prescribed for morning sickness were perfectly healthy. Others were born without arms, or without legs. The difference? It was not the dose that mattered in this case. It was the timing. All of the problems occurred when the drug was used between post-conception day 21 and 36. This two-week period is known as a *critical window.* The problem is that we only recognize critical windows in hindsight.

There is an idea that the health of an adult is determined, not merely by the choices that they make in adulthood (to smoke or not, to exercise or not, to drink or not), but by what transpired while they were in the womb. This theory is called DOHaD: Developmental Origin of Health and Disease. Again, the lesson was learned from tragedy. Women who had taken a form of synthetic estrogen called diethylstilbestrol (DES) during pregnancy did not immediately show any clinical evidence of harm, nor did their babies. However, when their daughters attained puberty, many of them developed a rare form of cancer: vaginal clear cell adinocarcinoma (Reed and Fenton). Further investigation revealed that the problems were not limited to the daughters. Sons had unusual health risks as well, which were not apparent until they reached early adulthood[19].

These sorts of delayed adverse responses are not limited to DES; however, data are incomplete. Retrospective studies that aim to characterize exposures during pregnancy are rife with recall bias and other challenges. The National Children's Study was designed to collect biological evidence from pregnant women (such as blood and urine samples) and then to correlate in utero exposures with health outcomes for their offspring in adulthood. Unfortunately, funding for this project was not sustained[20].

Evidence suggests that some monomers and additives used in plastics, particularly BPA, are developmental toxicants. We do not know exactly when the critical

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[19] https://www.cdc.gov/des/consumers/about/effects_sons.html accessed 11/10/2017
[20] https://www.nichd.nih.gov/research/NCS/Pages/default.aspx

windows are, but early first trimester is a sensitive time for the developing central nervous system, for male and female reproductive systems, the endocrine system, and the immune system, among other endpoints[21]. Some work has been done on characterizing the effects of BPA exposure in the second trimester, but to date no studies were undertaken during the third trimester[22]. Another challenge is that toxicology studies are designed to answer questions about one specific endpoint or one body system at a time. In the case of BPA, with effects as varied as weakened tooth enamel ("Exposure to Chemicals in Plastic") and increased susceptibility to addictions as an adult (Suzuki et al.), it is not possible to predict what might be in store for children exposed in utero.

How does this translate into policy? Since harm to future generations may begin with preconception exposures (Grandjean et al.), via epigenetic alterations transmitted through either the mother's egg or the father's sperm, *all* people who might someday procreate must be protected.

Thus far, we have been examining how the use of plastics has a direct impact on human health in consumers. The health impacts are more pronounced in resin synthesis and plastic fabrication workers, who tend to be exposed to high doses over long periods of time, and in those who handle plastics that have been discarded. Burning e-waste to reclaim marketable metals, for example, exposes the worker to the toxic fumes of burning plastics. As the next chapter will explore, however, even plastics that are not burned may have widespread environmental consequences after disposal

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[21] https://endocrinedisruption.org/interactive-tools/critical-windows-of-development/view-the-timeline/ accessed 9/28/17

[22] Ibid.

that lead to another form of indirect harm to human health.

Plastic Marine Debris as a Public Health Problem

I. Abundance

Only a decade ago, Captain Charles Moore, founder of the Algalita Marine Research Foundation (AMRF), raised concerns about the plastic trash floating in the North Pacific gyre. In 1999, Captain Moore and his crew ascertained that the ratio of plastic debris to plankton (by dry weight) in a certain area of the Pacific was 6:1 (Moore, C.J. et al.). Preliminary calculations from the 2007 voyage indicate that the ratio is now 50:1[23]. Samples taken by other research teams have corroborated his findings (Snowden and Fanshawe; Browne et al. 2009). Browne observed that the increase in the amount of plastic microdebris (< 1 mm) in the water column over the past forty years closely parallels the increase in global plastic production.

According to the United Nations Environment Program, there are now about 46,000 pieces of plastic litter per square mile (13,000 pieces in every square kilometer) of ocean surface, and this is not confined to the gyres (Gjerde). There are an estimated 51 trillion pieces of microplastic in the world's oceans, according to the United Nations, and each year we add eight million metric tons more ("'Turn the Tide on Plastics'"). In a 2011 study, every sample the crew took from the Antarctic Ocean contained between 956 and 42,826 pieces of plastic per kilometer squared. Sixty-three percent of samples taken from the Arctic Ocean in 2013 contained microplastics (excluding fibers and particles smaller than 0.5 mm)(Cózar et al.). All of this is indicative only of the surface of the seas. Since the US EPA estimates that 54% of manufactured plastic sinks, and since even plastic that is lighter than water will sink once fouling organisms colonize it,

23 Eriksen and C.J. Moore, personal communication.

there is a strong likelihood that even more plastic is collecting deeper in the water column. Five Gyres scientist Marcus Erikson concurs: "Recent studies show widespread occurrence of these microplastics throughout the vertical column and in benthic and coastal sediments. It is likely that sedimentation is the ultimate fate for plastic lost at sea" (Eriksen et al.).

II. Sources

What are the sources of this plastic? Derelict fishing gear, cargo lost from the decks of ships in storms or in shipwrecks, and other sea-based discharges contribute to the problem. According to one estimate, 639,000 plastic cargo containers fall into the sea each *day (*Derriak). However, 80% of plastic in the ocean can be traced to land-based discharges (UNEP "Marine Litter"). As consumers use more plastic, more finds its way to the oceans. Intentional littering accounts for a proportion of that. In the last 10 years, plastic drink bottle litter has increased by 67%, plastic bags by 54% and cigarette butts by 44% (Snowden and Fanshawe). In some cases, garbage is deliberately introduced in order to create habitat. Discarded automobile tires, along with scuttled ships and retired subway cars, are used to create "artificial reefs." Involuntary land-based releases are often more dramatic, however.

Storm events in coastal areas, such as Hurricanes Katrina and Rita, have been shown to mobilize a significant burden of plastic debris. The National Oceanic and Atmospheric Administration (NOAA)'s Gulf of Mexico Marine Debris Project[24] is attempting to survey the region to map submerged objects. It is clear from the website that this is an ambitious and resource-intensive undertaking. Coastal debris surveys are

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[24] http://gulfofmexico.marinedebris.noaa.gov

much more common. NOAA's National Environmental Satellite, Data, and Information Service tracked the debris swept into the Pacific by the March 2011 tsunami in Japan.

In a recent survey of United Kingdom beaches, the Marine Conservation Society found that over half of all beach litter was plastic: wrappers, caps and lids, Q-Tip sticks, cigarette butts (the filters are cellulose acetate, a type of plastic), fishing nets or rope, and tiny pieces of unidentified origin (Snowden and Fanshawe). In an interview with *Orion*, Richard Thompson, a marine biologist at the University of Plymouth, UK, estimated that 20% of what appeared to be sand on the beach in Plymouth, England is actually not fragmented rock but instead fragmented plastic. He immediately qualified that he believes the figure of 20% to be an underestimate (Weisman).

Thompson and his team studied archived samples of seawater that Sir Hardy had collected from the 1930s to the 1960s. They found that plastic began to appear in the water column in the 1960s, becoming increasingly prevalent thereafter. In the same interview with Weisman, Thompson said, "By the 1990s, the samples were flecked with triple the amount of acrylic, polyester, and crumbs of other synthetic polymers than had not been present three decades earlier."

To date, the highest recorded ratio of plastic to plankton (by dry weight) is 128:1. These samples were collected at the mouth of the San Gabriel River in 2000. Off northeastern Hawaii in 2000, a ratio of 112:1 was found (Derriak). The abundance of micro-plastics in the Central North Pacific has risen by a factor of 5 during the last decade, and off the coast of Japan by a factor of 10 every 2-3 years (Ogi). One study reported plastic debris stranded on shores as far north at Spitsbergen in the Arctic (Barnes and Milner).

Why can't we just clean up the plastic in the gyre? Think of how difficult it would be to gather confetti from along a stretch of beach. Now imagine that the area you are trying to clean is not only miles long but also miles deep. Remember that plastic debris occurs throughout the water column. Some of it floats, some of it has sunk to the sea floor, and some swirls below the surface. More trash is constantly being added. While some of the plastic debris is large enough to be scooped out, much of it consists of tiny plastic fragments. If we were to sieve out pieces that small, we would inevitably capture tiny fish and plankton as well. The by-catch would be impossible to sort without harming the marine life**.** Charles Moore likens the task to trying to empty a bathtub with a thimble while the faucet is still running[25]**.**

III. Ingestion and Transfer of Toxicants

Yet even as the abundance of plastics increases, there is a discrepancy between the volume of plastic known to be discharged into the environment and the amounts being measured at the ocean's surface. One explanation for the location of the missing plastic is the sea floor.

Another, more worrisome, hypothesis is that it is in the biota -- that is, it has been ingested and is trapped in the bodies of sea-dwellers large and small. Consumption of plastics has been documented in over 170 species of marine wildlife including cetaceans, turtles, birds, and fish (Snowden and Fanshawe). In laboratory experiments, Browne demonstrated that amphipods, lugworms, and barnacles ingest PVC (mean particle size 230 μm). Even coral has been found to trap microplastic in its digestive

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[25] http://www.algalita.org/mid-ocean-plastics-cleanup-schemes-too-little-too-late/

tract (Hall et al.)[26]. There is some suggestion that to coral, plastic "tastes" appealing, and that the coral prefers it to real food (Allen et al.).

AMRF is conducting a survey to quantify the ingestion of plastics at various trophic levels in the Pacific Ocean food web. Identification of the types of polymer resin pellets and post-consumer plastic fragments in albatross and lantern fish samples taken from the North Pacific gyre is ongoing, but the quantities are significant (Moore)[27]. In the stomach of one lantern fish (which is about six inches long) taken from the gyre, Christiana Boerger of AMRF found eighty-four distinct pieces of plastic (Moore)[28]. .

IV. Unanticipated Problems With Marine Plastics

One unanticipated public health problems is biological contamination. The plastic is readily colonized by invasive and sometimes pathogenic organisms whose reach is expanded beyond their previous limits. In what researchers call "the longest documented transoceanic survival and dispersal of coastal species by rafting (Carlton et al.)," 289 species floated to the US Pacific Northwest on debris from the Japanese tsunami. Much of the debris was plastic. The "Plastisphere," a term coined in 2013 by Erik R. Zettler, Tracy J. Mincer, and Linda A. Amaral-Zettler (Zettler et al.), may contain species of Vibrio that transmit cholera (Kirstein et al.; Oberbeckmann, et al.). The presence of plastic marine debris may also allow pathogens from fecal contamination to survive for longer periods of time, potentially endangering those swimming at recreational beaches (Quilliam et al.).

The concern that is receiving the most attention, however, is chemical transport.

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[26] Oysters exposed to polystyrene microparticles had fewer viable offspring (Sussarellu et al.).

[27] Moore, personal communication.

[28] Ibid.

There is evidence that plastic debris attracts persistent organic chemicals to itself, concentrating them at up to one million times the level in ambient seawater, and accelerating their biomagnification in the marine food web (Teuten; Mato). The greater the surface area of the plastic, the higher the concentration of adsorbed contaminants is likely to be.

Japanese scientist Yukie Mato and her team collected nurdles (pre-fabrication plastic resin pellets) by hand from three beaches and scooped floating nurdles from a canal using a stainless steel net. They sorted all of the nurdles by type of plastic, and picked out the polypropylene pellets. They measured the levels of DDE (a metabolite of DDT, an insecticide), polychlorinated biphenols (PCBs), and nonylphenol (NP) in the pellets. They learned that nurdles that had been in the ocean had soaked up so much of these chemicals that the amount in the nurdles was up to one million times higher than the amount in the seawater (the adsorption coefficient was 100,000 to 1,000,000) (Mato et al.). This is probably because the persistent organic pollutants (including the DDE, PCBs, and NP that Mato studied) are lipophilic (attracted to fat) and hydrophobic (averse to water). They are attracted to the chemical structure of the nurdles like metal to a magnet.

Mato and her team wondered if the nurdles might have had these contaminants in them before they fell into the ocean. To test this idea, they took new ("virgin") nurdles from a plastics factory and tested them. These nurdles did not contain DDE, PCBs, or NP. So, just to be sure, they put the new nurdles into a stainless steel basket (with a very fine mesh so none of them could escape) and dangled them in Tokyo Bay for six days. Then, they tested the nurdles again. Now, all of the nurdles had high concentrations of DDE, PCBs, and NP.

Table 4. Concentration of Contaminants in Polypropylene Nurdles

(from Mato et al. 2001)

	New Nurdles	After exposure to seawater			
		Kasai Seaside Park	Keihin Canal	Kugenuma Beach	Shioda Beach
∑ PCBs (ng/g)	<0.01	97.3	117	43.5	3.97
DDE (ng/g)	<0.002	2	3.1	1.6	0.16
NP (μg/g)	<6	16	8.9	12	0.13

Teuton and her colleagues also analyzed the process of how plastic resin powders soak up poisonous chemicals and how they release them into the food chain. They first studied how much phenanthrene (a hazardous polycyclic aromatic hydrocarbon that serves as a model for other POPs) each of three types of plastic could absorb from seawater. They analyzed whether adsorption varied with temperature and pressure. They found that polyethylene absorbed the most by far, but that all three types of plastic absorbed much more than did naturally-occurring sand and pebbles.

When they fed plastic bits contaminated with phenanthrene to lugworms (*Arenicola marina*), they found that adding even just 1 μg of polyethylene to a gram of sediment increased the amount of phenanthrene the lugworms accumulated dramatically. They concluded that consumption of plastics is a significant exposure pathway to persistent organic pollutants.

That a wide variety of biota are ingesting plastic marine debris is not in dispute. *All* of the crustaceans that Alan Jamieson and his team collected from the bottom of the

Mariana Trench -- 10,890 metres deep -- had eaten plastic (“Man-Made Fibres”). Photographs now capture images of tiny plastic particles scattered throughout the digestive tract of shrimp (Frith) and surveys of seafood in markets around the world find microplastics wherever they look (Moore). Numerous studies have shown that ingested plastic particles are deleterious to the health of marine life (Rochman et al. 2016). Nanoparticles of polystyrene dramatically impair reproduction of freshwater zooplankton and green algae (Besseling et al.). Larger polystyrene particles also impair the survival of marine copepod *Calanus helgolandicus* (Cole et al.). Marine worms' energy reserves dwindle when exposed to tiny particles of polyvinyl chloride (Wright et al.). Adaptive behavior may be affected, leaving prey more vulnerable to predation, as Culum Brown and his colleagues demonstrated in beachhoppers exposed to microplastics (Tosetto et al.). A study of demonstrates acetylcholinesterase inhibition, a neurotoxic effect, in goby (Oliveira et al.). The shape of the plastic may play a role in determining its impact, for reasons that are not yet fully understood (Gray et al.). While physical factors appear to be important, the blame may rest with the toxicants that come along with the plastics. Chelsea Rochman and her colleagues have established that ingested microplastic can transfer toxic chemicals into fish (Hoh et al.; Rochman et al. 2015).

Pilot Study: Adsorption of Methyl Mercury to Plastic in Seawater

Abstract

The propensity of plastic marine debris to adsorb persistent organic pollutants is well documented in the literature. However, to my knowledge, this is the first study to examine the interaction of mercury with synthetic polymers suspended in seawater. Mercaptan-containing plastics, including neoprene, and styrene-butadiene ABA block co-polymer, and post-consumer recycled automobile tire crumb intended for use as a playground surface, as well as polycarbonate pellets, were agitated in samples of seawater spiked with methyl mercury for a period of seventy-two hours. The mercaptan-containing plastics did adsorb the methyl mercury. The polycarbonate plastic, on the other hand, leached mercury. This works suggests the possibility that mercury may be transferred into the food web by plastic marine debris.

1. Introduction

Approximately 10% of the global burden of circulating mercury can be traced to natural processes: cinnabar (mercuric sulfide) washing from weathering rocks, and the venting of mercury in volcanic eruptions.[29] Human activities, however, particularly the combustion of fossil fuels and the use of mercury in gold-mining, account for at least three times that. The amount of mercury cycling through our atmosphere, oceans, and soil has increased by a factor of three to five since the Industrial Revolution (UNEP “Global Mercury Assessment”).

Up to 21% of industrial mercury, about 800 tons a year, is used in China's to catalyze the production of vinyl chloride monomer from coal (UNEP “Global Mercury

[29] http://volcano.oregonstate.edu/book/export/html/151

Assessment"). It is not clear how the spent catalyst is disposed of.

The idea that mercury adsorbs to plastics is not new, but the amount that has stuck to the plastic bottle has been relatively low, at 2-5% of the total mercury in the sample. Analytical chemists have been trained to compensate for this "bottle wall loss." The backbone of polyethylene is a repeating chain of hydrogen and carbon atoms with no substitutions. I wondered whether another type of plastic, with substitutions that attract mercury, would bind a more significant percentage.

Polymers are used as environmental sampling media, and for water filtration. Specialty polymers have been designed for these purposes. A team from the University of Genova (Chiarle et al.) found that Duolite GT-73, a poly-styrene/divinylbenzene resin, adsorbed significant amounts of mercury chloride over a twenty-four hour period (when immersed in a neutral to basic solution). In 2004, Pohl and Prusisz used Duolite to preconcentrate Hg(II) from hydrochloric acid media. (Dow's Duolight is now marketed under the name Amberlite® GT73 for Rohn & Haas[30].) Another study compared the performance of organic resins Purolite S-920 from Bro-Tech Corporation, Ionac SR-4 from Sybron Chemicals, and SIR-200 from Resin Tech in their ability to adsorb mercury from industrial effluent (Fondeur et al.). Each of these is also polystyrene crosslinked with divinyl benzene, with thiol functional groups bonded to the polystyrene.

Heavy metal ions were captured on active filters composed by a conducting surface covered by poly-4-vinylpyridine (P4VP) or Polyacrylic acid (PAA). Due to respectively pyridine and carboxylate groups those polymer films have chelating properties for heavy metals (Pascal et al.).

Mercury has a particular affinity for sulfur molecules, and an experiment using a

[30] See http://www.sigmaaldrich.com/catalog/product/supelco/10354?lang=en&region=US

polymer containing sulfur and limonene bound mercury in drinking water (Carter). Would conventional plastic marine debris that contains sulfur also adsorb mercury?

There is a growing awareness that plastics can adsorb lipophilic persistent contaminants like PCB and DDT (Mato et al.; Teuten et al.), and that fish are eating the plastics (Boerger et al.). The ingestion of plastics debris exposes the fish not only to the potentially toxic chemicals that are intentionally present in the plastic, such as phthalates, bisphenol-A, styrene, vinyl chloride, and so forth, but also to the contaminants that adsorb to the debris.

Yukie Mato and Emma Teuten have demonstrated that certain types of plastics (polyethylene, polypropylene, and polyvinyl chloride) concentrate PCBs, DDE, and phenanthrene – at up to one million times the levels found in the ambient seawater. Since they published their groundbreaking work, many other researchers have also investigated the sorption of POPs to plastic marine debris (Frias et al.), and several have looked into the sorption of heavy metal.

Karen Ashton sampled plastic marine debris for adsorbed metals. Her team found that polyethylene pellets suspended in seawater for 8 weeks adsorbed lead and cadmium (Ashton et al.). They did not, however, test for mercury. Nakashima et al. quantified chromium (Cr), cadmium (Cd), tin (Sn), antimony (Sb), and lead (Pb) in plastic litter collected during the beach surveys in Japan. Holmes et al. also quantified trace metals in polyethylene pellets (Cr, Co, Ni, Cu, Zn, Cd and Pb).

This is, to my knowledge, the first paper investigating mercury in plastic marine debris.

2. <u>Materials and Methods</u>

2.1. Phase I: Proof of Concept Testing

I suspected that plastics containing sulfur would be particularly likely to adsorb methyl mercury, so I first selected two common resins, styrene-butadiene and polychloroprene. I chose these because they intentionally incorporate thiolate (sulfer-hydrogen) molecules. Thiolates are a 'mercaptan,' which is derived from the Latin *mercurium captans* ("capturing mercury"). The name reflects the propensity of these molecules to bind to mercury. Mercaptan salts are used as chain transfer agents in the emulsion (but not solution ionic) polymerizations of synthetic rubber in order to control the molecular weight of the finished product. (Dibenzyltrithiocarbonate, which is not a mercaptan, could be substituted) (Senyek et al.).

Samples of pre-consumer styrene-butadiene and polychloroprene were immersed in seawater samples that had been spiked with an environmentally relevant concentration (100 nanograms/liter) of methyl mercury. After 72 hours, the styrene-butadiene pieces had adsorbed 72% of the mercury in the seawater. The polychloroprene had adsorbed 17% of the mercury in the seawater. Despite the small sample size (3 control and 3 experimental replicates for each substrate), this supported my hypothesis.

2.2 Phase II: Additional Testing

Next, the test was repeated with more replicates. Brooks Rand Labs staff tested seven replicates each of polycarbonate resin pellets (Acros Organics #178310050, lot A0287290), styrene/butadiene ABA block copolymer (30% styrene) crumbs (Scientific Polymer Products #057, lot 600503005) and post-consumer recycled rubber crumbs intended for use as a surface covering for playgrounds (Playsafer Rubber Products).

Brooks Rand Labs staff collected approximately 4 L of Puget Sound seawater from an area that is historically low in MeHg (< 0.02 ng/L). The seawater was passed through a 0.2-µm pre-cleaned filter unit and kept cold and dark until use (to remove most of the bacteria and reduce the changes of bio-methylation or de-methylation). Three aliquots of seawater were split off and analyzed for total mercury to assess the background concentrations prior to use, and the results were acceptable (all < 0.15 ng/L).

The 50-mL polypropylene centrifuge tubes were prepared by leaching them with a solution of 2% (v/v) 0.2 N BrCl for 48 hours, rinsing with ultra-pure reagent water, and drying them in a Class 100 clean hood. BRL staff prepared three control blank samples and three experimental (spiked) blank samples in the polypropylene tubes (these samples contained no additional plastics). The blank contained only unpreserved seawater and experimental sample was unpreserved seawater that was spiked at a concentration of 100 ng/L of MeHg.

For the samples to which plastics were added, 50-mL of each seawater sample was dosed with 1.0 g of the three (3) different plastic resin types. Again, experimental samples were spiked at a concentration of 100 ng/L of MeHg.

The vials were placed on an orbital shaker and agitated at room temperature for 72 hours.

During this time the vials were kept in the dark to reduce any bacteriological effect. Following agitation, the samples were centrifuged and decanted, retaining the pellets and discarding the supernatant. The pellets were then rinsed with ultra-pure reagent water. Finally, the vials were filled with a leaching solution of 1% (v/v) 0.2 N

BrCl and allowed to sit at room temperature for approximately 16 hours prior to analysis. The BrCl has the effect of converting all of the Hg in the samples (including MeHg) to the inorganic Hg(II) form.

Because the rubber crumbs samples had the affect of "consuming" all of the BrCl in the samples, these samples were re-prepared and re-extracted with a leaching solution of 5% (v/v) 0.2 N BrCl.

All samples were analyzed for total mercury (THg) by EPA Method 1631. The method involves reduction of the inorganic Hg(II) to elemental Hg by the addition of stannous chloride (SnCl2), single gold trap amalgamation, and cold vapor atomic fluorescence spectroscopy (CVAFS) detection using a BRL MERX-T CVAFS Mercury Automated Analyzer. The difference in the THg concentrations between control and the experimental samples represents the amount of MeHg that absorbed to the plastic resin pellets.

3. Results

Styrene-butadiene ABA block co-polymer, when immersed in seawater spiked with an environmentally relevant concentration of methyl mercury, adsorbed 72% of the mercury within three days. Polychloroprene (Neoprene, which is used for making wet suits, for example) adsorbed 17% of the mercury in the seawater.

Plastics known as polysulfides, which incorporate mercaptans (carbon-sulfer molecules) into their molecular structure, adsorb methyl mercury very efficiently. Mercaptan salts are used as chain transfer agents in the emulsion (but not solution ionic) polymerizations of synthetic rubber in order to control the molecular weight of the finished product. (Dibenzyltrithiocarbonate, which is not a mercaptan, could be substituted) (Senyek et al.).

One unexpected result was the observation that polycarbonate, rather than adsorbing mercury, leached it. The spiked sample results were about 20% lower than the unspiked sample results. The mercury may have been an intentional additive as it appears that it enhances the optical clarity of polycarbonate[31]. When broken bits of polycarbonate[32] were added to a test tube full of seawater spiked with methyl mercury, we were planning to measure how much mercury bonded to the plastic, thus removing itself from the sea water. Instead, to our surprise, after introducing the polycarbonate into the test tube, the level of mercury in the seawater rose by 8.6 ng/L ("Report for Methylmercury Absorption"). Apparently, mercury is used an additive in at least some batches of polycarbonate, perhaps as an antimicrobial[33] to achieve optical clarity[34].

Table 5. Mercury Adsorption to Polymers in Seawater

	Recovery in Phase I Tests	Recovery in Phase II tests
Control	2% (n=7)	< 1% (n = 2) one value omitted as an outlier
Rubber Crumbs	not tested	15% (n=7)
Polycarbonate	not tested	-9% (n=6) one value omitted as an outlier
Styrene/Butadiene ABA Block Copolymer	72% (n=3)	58% (n=7)
Neoprene	17% (n=3)	not tested

The background level of MeHg absorption to the polypropylene tubes was < 1% of the spiked amount. The styrene/butadiene ABA block copolymer absorbed 58% of the spiked MeHg, and the rubber crumbs absorbed 15% of the spiked MeHg.

31 http://www.tradeindia.com/fp669527/Sunglasses-With-Mercury-Coated-Polycarbonate-Lenses.html
32 Acros Organics #178310050, lot A0287290
33 Personal communication, Terry Collins, email, May 11, 2013.
34 Personal communication with a Comcast industry worker, May 2013 (phone), source wishes to remain anonymous.

4. Conclusions

These results are preliminary, but they do suggest that certain types of plastic marine debris, those that contain mercaptans, may be concentrating methyl mercury from the ambient seawater. Further studies are needed to quantify the distribution of mercaptan-containing plastics on the seafloor and in the water column, which to my knowledge has not yet been addressed. These results raise the possibility that the mercury could be transferred into the food chain, but further studies are needed to elucidate the toxicokinetics in marine species that have ingested it.

Now that the literature demonstrating that plastic debris is capable of concentrating and transferring contaminants into the marine food web has become so robust, I question whether the current understanding of biomagnification of contaminants is inadequate for the purposes of quantitative risk assessment. I propose a new term: "plastic-mediated magnification." I reflected on the broader meaning of disposable culture, using plastics as starting place, in an article titled "Plastics as a Spiritual Crisis" (See Appendix III).

Teaching about the Environmental Justice Implications of Plastics

Why are policy and practice not changing more quickly in response to all that we are learning about the dangers of disposable plastics? Building on the work of Robin DiAngelo, who coined the term "white fragility" (DiAngelo) and Joan Olsson's "detour spotting[35]," I have created labels for a predictable set of defensive strategies that dominant group members use to distance themselves from the consequences of their (usually unintentional) oppressive behaviors. These strategies provide a framework for

[35] www.racialequitytools.org/resourcefiles/olson.pdf

understanding how dominant group members dismiss new information presented to them about the harms of disposable culture[36], and also suggest strategies to break through those defenses.

The following are outlines for lectures and discussions that I have used with my toxicology, epidemiology, and global health students. It is my hope that teaching students to name and to scientifically deconstruct these false narratives inoculates them from being misled by them.

Table 6. Strategies for Responding to White Fragility Defensive Tactics

[36] and probably climate change...but I won't go there.

White Fragility Tactic to Counter	Environmental (In)Justice Case Study	Activities
Denial, Universalizing	Lead in Drinking Water in Flint, Michigan, USA	Making Environmental Privilege Visible, Developing Curiosity and Empathy, Understanding Intersectionality
Minimizing	Illegal Waste Dumping in Abidjan, Ivory Coast	Taking a Long-Term View, Where Does Waste Go?
Blaming the Victim	Cancer Alley in Louisiana, USA	Using Principles of Epidemiology to Understand Additive and Synergistic Effects and Variations in Individual Susceptibility
Scapegoating	toxic gas release by Union Carbide in Bhopal, India	Root Cause Analysis ("The 5 Whys"), Seeing Patterns
Giving Up	premature puberty in San Juan, Puerto Rico	The Precautionary Principle: Acting in Spite of Uncertainty

Tactic #1: Denial / Universalizing

"I live in Flint, I drink the water, I shower in the water, and I had my blood tested just yesterday, and I have no elevated blood-lead level...this is all a hoax." Bill Ballenger, political analyst (Gettys)

This comment, by a white middle-class resident, epitomizes the confluence of scientific misunderstanding and prejudice. The resident shares the common misconception that lead was *in* the water that was being piped into Flint homes. Rather, the water was "aggressive" and highly corrosive, with a pH that fell as low as 7.3 in August 2015 (Hanna-Attisha et al.) in the absence of an orthophosphate corrosion inhibitor. This destroyed the mineral passivation layer (Torrice) that protected pipes from dissolved oxygen and chloride ions. When the mineral passivation layer was compromised, the oxidizers were able to reach the lead and to corrode it. Lead solder is generally not present in the plumbing in new construction, though some high-end, sand-cast faucets have been found to have unacceptably high levels of lead (Wald). Pipes with lead solder are more likely found in older housing stock. It is the residents in these dwellings who are at risk of lead poisoning. The fact that the water at Mr. Ballenger's more recently-constructed residence is safe does not undermine the fact that the water that passes through pipes in older homes did have concerning levels of lead. If an epidemiologist were to pool the levels of lead in residential tap water without controlling for the age of the structure, the levels in newer homes would skew the average and make the problem seem less urgent.

Risks are compounded. Children who are malnourished are more susceptible to lead poisoning. Deficiencies of iron and calcium trick the body into absorbing more lead (Kwong et al.). Flint is a food desert (Anzilotti), which the USDA defines as a low-income area with limited access to nutritious food (Ver Ploeg and Rhone). This leaves more people susceptible to lead poisoning. The children most likely to be malnourished are also more likely to be living in older, more affordable housing, which may expose them to lead not only in their tap water but also in pre-1978 peeling paint. Unlike Mr. Ballinger, they may play with vintage / second-hand vinyl toys, many of which violate current safety standards for lead[37]. Let's assume that Mr. Ballinger's newer home does not have lead paint, that his income affords him a nutritious diet, and that he has access to private transportation, which expands his opportunities for procuring healthy foods.

To add another layer of complexity, there is much that is not understood about how lead interacts with the human body. Complex genetic polymorphisms regulate how lead is stored in our bodies, and how much is excreted (Barrett; Onalaja and Claudio). Lead may have downstream effects not only on cognition but also on impulse control, judgment, and behavior (Senut et al.). These effects depend on other neurotoxic

37 https://www.cdc.gov/nceh/lead/tips/toys.htm

exposures that the child may encounter, as well as the presence or absence of protective factors that would increase resiliency. Therefore, the dose, on its own, is not sufficient to predict the effect level.

I. **Making Environmental Privilege Visible**

I ask students to close their eyes and reflect on what they are most proud of about who they are. Then we look together at scientific evidence that for each of these traits or accomplishments there may be genetic and/or environmental influences that either help or hinder individual efforts. We create a list together on the board. I start it off with some examples:

- *I stay trim and fit.* Leaving aside for a moment access to fresh fruits and vegetables, to exercise equipment, gym memberships, safe sidewalks for walking and safe roadways for biking, consider mounting evidence that exposure (particularly prenatal exposure) to chemical obesogens can alter the body's metabolic set-point, can interfere with appetite regulation, can promote the production of surplus adipose cells, and can cause existing adipose cells to grow and to store more fat. Obesogens may act independent of diet and exercise, or in some cases a high-fat diet magnifies their impact. Examples of well-studied obesogens include DES, bisphenol-A, tributyl tin, and PFOA (from which Teflon is made). Obesogens act at very low concentrations, at levels found in the homes, schools, and workplaces of the average US American (Brown and Kuk; Penza et al.). Lead is also considered an obesogen. Chuanwu Xi's work suggests that perinatal lead exposure, at levels similar to those seen in lead-poisoned residents in Flint, caused lasting changes in the gut microbiome that were linked to adult obesity (Wu et al.).

A York University study (Brown and Kuk) found that "a given person, in 2006, eating the same amount of calories, taking in the same quantities of macronutrients like protein and fat, and exercising the same amount as a person of the same age did in 1988 would have a BMI that was about 2.3 points higher. In other words, people today are about 10 percent heavier than people were in the 1980s, even if they follow the exact same diet and exercise plans (Khazan)." They summed up their research with: "if you are 40 years old now, you'd have to eat even less and exercise more than if you were a 40 year old in 1971, to prevent gaining weight." They caution that the 'calories-in, calories-out' hypothesis of energy balance is overly simplistic: "That's similar to saying your investment account balance is simply your deposits subtracting your withdrawals and not accounting for all the other things that affect your balance like stock market fluctuations, bank fees or currency exchange rates."

- I don't use illegal drugs. Evidence suggests that prenatal exposure to certain chemicals, such as bisphenol-A, may alter the development of dopamine receptors in the brain, increasing the susceptibility for addictive behavior later in life (Jones and Miller). (There is evidence that lead also affects dopamine pathways in the brain; however, it is not strong enough in my estimation to tout it out for this example.)
- *I study hard and I do well in school. I stay out of trouble.* Cognitive ability, the ability to concentrate, and impulse control are all affected by a complex interplay of factors ranging from stress and trauma (Bremner) to ambient noise levels (Klatte et al.) to nutrition (Lieberman; Nyaradi) to chemical exposures (Grandjean

and Landrigan). Lead is a well-known developmental neurotoxicant (along with methylmercury, polychlorinated biphenyls, arsenic, toluene, manganese, fluoride, chlorpyrifos, dichlorodiphenyltrichloroethane, tetrachloroethylene, and the polybrominated diphenyl ethers) (Grandjean and Landrigan).

List your accomplishments and traits, and try to place them on a continuum, ranging from 'entirely of our own choosing' to 'determined by circumstances outside our control.' Of course, the objective is for the class to realize that we do not have enough information to accomplish this with any defensible degree of accuracy. One clear danger in this lesson is that some students will fall into the trap of false dichotomy. Either it is lifestyle choices (and therefore we know where blame falls) or environment (where blame is more muddled and diffuse). Too far on one side, and we are in denial of how our choices affect others. Too far on the other side, we risk minimizing how individual choices matter (to eat healthier food, to avoid smoking, for example), thereby creating victims rather than acknowledging the agency of EJ-impacted communities. It is for this reason that I construct a continuum, where both individual choices and environmental factors can slide the person towards or away from a particular outcome.

We might all wonder at this point, "Who might I have been if I had not been exposed to a polluted environment?"

Consider that while nearly everyone is routinely exposed to these chemicals, some are more highly exposed than others. I begin with these facts:

- Beauty products marketed to women of color, particularly skin lighteners and hair straighteners, tend to have more toxic ingredients than do products marketed to White women (Shamasunder and Zota).

- Those who are incarcerated have little control over their diet and environmental exposures. Some prisons are built on sites known to be contaminated (Bernd et al.)[38]. At some, the only drinking water inmates can access does not meet federal safety standards (Abel). Inmates may be exposed to second-hand smoke with no recourse (“Exposure to Second-Hand Smoke”).

Explore disparities in occupational exposures, indoor and outdoor air quality or a disparity of your own choosing. Does the data you found support or refute an environmental privilege / environmental racism framing? Which frame, "good/bad choices" or environmental privilege / environmental racism, do you hear most often in the media and in their other public health courses. Why is this?

[38] For more details, see “SCI Fayette – Coal Ash Investigation.” *Abolitionist Law Center*, 16 Oct. 2017, abolitionistlawcenter.org/our-work/cases/sci-fayette-coal-ash-investigation/.

II. **Developing Curiosity and Empathy**

In an oft-cited cartoon for social justice educators, a circle passes effortlessly through a brick wall with a circle-shaped hole in it. The circle calls back to the shapes that are still trapped inside, "I don't know what you guys are complaining about. If you want to make it through, just be yourself!"[39] What does this have to do with public health? This circle assumes that those left behind are not approaching the challenge properly. The circle believes that the square, triangle, and polygon will benefit from a motivational / educational intervention. To take one example, offering education about the importance of adequate iron and calcium intake seems reasonable in Flint, given its role in regulating lead absorption. However, low-income residents of a food desert, analogous to the shapes that cannot pass through the wall, will have more difficulty procuring these foods than would someone with more economic advantages (analogous to the circle, who is often the health educator). Structural changes (modifications to the brick wall) are also required. What might those look like in Flint? In what ways might we unconsciously universalize our own experiences and project them onto the population? What attitudes are most helpful for health promoters to bring to these situations?

III. Understanding Intersectionality

Jacqueline Patterson, the Director of the NAACP Environmental and Climate Justice Program, told Bill McKibben:

> (I show a) picture of this young boy named Antoine, who lives in Indiantown, Florida, 3 miles from a coal-fired power plant. He has severe asthma. There's a picture of his bag of medicines that show what he

[39] Bink, Charlie. "'Just Be Yourself!"." *This...is White Privilege*, 6 Mar. 2013, thisiswhiteprivilege.tumblr.com/post/44733676865/setfabulazerstomaximumcaptain.

depends on to get by from day to day. And there's a picture of him as a young boy watching other kids play in a fountain. Another one shows him looking out the window and watching kids go to school. Not him -- there's so many poor air quality days that would put his life at risk if he went.

I talk about the connection between the very facility that is driving climate change and the increased concentration of pollutants that come from climate change. And the kids who can't go to school. Or have a hard time paying attention because the other things that come out of the smokestacks [are] lead. Or they might be drinking it from their water supply. I want people to see all those levels of risk kids have from these impacts.

And then I overlay it with the maps that show these same communities are food insecure- more likely to get Doritos and Cheetos than kale and quinoa. And I overlay that with the fact that when you have this many problems, including living next to a toxic facility, on average your property values are 15% lower. So that affects the quality of their schooling because they're less resourced - fewer tax dollars. And then I show an image of a child standing on a milk crate being fingerprinted.

If you're not on grade level by grade 3, you're much more likely to enter the school-to-prison pipeline. And then the same entities that fight against the regulations to help the air are the same entities pushing forward punitive criminal justice measures, and privatizing our prisons, and so on. People see that through the lens of an actual child, how all

> those systems come into play. How they come into play against his chance to be a thriving adult (McKibben).

Imagine that you are reading this passage as Bill Ballenger. What pieces of this puzzle is he able to see? Which pieces are invisible to him? How might he respond to Jacqueline Patterson? I suspect that the class would begin to ask themselves how a spotlight could be shined on these links. Find examples of People of Color-led organizations that are already doing this work.

Tactic #2: Minimizing

"The slops could at worst have caused a range of short-term, low-level flu like symptoms and anxiety"("Côte D'Ivoire: Trafigura").

"In 2006, 528 tons of petroleum toxic waste have been released in Abidjan (Ivory Coast) during a major environmental accident" (Kouassi).

Analyze the "playbook" that those who profit from the petrochemical economy, including plastics manufacturers, use to minimize adverse public relations impact relating to its industries' toxic waste. For example, first focus on aesthetics. Emphasize "unpleasant" or "nuisance" odors, and on mild acute symptoms, like watering eyes or coughing. When things take a more serious turn, admit that some residents are "treated and released" at local hospitals but do not linger on the potential long-term impacts on their health. Above all, remember to refer to incidents as "accidents," lest the public realize that they are, in fact, a normal part of doing business in this economy.

An example of this is the 2006 Trafigura scandal. A Singapore-based shipping company charted the *Probo Koala* to transport coker gasoline. Aboard ship, they refined the gasoline to make naptha, which they sold. This left a foul-smelling concoction of residual caustic soda, phenolic compounds, and hydrogen sulfide in the ship's tanks. The captain attempted to pay a Dutch company to dispose of the waste, but after testing its chemical composition, they increased the quoted cost from €27 to €1,000 per cubic meter. The company opted not to pay, and instead sailed from port to port in search of a cheaper option. Ultimately, they paid a local contractor named Tommy in Abidjan, a port city in the Ivory Coast, to take the waste. Tommy and his subcontractors, presumably unaware of the risk, spread the waste around the city. Seventeen immediately succumbed to the toxic gases emanating from the piles they left along roadways and in parks and dumps. Another 30,000 sought medical attention[40].

In the three months following the dumping, 10, 598 patients were examined at the CHU de Cocody. Adults frequently reported coughing, difficulty breathing, chest pain, and sometimes hemoptysis (coughing up blood), while those under age 17 were more likely to present with abdominal pain, diarrhea, vomitting, and bloating (Kouassi). To my knowledge, no one is following these residents to asses the long-term health implications.

I. Taking a Long Term View

looking back...

> The Palestinian poet Mourid Barghouti writes that if you want to dispossess a people, the simplest way to do it is to tell their story, and to start with, "secondly." Start the story with the arrows of the Native Americans, and not with the arrival of the British, and you have and entirely different story. Start the story with the failure of the African state, and not with the colonial creation of the African

40 http://www.greenpeace.org/international/en/publications/Campaign-reports/Toxics-reports/The-Toxic-

state, and you have an entirely different story.[41]"

Where should the story of the Western waste dumped in Abidjan begin? Does it begin when the *Probo Koala* took on this questionable cargo? Go back farther...before the 1989 Basal Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (which the United States has yet to ratify) . . . why was this treaty considered necessary in the first place? This is another approach for getting beyond proximal causes to distal and root causes (see also the 5 Whys in the case study on Bhopal).

looking forward...

Drosophila (fruit flies) are often used in experiments that study the impacts of toxic exposures or of changes in the various environmental conditions that sustain life. They were selected because they breed prolifically, mature rapidly, and therefore offer geneticists multiple generations in what is for humans a very short time frame. Because so many fruit flies have made the ultimate sacrifice, we know which genes are associated with the familial form of Parkinson's Disease (Guo), and we understand more about how problems with the Tau protein can result in Alzheimer's (Gistelinck).

Humans, of course, tend to have a much longer reproductive life, resulting in at most sixty-nine but rarely more than twenty offspring[42].This makes it much more difficult to control for changing environmental conditions while studying genetics.

Until recently, a debate raged over whether genes or environment were the primary drivers of disease. Now, we add a third actor: epigenetics. These are changes in the expression of an existing genome. Without changing the order of genes,

Truth/

41 http://ssw.unc.edu/files/TheDangerofaSingleStoryTranscript.pdf

42 http://www.guinnessworldrecords.com/world-records/most-prolific-mother-ever

epigenetics acts as the control switch, turning them on or off by adding or removing a methyl or acetyl group to a strand of genetic material, or by altering the histone (how tightly wound the chromatin is). These additions and subtractions can occur throughout the lifespan, and are triggered by environmental factors, broadly construed. Everything from starvation (or, protectively, eating cruciferous vegetables that donate methyl groups), to psychological trauma to chemical and radiological exposures has the potential to silence or activate genes, but endocrine disruptors are the most intensely studied. We do not yet have a one-to-one map of how any given exposure will affect a given individual; however, scientists are busy following subjects through multiple generations in order to understand epigenetic transgenerational inheritance, that is, how an exposure in one generation has the potential to impact subsequent unexposed generations (Nilsson and Skinner).

In a recent study, researchers in Patricia Hunt's lab followed three generations of mice and exposed them to a more realistic scenario: Each generation of an experimental group was exposed. They found, "...multiple generations of exposure not only exacerbate germ cell exposure effects, but also increase the incidence and severity of reproductive tract abnormalities. Taken together, our data suggest that male sensitivity to environmental estrogens is increased by successive generations of exposure" (Horan et al.).

The effects that we can measure may be just the tip of the iceberg. Female rats showed a persistent aversion to potential mates whose fathers, or grandfathers, or even great grandfathers, were exposed to the fungicide vinclozolin (Crews et al.). However, none of the characteristics of the rejected mates differed from the controls in any way that was apparent to researchers. Perhaps there is a difference in pheromones, or in some other trait that is only evident to other rats. At any rate, it is another reminder of the dangers of scientific hubris. There is much going on that we do not yet know to look for.

Given that hydrogen sulfide, along with many other constituents of the petrochemical slops spread around the city, appear to be endocrine disruptors (Xu et al.), are those who were exposed in 2006 passing on epigenetic changes to their children? And, given that the waste has not been cleaned up, will those children be exposed again? Where will the story end?

The type of research that would be needed to document this, a long-term prospective cohort study, would be quite expensive and would require a substantial staffing commitment to follow each member of the cohort. This is further complicated by the large number of victims who live in the instability of poverty. Ethical considerations demand that the research itself would need to provide some direct benefit to those being studied.

Perhaps this explains why most narrators stick to documenting acute effects, those symptoms that present in the first days, weeks, and months following exposure. Rarely do we hear of long-term sequalae, let alone transgenerational effects.

What would need to change in order for *all* of the potential impacts of the Trafigura dumping to be made known?

II. Where Does Waste Go?

I propose to the class that when toxic waste is "cleaned up" it generally follows one or more of the following routes:

- displacement across space -- The waste is moved from one location to another.
- displacement across media -- In this case, "media" refers to environmental media (air, water, soil, or biota). This occurs when, for example, a filter captures smokestack emissions, which would otherwise be released into the air. Now, we have a solid waste problem instead of an air pollution problem. Where will the filter go? Another example is the containment of an oil spill by either causing it to floculate and sink into the sediment (moving it from the water into the sediment) or by capturing it in absorbant material (moving it from the water into a solid).
- displacement across time -- When we store waste in sealed repositories, we are shifting the problem to future generations. In most cases, the waste will not break down in an appreciable time scale. The problem that future generations inherit will be no less vexing than it is for us.

What are the alternatives?

These may include:

- bioremediation / phytoremediation -- Some species of mushrooms and some species of microorganisms are capable of breaking toxic compounds into their harmless constituents (Adenipekun and Lawal; Chen). Adding "probiotics" to the environment may enhance the breakdown of toxicants. A recent example is the use of poplar trees inoculated with a species of *Enterobacter* brought concentrations of trichloroethylene down from 300 µg/L (upstream of the stand of trees) to 5 µg/L (downstream from the treated trees) (Lockwood).
- green chemistry -- For example, Terry Collins' group has developed TAML/iron catalysts that can neutralize 99% of the estrogenic contaminant BPA in

wastewater with no toxic degradation products (Onundi et al). Electrochemical oxidation appears to reduce PFAS contamination in water (Blotevogel). Supercritical water oxidation may remediate soil contaminated with polyaromatic hydrocarbons (Kronholm et al.).

Here is the hierarchy of hazard controls, developed by National Institute of Occupational Safety and Health at the Centers for Disease Control and Prevention:

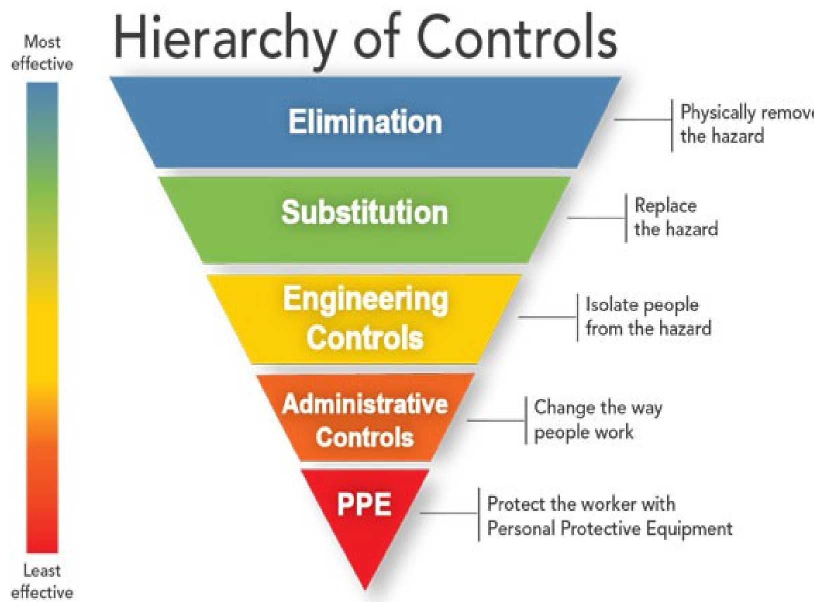

Illustration 1: https://www.cdc.gov/niosh/topics/hierarchy/default.html

This is designed to help us think about the protection of workers from occupational hazards, but with some modifications it can be applied more broadly to protection of the public (particularly fenceline communities) from toxicants. Most of the "solutions" that we just named would fall into the yellow "engineering control" zone. What are some solutions that align more closely with "elimination" and "substitution" -- the strategies considered most effective? Consider the distal and root causes of the Trafigura tragedy and imagine alternatives such as moving away from a petrochemical economy.

Tactic #3: Blame the victim

"*Therefore, smoking, not smokestacks, is to blame."*

Thus concludes Frederick Billings III, MD in a study of the epidemiology of cancers in an industrialized, primarily low-income and minority area of Louisiana, which he disparagingly dismisses as “toxic terrors” of the myth of “Cancer Alley.” In later discussion, he adds, "Some think that the 'let the good times roll' attitude with its lifestyle choices has resulted in a very high incidence of obesity, diabetes, and tobacco related problems."

It is impossible to determine the cause of any individual's cancer. In some cases, it *is* quite likely that "smoking, not smokestacks" triggered the malignancy, or at the very least contributed significantly. According to what we now know, many cancers are caused by "two hits" or "multiple hits." For example, there may be an exposure to an "initiator" and subsequently to a "promoter." On their own, neither of these exposures would be sufficient to cause a malignancy; however, they do when combined. Further, we are now aware that certain exposures, while not strictly speaking an "initiator" or "promoter" themselves, can have a synergistic effect on carcinogens. Smoking is an infamous example (Ngamwong et al.) If a non-smoker and a smoker were both to inhale the same number of asbestos fibers, the smoker would have a much greater risk of mesothelioma (the particular lung cancer associated with asbestos) than would the non-smoker. Thus, the false dichotomy that Billings constructs, smoking *or* smokestacks, is not all that helpful. Reality is much more complex.

Another problem with his analysis of cancer incidence is the potential for classification bias. Classification bias means that there is a systematic error in labeling groups as exposed / unexposed. He groups the seven parishes of the Industrial Corridor together, and tallies the number of cancer cases diagnosed there based on unpublished data from the Louisiana Tumor Registry. Classification bias has been discussed elsewhere in the context of occupational exposure studies (Heathemail), the true incidence of cancer may be diluted by including unexposed subjects in the "exposed" groups. In order to accurately assess whether the airborne emissions were carcinogenic, the exposed / unexposed groups would need to be sorted by actual exposure. This could be accomplished either with an analysis of prevailing winds and a map of the plume, or by personal air quality monitoring (using the methods developed with air monitors modified to be worn in backpacks [Washam] or perhaps by analyzing household dust samples [Mitro et al.]). Even a study using simple concentric circles of distance from the point-source of pollution to residence would be more accurate than aggregated parish-level data. Ecological studies, such as this, are useful in hypothesis generation, but it is not possible to prove or disprove a hypothesis based on this level of analysis.

The endpoints that Billings chose to study (colon cancer, breast cancer, lung cancer, and prostate cancer) are dubious. Colorectal cancer, for example, is as closely linked to consumption of nitrosamines in deli meats as it is to industrial emissions ("Toxicant and Disease Database"). The absence of a higher-than-expected frequency of these diseases is no proof of the safety of industrial emissions, which may be more strongly associated with asthma, cardiovascular disease, and prematurity ("World Energy Outlook"; "Ambient Air Pollution"). The endpoints he selected are the leading causes of cancer, and therefore data pertaining to them is readily available. When attempting to identify a cancer cluster, however, it is standard to focus instead on a rare form of cancer, or a cancer that is appearing in a sub-population where it would not be expected (i.e., a cancer that is typically adult-onset now being diagnosed in children) (Abrams et al.).

Returning to his claim that smoking is the true culprit, it is curious that the lung cancer rate for the state overall is higher than it is in the Industrial Corridor. Is smoking actually more common outside the 'let the good times roll' region that includes New Orleans? This would appear to contradict his premise.

Victim-blaming tends to mask structural and institutional oppression by presenting harm as the result of individual choices. These choices, however, are always made in the context of external constraints and rewards. The social determinants of health are the most readily apparent. Extensive data demonstrating that tobacco marketing targets minority groups, and particularly minority youth ("Tobacco is a Social Justice Issue"). There may be a biological determinant of health at play as well: melanin binds nicotine, slowing its excretion from tissues such as the heart, lungs, liver, and brain (King et al.). Thus, according to one hypothesis, darker-skinned smokers may be at a higher risk of addiction and may have a more difficult time quitting smoking. These are just a few factors among many that might "nudge" (Wilk) someone towards or away from a smoking habit.

I. **Using Principles of Epidemiology to Understand Additive and Synergistic Effects and Variations in Individual Susceptibility**

Use the Toxics Release Inventory ("Toxics Release Inventory") to look up which chemicals are emitted in the parishes Billings cites in his articles. Then, enter each into the Collaborative on Health and the Environment's Toxicant and Disease database ("Toxicant and Disease Database"). The list will show that each chemical is capable of contributing to a wide variety of diseases. Note overlap - often more than one chemical is associated with a particular disease.

How chemicals work together to cause disease is not fully understood. When we try to measure risk, we have to decide whether a particular combination of exposures will have "additive" or "synergistic" effects. When risk is additive, and I'm breathing something that doubles my risk and my tap water has something in it that triples my risk, then my risk is 2+3=5. I have five times the likelihood of developing that particular health problem than would someone who is not exposed to either. More often, however, calculating risk not so tidy and predictable. The above example of asbestos exposure being much more dangerous in a smoker than in a non-smoker illustrates this point.

Given that, what can we make of our lists? Which endpoints would it make the most sense to study in this population, based on what we know of the demographics? Search the peer-reviewed literature for studies that match our criteria. Do those authors' conclusions agree with Billings? Why or why not?

Tactic #4: Scapegoating / Refusing to See Patterns

Bhopal. The name of this city in Madhya Pradesh, India has become synonymous with the tragedy that befell it on the night of December 2, 1984. A leak in a methyl isocyanate tank in the Union Carbide (now Dow) pesticide factory allowed a cloud of some 30 metric tons of toxic gas to escape and settle over the residents of the surrounding dwellings.

The methyl isocyanate had mixed with water and impurities in the tank as well as with compounds in the atmosphere to produce a mixture that likely contained phosgene (a World War I era chemical weapon as well as an industrial feedstock at this factory), chloroform, hydrogen chloride, oxides of nitrogen, and monomethyl amine (Eckerman).

That gas was being stored in three 15,000 gallon tanks, rather than in 52-gallon drums, was already an anomaly. Maintaining a constant supply of MIC in bulk storage allowed production of Sevin and other pesticides to continue unabated even during maintenance and other temporary work stoppage events. It also dramatically increased the risk to the workers and the surrounding inhabitants.

A refrigeration system, which would have chilled the gas and slowed the chemical reaction, had been shut off as a cost-saving measure. Transferring the MIC to the smaller drums would have eliminated the need for refrigeration, but this precaution was not taken (Diamond). The flare, which was in need of replacement parts, was not operable. The lye and water neutralization system was also inoperable. Instrumentation showing that the pressure had risen to dangerous levels was initially ignored, as the instrumentation in the plant was not well-maintained and was therefore notoriously unreliable. Even the warning sirens had been disabled. There was no way to alert and evacuate the city.

People awoke, coughing, their eyes burning and tearing. They became nauseous, and vomited. They had increasing difficulty breathing as fluid filled their lungs. Because the gas is heavier than air, those who were closest to the ground - children- perished first. Others ran towards the river to cool their burning skin and burning eyes in the water. By morning, thousands lay where they had fallen.

Many were able to reach the hospital, but doctors there were unprepared to assist them. The company would not disclose the chemical composition of the gas, nor did it have any suggestions to offer for treatment. No risk management plan had been prepared...not that it would have helped. There is no antidote for methyl isocyanate poisoning. All that can be done is supportive treatment of symptoms -- rinsing the patient's skin and eyes with water or saline, opening an airway and providing supplementary oxygen, and hoping for the best ("Methyl Isocyanate"). There is, however, treatment for cyanide poisoning. Sodium thiosulphate was administered to certain patients, with generally (but not universally) positive outcomes, although the treatment protocol was discontinued after Union Carbide withdrew advice recommending it. Eckerman proposes that suggesting this course of treatment might be construed as an admission of guilt on the part of Union Carbide: "To admit that sodium thiosulphate could give symptomatic relief would be to admit that toxic gases had crossed the blood-lung barrier. This is probably the explanation of why UCC withdrew their recommendation on treatment" (Eckerman 103-4).

Those who did survive were frequently left blind and crippled by diminished lung, kidney, and liver function. There was an unusually high number of miscarriages among the women who survived the gas (Bhandari et al.). Their children had physical and developmental abnormalities more frequently than did children in unexposed populations ("Bhopal Gas Tragedy"). Residents of Bhopal continue to suffer disproportionately from chronic illness and adverse reproductive outcomes, which some blame on contaminated groundwater (Labunska et al.).

Officially, the Indian government now owns the site and bears financial responsibility for its clean-up and remediation; however, activists continue to press Dow to dip into their deeper pockets. Neither party has been proactive in removing contaminated soil, or leaking barrels of chemicals, which have been slowly seeping into the aquifer.

UK-based Bhopal Medical Appeal calls this "the second poisoning." For fifteen years before the gas disaster Union Carbide had routinely dumped highly toxic chemical wastes inside and outside its factory site. Some were buried, some simply lay heaped on the soil, open to the elements.

Thousands of tons of pesticides, solvents, chemical catalysts and by-products lay strewn across 16 acres inside the site. Huge ‘evaporation ponds’ covering an area of 35 acres outside the factory received thousands of gallons of virulent liquid wastes.

After the catastrophic gas leak, the factory was locked up and left to rot, with all the chemicals and wastes still there. Union Carbide left the factory and its surrounds without cleaning them.

As each year’s monsoon battered the decaying plant and rain overflowed the huge ‘ponds’, the toxins seeped down through the soil, and filtered into underground channels and pools. Wells drawn from these ground water pools serve around 50,000 people living in eighteen townships. Among them is JP Nagar, the community most devastated by the gases of 1984 (“Bhopal’s Second Poisoning”).

Safer chemistry has been promoted as a protective measure. In fact, the methyl isocyanate pathway that the Bhopal Union Carbide plant used had already fallen out of favor as being too dangerous. A two-step reaction of 1-naphthol with phosgene, producing chloroformate, followed by a reaction with methylamine also produces carbaryl (i.e., Sevin), but bypasses the MIC intermediary. This method, for which Union Carbide held a patent, was used between 1958 and 1973. Objections over marginal increases in production costs were responsible for Bhopal's factory using the older, more dangerous pathway (Eckerman 25).

In the United States, the disaster prompted national community right-to-know legislation. In Institute, West Virginia, where a factory constructed to the same specifications as its counterpart in Bhopal was also using methyl isocynate in the production of carbaryl pesticide, a new $5 million emergency alert system was installed. Leaks have also occurred in the West Virginia plant; however, unlike Bhopal, there have been no fatalities.

What led to these disparate outcomes? One reason appears to be investment of sufficient financial resources to ensure safe operations. Union Carbide engineers warned in a May 1982 inspection, "there is real danger of a runaway reaction." They suggested measures to avert danger but "UCIL management reports to UCC on follow-up, saying they will undertake all suggested measures, but do not act on the recommendation to increase the range of the firewater spraying system from 15 meters to 35 meters so it can reach the top of the MIC vent pipe. The last UCIL communication on followup, dated 26 June 1984, says all changes have been made except one to the Sevin feed tank, which will be completed when the needed control valve is delivered in about a month" (Peterson). Five months later, the predicted runaway reaction occurred. None of the safety measures were in place.

Warren Anderson, who was at that time the CEO of Union Carbide, flew to Bhopal four days after the leak to oversee recovery efforts. He was met at the airport by police and symbolically arrested for culpable homicide. He was detained at Union Carbide's guesthouse for three hours, then released on bail and flown to Delhi on a government plane. He waited in the ambassador's residence until his travel home could be arranged (Frank). As a condition of his release, he promised to return to face trial when summoned. This was a promise he did not keep. Neither did the United States government honor India's extradition requests (Shukla and Shukla). He was burned in effigy in the streets of India.

On Valentine's Day 1989, the Indian Supreme Court accepted a settlement of $470 million dollars in return for immunity for Warren Anderson and Union Carbide from all civil and criminal suits (Hazarika). Anderson had already retired three years earlier, and he and his wife divided their time between Florida, Connecticut, and New York. They owned luxury homes in all three states, one of which was valued at $900,000 (Bhatt). In 2004, he died of natural causes at the age of 92.

To put the Bhopal settlement in perspective, it was meant to cover expenses for not only the 200,000 injured survivors (many of whom were permanently disabled) and their dependents, but also as compensation for the families of the 15,000 who died (this figure counts both those who were killed in the immediate aftermath, as well as those who later succumbed ["7 Guilty in Bhopal Tragedy"]). As of October 2003, according to the Bhopal Gas Tragedy Relief and Rehabilitation Department, compensation had been awarded to 554,895 injured survivors and 15,310 families of the dead. Payments averaged just $2,200 (Kumar).

One commentator noted, "Had compensation in Bhopal been paid at the same rate that asbestosis victims were being awarded in US courts by defendant including UCC – which mined asbestos from 1963 to 1985 – the liability would have been greater than the $10 billion the company was worth and insured for in 1984" (Castleman).

For its part, Union Carbide scapegoated the workers. The official company position was that a disgruntled worker must have sabotaged the tank that held methyl isocyanate, but such a worker could not be found. Instead, in 2010, eight low-level

Indian executives of Union Carbide’s Bhopal subsidiary were convicted of negligence (Martin).

Attributing the fault to individual and corporate hamartia serves only to exonerate the system in which these actors function. It may be cathartic to direct rage at Warren Anderson or at another representative of Union Carbide (now Dow, perhaps soon to be Dow-DuPont), but if this is our sole focus, we overlook the root causes of this tragedy.

I. Root Cause Analysis

To perform a root cause analysis, use the Five Whys technique. Ask "Why?" and then for each reason you list, ask "Why?" again until you have done this five times, and until proximal, distal, and root causes have been identified. How do structural, institutional, economic and cultural factors set the stage for the disaster? For example, in the United States, corporations (excluding B corporations) have a legal obligation to maximize shareholders' profit.

Another scale, consider how a legacy of colonialism / neocolonialism shapes relationships between India and the United States, and how those tensions have impacted the management of the disaster in Bhopal. Contextualize the presence of Union Carbide. What were they producing, and for whom? The end product, Sevin (a brand of carbaryl), is part of a class of pesticides that inhibit acetylcholinesterase. The pesticide is toxic to humans and to the ecosystem[43], though it is not persistent. Recent research suggests that it may binds to the MT2 melatonin receptor, potentially disrupting circadian rhythm, which can have deleterious effects on the endocrine and immune systems (Popovska-Gorevsk). How did something so risky become "necessary"? Who

[43] In 2014, the IARC recommended that carbaryl be a "high priority" for review, as new epidemiological data had emerged since it was last studied. https://monographs.iarc.fr/ENG/Publications/internrep/14-002.pdf

benefits?

A bit of background would be helpful here on the "Green Revolution," the ensuing debt burden (“World Bank 2015”), and post-Bhopal structural adjustment policies, namely the New Economic Policy which entered into force in 1991 (Deshpande). Arguably, this served to undermine the power of India's government to act independently on behalf of its most vulnerable citizens both before and after the incident. To add insult to injury, the disaster has made the people of Bhopal vulnerable to further exploitation, such as being enrolled without their knowledge or consent in clinical trials for Western pharmaceutical companies (Lloyd-Roberts). Since all, or nearly all, of the livestock tended by residents of Bhopal were killed by the gas, as well as many families' primary wage earners, and since the closure of the factory eliminated one of the surest routes to a living wage, the community was left destitute. Did the influx of "aid" shift the community from economic dependence on a transnational corporation to economic dependence on what some term the non-profit industrial complex?

II. Seeing Patterns

In *The Bhopal Saga,* Ingrid Eckerman quotes T. MacSheoin's *Asphyxiating Asia* when she writes, "The Indian government was very keen on establishing chemical industries. Indian authorities stated in 1998 that one of the competitive advantages that India had was that companies were comparatively free to pollute there" (Eckerman 22). “Why might this be? Are some people (and ecosystems) more likely to be slated for economic development at the possible expense of pollution-related health risks? Is this an apolitical, one-off luck of the draw, or can be patterns be detected?

The comparison of Union Carbide investment in the plants in Industry, West

Virginia and Bhopal, India are not as straightforward as it might seem at first. While West Virginia received significantly more investment in its safety infrastructure than did its Bhopal counterpart, we might ask why the plant was sited in Appalachia -- a zone that within the United States experiences a disproportionate share of environmentally destructive industrial activity, not least of which today is mountaintop removal coal mining. Yet all the industrial activity does not translate into increased regional wealth. Appalachia has consistently higher rates of poverty than the US as a whole ("Mapping Poverty in the Appalachian Region") and has consistently less favorable health indicators ("Health Disparities in Appalachia"). It almost seems like an example of the "resource curse paradox" *within* a wealthy country.

Political Difficulties Facing Waste-to-Energy Conversion Plant Siting, more commonly known simply as *The Cerell Report*, was commissioned by the California Waste Management Board to identify the characteristics of communities least likely to successfully resist the siting of a trash incinerator, and by extension, other "locally undesirable land uses" (LULUs). While race is not explicitly mentioned, low-income and otherwise politically disenfranchised communities are *intentionally* targeted. The Cerell Report enumerates the reasons why it makes sense for companies to select vulnerable communities to "host" their facilities.

This from a section entitled "Personality Profile":

> Certain types of people are likely to participate in politics, either by virtue of their issue awareness or their financial resources, or both. Members of middle or higher-socioeconomic strata (a composite index of level of education, occupational prestige, and income) are more likely to organize

> into effective groups to express their political interests and views. All socioeconomic groupings tend to resent the nearby siting of major facilities, but the middle and upper-socioeconomic strata possess better resources to effectuate their opposition. Middle and higher-socioeconomic strata neighborhoods should not fall at least within the one-mile and five-mile radii of the proposed site...Technically feasible sites could then be rated in accordance to the composition of the nearby residential clusters, weighing the “strong personality indicators” of opposition greater than the secondary features. (26)

Nevertheless, even in communities with favorable "personality indicators," there will be resistance. The demographic perceived to be the greatest threat to LULU siting? Housewives.

The report has no strategy suggestions to overcome mothers' fierce instincts to protect their children. However, the authors are convinced that other potential opponents can be manipulated.

Environmentalists are one such group. Presumably by greenwashing incineration as an environmentally sound activity, the environmentalists will be won over:

> The concept of a Waste-to-Energy project should be introduced to the public at the onset as part of a recycling program. Typically, the leading opponents to Waste-to-Energy projects in California are environmental groups.

Does Bhopal conform to the profile of a Cerrell community? Do domestic and international criteria for LULUs differ? Where are the risks concentrated? Where do the profit / benefits accrue?

Augusto Boal's *Theater of the Oppressed* techniques have been used by communities impacted by environmental injustice to organize, to deepen their collective analysis of the situation, and ultimately to resist. John Sullivan and Juan Parras have written about one project in Texas (Sullivan and Parras). What other stories of successful resistance can you tell? What makes resistance "successful"?

Tactic #5: Giving Up

It turns out that the world's youngest mother gave birth (by Cesarean) in 1933, at the age of five. Doctors do not know when her menstrual cycles began, but she had conceived when she was only four. This is the youngest documented instance of what is called "extreme precocious puberty," and it remains quite rare.

However, premature thelarche (defined as early development of the breasts without necessarily leading to early menstrual cycles, which would be called premature menarche) is not uncommon. A Mayo Clinic study in Olmsted County, Minnesota followed a cohort of girls from 1940 to 1984. They found that overall, 29.1% of the girls had early breast development, most before the age of two. No cause was identified, but the researchers were reassured that the girls seemed otherwise healthy and evidenced normal reproductive function.

A strange accidental experiment unfolded in Michigan. In 1973, a worker at the Michigan Chemical Company accidentally sent the Farm Bureau several thousand pounds of a white powder that he thought was NutriMaster (a magnesium oxide feed supplement). It turned out that inside the nearly identical 50-pound sacks was actually a different product that the company manufactured -- a plastics additive called FireMaster BP-6, which is a toxic mix of polybrominated biphenyls (PBBs). By the time the error was caught, the PBBs had been mixed with feed that was distributed to farms all over Michigan. At least one and a half million chickens, thirty thousand cattle, nearly six thousand pigs, and about fifteen hundred sheep ate the flame retardant, and many died slow and gruesome deaths. The rest of the animals were shot, but not before thousands of people had consumed the tainted meat and dairy products (Van Winter et al.). Since PBBs are known to affect the immune system as well as human hormones, scientists carefully tracked the health impacts of this accident. They found that children whose mothers were exposed during pregnancy had an earlier onset of menarche and pubic hair development, but that the age at which breast development occurred was no different than in unexposed girls (Blanck et al.).

In China, in 2010, three infants aged four to fifteen months old began developing breasts. Doctors found that their estradiol levels were as high as that of a typical adult woman. Their levels of lactogen were also elevated -- three to seven times what is considered normal for infants. The babies lived in different cities, but all were all given the same brand of powdered milk (Webley), which was assumed to be the cause. It is not understood why other children drinking the milk were not immediately affected.

It isn't only girls. Sudden breast enlargement in both boys and girls was documented in 1979 at a school in Milan, Italy that inadvertently served DES-contaminated veal (Fara et al.). After the incident, the children's breasts regressed. The researchers who had documented this incident undertook a study that compared children in Milan to those in Mantova, another northern Italian city. They found a a 36.6% prevalence of breast enlargement among girls under two years of age in Milan, whereas in Mantova the prevalence in children under six was 0%. They posit that something other than contaminated food may be playing a role, but they do not hypothesize what it might be.

Puerto Rico, which has the highest incidence of premature thelarche ever recorded, presents an even bigger mystery. Beginning around 1979, pediatric endocrinologists began reporting unusual numbers of patients with signs of early puberty. The Puerto Rico Department of Health created the Premature Thelarche and Early Sexual Development Registry in 1987 to collect these patients' medical histories. By 1998, over 4,674 girls were registered (Colón et al. 2000). Not included in the registry are the men and boys. A pediatric endocrinologist with whom I spoke informed me that transient gynecomastia (breast tissue that grows and then inexplicably recedes) is almost universal among pubertal boys in Puerto Rico.

Not only teens, but also grown men are susceptible. Twenty-one men from Haiti who were taken into custody by immigration officials developed enlarged breasts during their stay in Fort Allen, a Puerto Rican detention facility. Further, the *Lancet* reports that "six of fifty-two Haitian males who had been transferred to Fort Allen from processing centers in New York State and Texas acquired gynecomastia after their arrival on (sic) Puerto Rico" ("Unusual Breast Development"). Their condition resolved when they left Fort Allen.

According to some reports, their condition could be attributed to a delousing treatment. The detained men were forced to douse themselves and spray their rooms with insecticides known to be endocrine disruptors (lindane, which is weakly estrogenic, and phenothrin, an anti-androgen), whether or not lice or scabies were present. This use is off-label for phenothrin, which is not approved for use in humans (Brody and Loriaux). Maria Rodriguez, who was a supervisor at the detention facility, admits that Haitians were singled out: "It was the policy at Krome...to delouse only the Haitians. Cubans and other undocumented aliens were not deloused upon arrival" (“Haitians Suing U.S.”)

Ivelisse Colón, a researcher in the chemistry department at the University of Puerto Rico, had a theory. Phthalates, a class of anti-androgenic chemicals used to make vinyl soft and flexible, are known to alter the age of onset of puberty. She took blood samples from 76 girls: 41 cases and 35 controls. She found "significantly high levels of phthalates [dimethyl, diethyl, dibutyl, and di-(2-ethylhexyl)] and its major metabolite mono-(2-ethylhexyl) phthalate" in 28 (68%) of the serum samples from the cases, but only in one of the control subjects, and that was a different form of phthalate (di-isoctyl) (Colón et al.). While sample sizes were admittedly small, the data are compelling. However, when I mentioned her study at scientific conferences, it was met with derision. Some contended that it was unlikely that such high levels of exposure were possible in the general population, and that only cross-contamination or other errors in the lab could explain what she was seeing. After all, it has a short half-life. Why was she testing blood anyway, rather than looking for urinary metabolites, which is standard procedure?

The levels turned out to be not so unusual. NHANES data confirms that the average phthalate levels in the general population in the US are in the range that Colón saw (Silva et al.), with children's levels considerably higher than adults for most of the metabolites detected. Why, then, are cases of premature thelarche less common on the mainland?

In addition to their role in the manufacture of PVC, phthalates are used as an "inert" ingredient in many pesticides, cosmetics, and fragrances. Dimethyl phthalate is an inactive ingredient in many pesticide formulations, and along with diethylphthalate has been used as an insect repellant since World War II. Could the phthalate exposure Colón found be a proxy for insecticide exposure? Could the phthalate itself be responsible for the hormonal effects, or perhaps it was a combination of phthalates and insecticide?

Or perhaps there are other, less widely acknowledged, exposures. During the 1960s and 70s, the United States military used diethyl phthalate and another plasticizer, trioctyl phosphate, to simulate VX (an orgnophosphate nerve agent) in Cold War chemical and biological weapons tests (*2003 Report to Congress*). Di-(2-ethylhexyl) phthalate was also used as a chemical weapon simulant. In the May 1969 Desert Test Center Test 69-10, "Project SHAD" trioctyl phosphate (TOF), presumably along with phthalates, was sprayed over the beaches of Vieques (*2003 Report to Congress* 109-10). (VX and diethylphthalate were tested over Oahu, HI in Aug-Sept 1965 Fearless Johnny [136-9] and in the Dugway Proving Ground in Utah in 1971.) Since many details of these tests are classified, questions remain. Have these tests ceased, and if so, when? Phthalates, particularly the high molecular-weight congeners, are relatively long-lived. The volatization half-life from water is fifteen years (Neff) and they appear to accumulate in seafood[44].

Many other theories have emerged to explain Puerto Rico's epidemic of premature thelarche. Contamination of the food supply is a popular guess. DES, a synthetic estrogen, was routinely prescribed to pregnant women until it was found to cause a rare vaginal cancer in daughters exposed in utero. It is also used in livestock, and has been detected in milk, meat, and chicken. Although it was banned in US cattle farming in the early 70s, it was reportedly still being marketed in Puerto Rico in the mid-80s (Engel). As you may recall, DES-contaminated veal was the culprit identified in Milan, Italy in two outbreaks of unusual breast development in school children in 1979 and again in 1986 (Fara et al.; Nizzoli et al.). A British veterinarian suggested that an estrogenic mold, Zearalenone, might be present in imported corn (Schoental). Some speculated that babies given soy formula might be responding to the naturally occurring phytoestrogens; however, babies in other places also drink soy formula, without developing breasts. Some blame a pharmaceutical company that manufactured birth control pills and discharged estrogenic wastewater into a receiving water body used for recreation and fishing (Colón).

Epidemiolgists from the Centers for Disease Control and Prevention conducted a case-control study focused on suspected risk factors, including diet and parental employment in a pharmaceutical manufacturing facility, and found nothing conclusive.

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[44] The octanol-water partition coefficients (K_{ow}) of the larger molecular weight species, such as di-iso-decly phthalate (10 to the 9.46) indicate a relatively high degree of hydrophobia and lipophilicity, which would suggest that phthalates might be likely to respond similarly to POPs in their propensity to adsorb to plastic marine debris, and to biomagnify in the marine food web. Bioconcentration factors measured in fish range from 42 to 2680 (Thornton et al.) Phthalate concentrations, like those of BPA, demonstrate a seasonal variation. There is an additional mechanism at work, however. In the summer, when the water is warmer, DEHP in sea water metabolizes to carbon dioxide, lowering its concentration. Thus, higher levels would be expected in the winter (Neff).

They tested water for estrogenic activity and found nothing (Lamberina et al.).

Whatever the cause, early sexual development is thought to put girls at higher risk of sexual abuse (Herman-Giddens et al.), drug use (Steingraber), and to increase the risk of breast cancer later in life (Bodicoat et al.). Despite these potentially devastating sequalae, scientific interest waned and the epidemic, which I am told is ongoing, has been deemed an unsolvable medical mystery. While significant (though insufficient) resources are devoted to understanding other risk factors for breast cancer, in the general population, the women of Puerto Rico are no longer a research priority.

I. **The Precautionary Principle: Acting in the Face of Uncertainty**

One formulation of the precautionary principle is, "When an activity raises threats of (catastrophic) harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically" ("Wingspread Statement"). We must weigh the potential harm in not acting, as well as in taking action. For example, if one suspects immunizing pregnant women against swine flu might cause them to give birth prematurely, one would also need to consider what the risks of swine flu itself would be in the expectant mothers (Stobbe). Create a chart of actions that could be taken to prevent additional cases of premature thelarche in Puerto Rico, given what we know -- and don't know-- today. In one column, they list the potential benefits of the action, and in the second column the potential medical and / or social harms. The projected expenses are tallied in a third column. Based on these charts, which actions would it be prudent to take? Why? For which would be wise to wait for more evidence? Why?

Instead of the precautionary principle, however, Congress has mandated that the

EPA use cost-benefit analysis (CBA) in its rule-making. It may be useful to note which agencies use a CBA and which do not. For example, actions to prevent terrorism do not appear to be subject to a CBA. Various models of risk perception incorporate constructs such as dread, familiarity, locus of control, visible / invisible threat, and so on. In addition to these constructs, does the vulnerability of the population affected by the potential threat (in terms of political power) shifts CBA parameters in practice. This is, of course, one of the central questions of environmental (in)justice.

Conclusion: Solutions

Public health speaks of three types of prevention. Primary prevention keeps people from experiencing injury or illness in the first place. Secondary prevention aims to diagnose problems early in hopes that prompt treatment will improve the chance of a cure. Tertiary prevention is a set of mitigation strategies that are designed to decrease symptoms and to facilitate adaptation to the new-normal impairment. So we have an emphasis on a healthy diet and sufficient exercise as primary prevention, mammograms for early detection of breast cancer as an example of secondary prevention, and occupational therapy following an amputation as one type of tertiary prevention. What would this framework look like if applied to the world's plastic problem?

I would liken the burgeoning science of quantifying microplastics in seawater, foodstuffs, tap water, and puddles to secondary prevention. We are diagnosing a problem that already exists and assessing the extent of the damage. Post-consumer recycling, finding microbes to eat our trash, and launching enormous drift nets to capture ocean waste could only be called tertiary prevention. They are not a cure; they merely mitigate the symptoms and help us adapt to a new-normal diseased state. What, then, of primary prevention?

Tertiary Prevention: Clean it up

As discussed in the preceding chapter on environmental justice, sometimes "clean up" projects function to euphemistically mask moving a problem from one place to another, or from one media to another (solid waste being burned and created air pollution, for example), or from one generation to another. I termed these displacement across space, displacement across media, and displacement across time. In some instances, however, remediation techniques do exist to degrade plastic completely into its atomic-level building blocks, rendering it once again non-toxic.

Mealworms (*Tenebrio molitor* larvae) can digest polystyrene[45]. *Ideonella sakaiensis* 201-F6 bacteria have evolved to produce an enzyeme (PETase) that degrades polyethylene terephthalate (Yoshida et al.). The fungus *Pestalotiopsis microspora* can subsist on polyurethane (Russell et al.), as can *Aspergillus tubingensis* (Khan et al.). Various microbes eat polyvinyl chloride (Kumar et al.) and polystyrene (Shah et al.). While promising, these novel trophic relationships raise questions. Given the abundance of plastic waste we provide them, these tiny creatures have a marked advantage over their counterparts who thrive on plant matter, potentially shifting the composition of the ecosystem. If we raise these specialists in the laboratory for release into landfills, which in turn release them into the soil and groundwater, will there be unintended consequences for the existing biota?

Meanwhile, we busy ourselves moving waste around rather than detoxifying it. Small-scale cleanup projects are often organized by environmental advocacy groups

[45] Personal communication (January 24, 2017 email from Charlotte Frank, master's student at the University of North Carolina Wilmington.)

and by state and federal entities such as, in the United States, The National Oceanographic and Aeronautic Administration (NOAA). Volunteers collect macro-plastics, preventing them from becoming micro-plastic contamination. The garbage is moved from waterways and from coastal habitats to landfills, or in some cases, to incinerators. Volunteers may take home increased awareness and a sense of ownership of the problem that leads them to change their own behavior and to educate others.

Ironically, we have delegated some of this labor to automated plastic devices, such as the Seabin: a "floating debris interception device" marketed for deployment at marinas and other coastal hotspots. It is constructed of plastic mesh and relies on a 110/220 V motor. It can capture up to 1.5 kg / day under ideal conditions[46].

Others aim to clean up the plastic dispersed at sea. Among these initiatives, Boyan Slat's Ocean Cleanup is the most ambitious. It aims to collect half of the plastic from the North Pacific "garbage patch" within five years using an energy-neutral system of 1-2 km long polypropylene floats attached to massive screens that will follow the same currents as the debris, slowed by drift anchors. The collected trash will be brought to shore for recycling[47]. This will capture the neustonic (floating) plastic larger than 1 cm, but not smaller pieces or pieces submerged below the catchment area of the screens.

The success of marine debris removal projects, however, is entirely dependent on upstream source reduction. That is, as long as we continue to add the equivalent of one full garbage truck full of plastic to the ocean *each minute* (Pennington), our efforts to skim it off will be in vain.

More Tertiary Prevention: Reduce, Reuse, Recycle

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46 http://seabinproject.com/#home

47 https://www.theoceancleanup.com/about/

Many individuals, groups, and some companies have taken steps to reduce their use of disposable plastic. At the level of individual behavioral change, I am an admirer of Beth Terry, author of *Plastic-Free: How I Kicked the Plastic Habit and How You Can Too* (Skyhorse Publishing, 2012) and blogger at *https://myplasticfreelife.com.* We can follow her lead and commit to #StopSucking[48] (to refrain from using disposable straws) or take the Plastic Pollution Coalition's 4R Pledge[49]. However, as we brush with bamboo toothbrushes, using tooth powder from a glass jar, we are still probably standing in a building sided with vinyl, with vinyl windows and probably vinyl flooring. The toilet seat and shower curtains are more than likely also plastic, as are the pipes that drain the water from the sink and the tub, and as are the jackets around the wires that bring electricity to the bathroom light. Most of the plastic we use is invisible to us or is not there by our choosing.

I was browsing the fresh produce section at Whole Foods™ when I spotted an employee stacking organic eggplant. Each was in an individual plastic sleeve, which he was busy removing before adding the eggplant to the display. I asked him how many "unpackaged" fruits and vegetables arrive at the store wrapped in plastic but his answer was an evasive, "I don't know." There was no reply to my email to corporate headquarters. This underscores the importance of demanding transparency and of acting collectively in addition to making our own lifestyle changes.

Just as individuals can take a public pledge to reduce their plastic use[50], corporations too can publicly quantify their plastic footprint at the Plastic Disclosure

48 https://www.strawlessocean.org/
49 http://www.plasticpollutioncoalition.org/take-action-1/
50 https://www.lifewithoutplastic.com/store/pledges_galore

Project[51]. Fabricators can follow best practices to minimize their nurdle[52] loss by following the guidelines set forth in Operation Clean Sweep[53]. Some companies are experimenting with laser etching instead of plastic tags on loose bananas (Pullman) and avocados (Butler). Lush™ has a line of "naked" shampoo bars, soap bars, toothpaste tablets, and other cosmetics sold without any packaging. Patagonia bears mention as well for their investment in evaluating the damage that microfibers shed from their synthetic garments do and in seeking ways to mitigate it[54]. Avasol is pioneering non-toxic sunscreens packaged without any plastic[55]. Sky, a European satellite broadcaster, has committed to not using single-use plastics at all by 2020 (Moore, “Sky to Remove All Single-Use Plastics”).

These forms of use reduction, or "source reduction," are preferred over finding ways to recycle plastic. The use of the term "recycling" in reference to plastics is contentious. Rarely can a plastic be reformed in a closed loop into the same sort of object again and again. Instead it is typically "up-cycled" into art, or "down-cycled" into a less technically demanding application. For example, one of the few uses of post-consumer polyethylene film (such as single-use plastic bags) is being incorporated into Trex™ (Paben, “End User of Recovered PE Film”), a wood substitute. Polyethylene terephthalate bottles often become fleece. This postpones the problem of the ultimate disposal of the plastic only as long as the Trex™ or fleece product is in use. Still, there are encouraging examples of downcycling. Hewlett Packard™ has stated an intention to decouple business growth from materials consumption. Towards this end, they are

51 http://plasticdisclosure.org/
52 Nurdles, also called mermaid's tears, are per-fabrication plastic resin pellets.
53 https://www.nurdlehunt.org.uk/whats-the-solution.html
54 https://www.patagonia.com/blog/2017/02/an-update-on-microfiber-pollution/
55 http://avasol.com/

working with THREAD in Haiti to collect plastic bottles that can be turned into ink cartridges. Because the ink cartridges are black, its producers, unlike most, can accept bottles in a mix of colors (“HP Announces Commitment”).

To complicate matters, incorporating post-consumer plastic into a product tends to be more costly and complex than using a fresh batch, with unstable supply chains posing even more complications. The international market for plastic recycling is volatile, and as of this writing, China's "National Sword 2017" initiative, increasing enforcement of the 2013 "Operation Green Fence" rules, has sharply limited the quality of material that Chinese (re-)processors will be allowed to accept, leaving some US recycling companies renting warehouse space to store their sorted plastics in hopes of a near-future return to a more relaxed market (Paben,”China Announces ‘Sword’ Crackdown”). This is already having dramatic effects on municipal curbside recycling programs (*Oregon Refuse and Recycling*).

For these reasons, a study by the U.K.-based circular-economy focused nonprofit Ellen MacArthur Foundation estimates that just 14 percent of the world's plastic packaging is collected for recycling, and of that, only 2 percent goes toward a closed-loop system. Eight percent is downcycled, and the remaining 4 percent is diverted back into the regular waste stream (“The New Plastics Economy: Rethinking”).

Industry frequently laments that the plastic problem would be solved if consumers would simply dispose of plastic waste "responsibly." However, the infrastructure is not ready to accommodate it. In the UK, 2.5 billion disposable "paper" coffee cups are used each year, but since they are lined with plastic, even those sorted into recycling bins are ultimately rerouted to landfills or incineration. The plastic lining complicates the recycling process and requires specialized machinery, which is not widely available. Only 1% of these cups are actually recycled (Taylor, “Coffee Shops”). Encouraging customers to bring in a reusable travel mug to be filled would be an alternative; however, there would need to be infrastructure to sanitize reusable containers and cups to avoid a different sort of public health problem (Dennis).

Bioplastics: Moving Towards Primary Prevention?

Bio-derived plastics are chemically indistinguishable from their petrochemical counterparts. It does not matter whether the constituent carbon and hydrogen atoms were extracted from plants or from oil. Once they are are mixed with oxygen and rearranged into long chains of bis(2-hydroxyethyl) terephthalate, they have exactly the same toxic properties as do the conventionally manufactured monomers, and in all likelihood use the same problematic additives as do conventional plastics, conferring no environmental advantages at the disposal stage. An example of this is the blend of PET used in Coca-Cola's "Plant Bottle™" [56].

Some, however, use natural materials to create an entirely different monomer, such as polyethylene furanoate (PEF)[57]. If the toxic petrochemical additives are not used, and if it biodegrades (not all bioplastic is biodegradable), then we are moving back towards materials borrowed from nature. There has been concern about using plants for plastic that would otherwise be used for food. In response, researchers are making some bioplastics from bacteria. One example is polyhydroxyalkanoates

56 http://www.coca-colacompany.com/plantbottle-technology
57 https://polymerinnovationblog.com/polyethylene-furanoate-pef-100-biobased-polymer-to-compete-with-pet/

(PHA)s[58]. Then there are the truly innovative solutions: "Ooho," an edible water bottle, is made of a simple seaweed and calcium chloride membrane[59].

Compostable / biodegradable plastics are another active front for research, albeit one rife with dubious claims that border on greenwashing. One example is the blending of conventional plastic with starch in order to give the illusion that it breaks down in a compost bin. In reality, the starch breaks down, leaving tiny pieces of plastic invisible to the naked eye, but all the more easily ingested by unwary organisms. If these organisms do not digest it but merely carry it within their bodies, then it may accumulate in its predators as well, introducing yet another pathway for plastics to concentrate in the food web. Other compostable plastics, such as polylactide (PLA) and polybutylene adipate terephthalate (PBAT), have been blamed for contaminating the recycling stream and rendering bales of conventional post-consumer plastic worthless (Stephen).

Nevertheless, Saudi Arabia and the United Arab Emirates, among other nations, have mandated that polypropylene and polyethylene for use in non-durable goods (though packaging is excepted [Giger]) be modified with a petrochemical-derived oxo-biodegradable catalyst that speeds the end-of-life decomposition of (otherwise conventional) plastics ("Preventing Oceans of Plastic Soup"). It does this by breaking the high-molecular weight polymeric chains into lower-weight molecules. However, a coalition of 150 groups, from industry to environmental advocacy organizations, have signed on to the Ellen MacArthur Foundation's New Plastics Economy initiative to call for a ban of these additives, arguing that they create more environmental problems than they solve (Staub). For example, when consumers believe that a product while degrade

58 http://www.european-bioplastics.org/these-were-the-highlights-that-shaped-bioplastics-in-2016/
59 http://www.skippingrockslab.com/

"more quickly than a leaf[60]," as the promotional materials promise, they are more likely to litter than to bother with putting it into a trash or recycling bin (*The Impact of the Use of '"Oxo-Degradable" Plastic*).

Policy and Regulatory Solutions: A Mixed Bag

Costa Rica has declared that it will develop a plan over the next four years to end its use of all forms of disposable plastic (Gutiérrez). The Indian state of Karnataka has banned not only all forms of plastic carry bags, but also plastic banners, buntings, flex, flags, plates, cups, spoons, cling films and plastic tablecloths (Moudgal). Sikkim, India, has also banned expanded polystyrene food containers, with an exemption for milk products (Mougdal). As of 2020, any disposable cutlery, plates, or cups used in France will be required to break down in home compost bins to be at least 50% biologically sourced[61]. More than twelve US cities have implemented a complete or partial ban on polystyrene, although some of these are being challenged in court[62].

Several countries have joined the UNEP's Clean Seas campaign, including Belgium, Brazil, Canada, Costa Rica, France, Grenada, Indonesia, Italy, Madagascar, the Maldives, Norway, Panama, Peru, Saint Lucia, Sierra Leone, and Uruguay[63].The European Union as a whole, however, has ruled out penalties on single-use plastic products, in favor of raising public awareness of the damage consumer plastics are doing to the world's oceans (Harvey).

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60 "Nature's wastes such as leaves twigs and straw may take ten years or more to biodegrade, but oxo-bio plastics will biodegrade more quickly than that, and much more quickly than ordinary plastic." http://www.biodeg.org/standards.html accessed 11/8/17

61 https://www.banthebottle.net/news/france-bids-adieu-to-plastic-cups-plates-and-cu

62 http://storyofstuff.org/blog/styrofoam-bans-are-sweeping-across-the-nation/

63 http://cleanseas.org/take-action and http://web.unep.org/newscentre/un-declares-war-ocean-plastic

By 2021, the world will produce half a trillion single-use plastic bottles each year (Laville and Taylor). Coca-Cola™ alone produces 110 billion bottles each year, according to Greenpeace (one billion more this year than last) (Laville). Only 3% of all plastic bottles were collected for recycling and turned into new bottles. Recognizing the danger, over eighty schools, colleges, and universities have forbidden the sale of bottled water on their campuses[64]. Instead they offer free filtered water at bottle refill stations and drinking fountains. Some towns and cities in Australia, Canada, India, and the United States have banned bottled water with various exceptions[65]. A short-lived ban on bottled water in US national parks was estimated to have prevented the waste of between 1.32 and 2 million plastic water bottles annually before the Trump administration rescinded the ban (*Disposable Plastic Water Bottle Recycling*).

New Zealand, Australia, UK, Canada, Taiwan, and the United States have banned microbeads in personal care products, and several other countries are considering such legislation (Lai).

Disposable shopping bags are one of the most frequently regulated uses of plastic. In Bangladesh, the first nation to enact a ban, concerns were centered not on marine debris but on the problem of clogged drains, which increase the likelihood of flooding (Admin; “Polythene Choking Drains”). Littered plastic bags also pool water, creating new breeding sites for mosquitoes (Traore). Nearly 40 countries have followed Bangladesh's lead (see Appendix 1); however, lax enforcement reduces the impact in many parts of the world. While the USA, Canada, Australia, Argentina, and Malaysia have no national regulations, many local, state, and provincial governments have

64 https://www.banthebottle.net/map-of-campaigns/
65 https://en.wikipedia.org/wiki/Bottled_water_ban

imposed bans or fines[66]. However, Michigan, Arizona, Idaho, Minnesota, Iowa, Missouri, Wisconsin, Florida and Indiana have passed legislation *preventing* local governments in their states from regulating plastic bags[67].

Secondary Prevention: Measure the Mess

There is often an overlap between research and teaching, by design. Citizen science itself can be viewed as a form of popular education. Hideshige Takada, a professor at the Tokyo University of Agriculture and Technology and founder of the International Pellet Watch program, is engaging citizen scientists in collecting pellets along beaches throughout the world, which Takada then analyzes for POPs. This project of synthesizing data that quantifies the contaminants of interest in the water matrix and biota is intended as a first step towards understanding the movement of contaminants through the food web. Another example is Five Gyres, TrawlShare program. This makes the equipment necessary to sample at sea available at no cost.

Governments could be more involved in this endeavor. Now that micro- and nano-plastics have been widely detected in tap water (Morrison and Tyree), the US Geological Survey should consider adding this testing parameter to its data collection[68]. The National Health and Nutrition Survey (NHANES), which collects biospecimens and survey data from thousands of volunteers in a nationally representative sample, should begin testing for microplastics and nanoplsatics in human serum and urine[69].

Using Plastics to Purify

Ironically, polymers themselves may be a useful tool in understanding our

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[66] Data for this table was aggregated from http://study.com/blog/which-countries-have-banned-plastic-bags.html, http://www.bigfatbags.co.uk/bans-taxes-charges-plastic-bags/, https://en.wikipedia.org/wiki/Phase-out_of_lightweight_plastic_bags and local press

[67] http://www.ncsl.org/research/environment-and-natural-resources/plastic-bag-legislation.aspx

[68] https://waterdata.usgs.gov/nwis/rt

[69] https://www.cdc.gov/nchs/nhanes/index.htm

"exposome." Dr. Kim Anderson has created a silicone bracelet that records, so to speak, any of 1,200 chemical compounds that the wearer's wrist comes into contact with -- either in water (from showering, swimming, or precipitation) or in the air. This does not, of course, take into account anything that the wearer ate, or personal care products (such as makeup) that did not touch the bracelet. It is being used now to track the exposures of residents in Texas following the Hurricane Harvey-related flooding of toxic waste sites (O'Connell et al.).

The bracelet itself is inexpensive; the chemical extraction of the contaminants it holds, however, costs thousands of dollars, putting it out of reach of unfunded citizen scientists. Another disadvantage is that because it utilizes a targeted approach, we only find what we are looking for. Still, it could archive our exposome for future research when we know different questions to ask.

Because of this lipophilicity, plastics can pollute, and plastics can also purify. Polystyrene and other synthetic polymers are used in ion-exchange media to filter such varied liquids as drinking water, fruit juices (to remove bitter flavors), and biodiseal. The resin beads can capture lead and cadmium, replacing them with sodium and potassium. "Bio-beads" are already used, though not widely, in the UK in water filtration plants (Taylor, "Sewage Plants"). There are concerns about wastewater treatment plants themselves becoming sources of microplastics via these fugitive beads, however, and hopefully a safe method of rinsing and reusing the beads will be developed.

Primary Prevention

A primary prevention approach that addresses the root causes would involve not only technological advances but a new worldview. Our task is not necessarily to imagine a world without plastics, but a world without disposable plastics -- and without the habits of instrumentalism that they signify.

Plastics are accelerating the commodification of the planet. Twenty-six percent of all plastic (311 million tons in 2014) is used for packaging (*The New Plastics Economy*). We are told that this serves to protect our products, and to extend their shelf life (Tullo), in some cases rather dramatically, which is all quite true. However, it is also true that much of this packaging is devoted simply to advertising and branding -- and this is where a great deal of industry's profits are to be made. Only 15% of the price of cosmetics, for example, represents the cost of the ingredients (Bryant). The rest is for "marketing, packaging, and branding" (Bryant), and the line of demarcation between these is fuzzy indeed.

Packaging signifies that an item has become a commodity. Until it is bottled and stamped with a brand logo, water does not seem to belong to anyone. It doesn't make much sense to sell it (unless you are selling the infrastructure used to deliver it, as is the case with municipal water utilities). Once it has become Evian™ or Fiji™ water, however, it can be sold for up to 2,000 times the price of tap water (Boesler). In the past, explorers from colonizing nations planted a flag to assert possession of a territory[70]. Today we use a plastic bar code sticker.

Of course, plastics are not the first material to be used for this purpose. In the past, however, the materials used for packaging were either borrowed from nature, such as corn husks or banana leaves, or were on loan to the consumer. The market value of glass bottles and metal cans incentivized, and continues to incentivize, their collection,

70 I cannot resist pointing out that today almost all flags are plastic (either polyester or nylon).

sterilization, and reuse. In the case of most cheap plastic packaging, virtually no one has an interest in reclaiming it.

Today, half of all plastic produced is intended to be single-use / disposable (Hopewell). And there is quite a bit of it. As of July 2017, 8300 million metric tons of plastic have been produced, of which only 2 000 million metric tons are still in use. Seventy-nine percent of the spent 6,300 million metric tons is already in landfills or littering the natural environment (Geyer). Twelve percent has been burned. Nine percent has been recycled, delaying its inevitable disposal (Geyer).

In order to create a society where no one and no-thing is wasted, we will need a fundamental shift in our relationships. Astrid Ulloa calls for a relational indigenous environmental justice that is:

> based on a sense of responsibility and reciprocity...putting relational ontologies at the center of a rights-based approach to consider nonhumans' rights, including to not forget the implications of epistemic violence and ethno- and ecocide generated by the current global environmental geopolitics of knowledge and economic dynamics; proposing other notions of justice by including territory and ''nature'' as ''victims'' of processes of extractions and destruction of environment; considering historical inequalities that were respondent to modern dual conceptions, which were implemented since the conquest and colonial processes; confronting the extractivist processes that erased legal, environmental, and cultural rights previously recognized; and demanding other perspectives of environmental justice in which humans, nonhumans,

> and the territory are included as living beings and as political actors (Ulloa).

Ulloa reminds us that some people and some ecosystems have been treated as disposable long before commodity plastics entered the scene.

Fundamentally, plastic marine debris and terrestial plastic litter do not bother us because it is unsightly or even because it is toxic. Collectively, far fewer voices protest other unsightly and toxic situations like Agbogbloshie or Chemical Valley in Sarnia. No, we protest because plastic wastelands hold up a mirror that reflects what we do not want to see in ourselves. Plastics were going to protect rare species from poaching, by offering an alternative to ivory. Plastics were supposed to democratize. Luxury goods, or at least facsimiles thereof, would be mass produced and available to all. Plastics were supposed to reduce drudgery. Instead of washing dishes, some of us could simply toss them in the bin. We thought that they made us modern and free.

Instead, they remind us that the world of abundance and luxury that we have created is merely an illusion. Rejecting 侘寂 *wabi-sabi* -- the beauty of imperfection and impermanence-- we hold ourselves to the same low standards that we do our mass-produced goods. We imagine that we, too, should be functional, uniform and without any distinguishing blemishes.

We are reminded when children mouth their plastic toys that they are taking in more than marketing and early socialization. They might be swallowing chemicals that reduce their chances of someday starting a biological family of their own. That these chemicals, having initiated harm that may take decades to manifest, will pass through their bodies and into the watershed. That they will go on to harm many many more, perhaps for centuries to come.

To make matters worse, someone else's child choked on the fumes from the petroleum distillate, naphtha[71], that was "cracked" into ethylene and mixed with chlorine to produce the sickly sweet-smelling vinyl chloride monomer that became the toy. Someone else's child might have made this toy, earning US 0.016¢, which is 1 / 2000 of the price it sells for. [72] Someday someone else's child might come across that toy as they sort through mountains of garbage, earning between .05¢ and .23¢/ kilogram for the resalable or recyclable plastic they find (Ocean Conservancy). They would toss it aside. Post-consumer PVC has no value in the modern economy. Nor does the waste picker.

That waste picker, who earns less than $2.00 a day, cannot afford soap or cooking oil. They purchase it, one single-use portion at a time, in little plastic pouches. And some Western environmental activists blame them and the "sachet economy" they "support" for the plastic scraps that scatter in the wind, burying the reclaimable pieces that mound in ever-higher piles in the dump.

The world we are creating is incompatible with life. We have devised an economic system that would collapse if people's real needs were met. Insatiable greed is slaked in single-serving portions that come individually wrapped in plastic.

We are better than that...aren't we?

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71 As you might recall, it was naptha and residual condensates that the *Trafigura* dumped in the Ivory Coast.

72 "For instance, in 2007 more than 300 middle school students, some child labor under 16, were discovered toiling 11 hours a day at a plastic toy factory. Several students' health suffered as a result of long hours and chemical poisoning; one female student even died." http://www.chinalaborwatch.org/report/111

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Appendix 1: **Plastic Bag Bans and Fees**

Country	Year of First Legislation	Type of Regulation	Notes
Bangladesh	2002	ban	
Belgium	2007	tax	
Botswana	2007	levy	
Brazil	2007	ban	
Cameroon	2014	ban	
China	2008	ban	
Columbia	2016	ban on bags under 30 cm by 30 cm	
Costa Rica	2017		"will take measures to dramatically reduce single-use plastic through better waste management and education[73]"
England	2015	5 p tax	applies only to all companies with 250+ employees and does not apply to paper bags
Eritrea	2005	ban	66% reduction in the use of plastic and paper bags
Ethiopia	2011	ban on imports	not enforced
EU	2014		"passed a directive to reduce plastic bag use by 50% by 2017 and 80% by 2019"
France	2014	ban on < 50 microns	includes produce bags
Germany	2016	"recycling tax"	
Greenland	2004	tax	
Guinea-Bissau	2013	ban	
Hong Kong	2015	levy	
India	2002	ban	2002: a ban on production of plastic bags < 20 μm in thickness, 2016: ban expanded to all polythene bags < 50 microns; enforcement very lax

73

75 "United Nations Declares War on Ocean Plastic." 23 Feb. 2017, web.unep.org/newscentre/un-declares-war-ocean-plastic.

Indonesia	2016	tax	
Israel	2017	tax	
Ireland	2002	€0.22 tax, paid into Environment Fund	(Northern Ireland, 5 p tax, 2013)
Italy	2011		banned the distribution of plastic bags that are not from biodegradable sources
Kenya	2007, 2011, 2017	ban	
Mali	2012	ban	
Malawi	2015	ban	
Mexico	2010	fine	fines stores distributing plastic bags, but not enforced
Morocco	2015	ban	
Myanmar	2009	ban	
Netherlands	2016	€0.25 levy	
Papua New Guinea	2015	ban	
Romania	2006	tax	tax reduced in 2011
Rwanda	2004, 2008	ban	
Scotland	2014	5p tax on all bags	carrier bag usage fell by 80%
Senegal	2015	ban	
South Africa	2004	levy	
Switzerland	2016		two largest supermarket chains voluntarily discontinued providing free plastic bags
Taiwan	2003	ban	amended in 2006 to permit free plastic bags at restaurants
Tanzania & Zanzibar	2005, 2006	ban	By July 2012, evidence showed the number of plastic bags given away by shops had fallen by up to 96%.
Tunisia	2017	ban	
Uganda	2007	ban	
Uruguay	2017	tax	Uruguay has pledged to take this action in conjunction with the UNEP's Clean Seas campaign[74]

[74] "United Nations Declares War on Ocean Plastic." 23 Feb. 2017, web.unep.org/newscentre/un-declares-war-ocean-plastic.

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Appendix III

Plastics as a Spiritual Crisis

SASHA ADKINS

Summary: Disposable plastics are paradigmatic of a culture that has lost its ability to form healthy relationships. We vilify the plastics that infiltrate our oceans, our water, and our bodies without reflecting on why we produce over 300 million metric tons of it a year. While plastics are only one of many unhealthy components of a society premised on planned obsolescence, I single them out because not only are they inherently toxic at each stage of their "life" cycle, they may become even more dangerous once they are thrown away. This is fundamentally a spiritual problem, which technological fixes will not resolve, but only a cultural transformation concerning disposability.

WRITING ABOUT PLASTIC BY industry employees or environmental activists, whether scientific or literary, invariably begins with a paean. The authors remind us how lucrative the plastics industry is, how dependent we've becorne on the "convenience" plastics provide, and how unrecognizable life would be without them. Some hearken back to a famous scene from the 1967 film *The Graduate:* Mr. McGuire offers career advice to recent college graduate Ben at a cocktail party, conspiratorially whispering, "I have one word of advice to you, just one word: *Plastics:'* Mr. McGuire's faith in the great promise of plastics has, in the view of most commentators, been fulfilled. Even those who enumerate the ways that plastics are harming us feel obliged to assert a basic loyalty to them-an expression, I suppose, of the Stockholm Syndrome.

I feel no such obligation, and see the abundance of plastics as a pro found problem, not a point of pride. Plastics are a convenience only to the short-sighted. In 1950, the world produced 1.7 million tons of cellulose, urea formaldehyde, Bakelite, PVC and nylon. By 2012, we were making 288 million metric tons of synthetic polymers a year (UNEP 2014; see http:/ /www.statista.com/ statistics/ 282732/global-production -of-plastics since-1950/). When will we reach a saturation point? Plastic medical equipment, from disposable gloves to pacemakers, has prolonged many lives; yet plastics themselves are suspected of contributing to many of the diseases we try to cure. In my opinion, we would have been better off without plastics, but I believe it is still possible to break free from and relearn to live without them. I think our survival depends on it.

I. Plastics in Our Food

Let's begin this overview with how we are ingesting plastics at a far higher rate than we realize. For example, many time-release medications and vitamins are microencapsulated in plastics (see presentation at http:/ /www.authorstream.com/Presentation/vamshi767-2066171-microencapsulation/). Fresh fruit may be coated in vinyl chloride-vinylidene chloride copolymer (similar on a molecular level to an invisible layer of Saran Wrap) or oxidized polyethylene to prolong its shelf life (see FD& "Everything Added to Food in the U.S:' site: http://www.accessdata.fda.gov/ scripts/fcn/ fcnNavigation.cfm ?rpt =eafusListing). Chewing gum bases made of natural chicle or beeswax have been replaced with sugar-coated polyvinyl acetate and synthetic elastomers like styrene-butadiene. Some exfoliants and toothpastes also contain plastic microbeads (http://www.ctvnews.ca/business/ crest-removing -controversial microbeads-from-toothpaste-after-outcry-1.2013155). Cows chew cud in stead of gum, but a U.S. patent for "artificial roughage" eliminates the need fort hem to graze: yet "synthetic hay" is simply strips of shredded polyethylene (http://www.wikipatents.com/US-Patent-3876793/method-of-aiding digestion-with -artificial-roughage-materials). Fortunately, this practice is not yet widespread.

We also add plastics to our food indirectly. Many studies demonstrate that the plastic containers in which we store, heat, and freeze food and beverages leave traces of themselves behind in the food (Adkins 2014). Many of us try to avoid microwaving plastics, place our leftovers in glass or stainless steel, and avoid brewing coffee in plastic. However, most of the contact between food and plastics is invisible, occurring long before we bring it home. Martin Wagner and Jorg Oehlmann compared snails Iiving in mineral water from plastic bottles to snails living in mineral water taken from glass bottles (2009). The former had many more offspring, which is one indirect way to measure their estrogen levels. The confusing part was that sometimes the water from glass bottles seemed to have high levels of estrogenic chemicals, too. The mystery was solved by a visit to the bottling facility: it turned out that the glass bottles were inert, but that the water had been stored in plastic *before* being transferred to glass bottles!

Even before food is processed, it may be grown in plastic. Produce grown in greenhouses constructed with plastic panels may contain significant levels of bisphenol-A (BPA), a hormone-disrupting component of polycarbonate plastic (Sajiki et al. 2007). Researchers suspect that this chemical might be transferred through the air. Another potential source of indirect contamination is the post-consumer polystyrene pellets that are sometimes mixed with the soil in which some crops grow in order to hold water, minerals, and nutrients" (http://tamgreen.com/gaia_soil). We know that heat increases the rate of transfer of chemicals from plastic into whatever it is touching. When soil is steamed (as is often done as a non-chemical means of sterilizing it), or on hot summer days, are plants taking chemicals from these pellets up into their root systems? We do not know enough about how much of a risk this could pose to people or to the plants themselves. Rhizobial bacteria fix nitrogen, communicating with their host plant using phytoestrogen signals (the plant version of our body's estrogen signals); BPA disrupts this process (Fox et al. 2001, Vivacqua et al. 2003).

It is in the oceans, however, that plastic's impact on the food chain is most worrisome to me Some of the physical hazards of plastic are readily visible: plastic marine debris strangles, suffocates, and drowns birds and marine life. Some seabirds seek synthetic rope as a building material for their nests, which can result in entanglement (Votier et al. 2011). Over 260 species of marine wildlife, including whales, turtles, birds, and fish have been observed feeding on pieces of plastic large enough to choke them or to obstruct their digestive tract (see https://www.mcsuk.org/press/view/181 and http:llwww.seashepherd.orglreef-defenselmarine-debris.html). Large pieces of plastic debris slam into coral, breaking off pieces of fragile reefs and ruining habitat for the prey; the smaller pieces the coral eats (http:l/ www.thehindu.comltodays- pap er*ltp*-nationall corals-feeding-on-plastic debrislarticle6930514.ece).

Plankton comprises the base of the marine food chain, and along with krill, is the largest animal biomass on our planet. One type of plankton often used as a biodiversity indicator is the copepod (https:l/en.wikipedia. orglwikiiCopepod). Without it, many small fish would go hungry. Plankton feed at the surface, where lighter plastic debris is abundant. Could plankton be eating it, and what impact would that have? A lab experiment attempted to answer these questions (Cole et al. 2015). Finely powdered polystyrene was added to the water in the tank of a copepod, which did indeed feed on the polystyrene; subsequently its ability to ingest nutritive 'food decreased, and its survival rates plummeted. It is not clear whether this is because the plastic was a physical obstruction in its digestive tract or whether it was acting as a poison.

Whole plastics are called *polymers;* their chemical building blocks are referred to as *monomers.* To further complicate matters, each polymer also contains a blend of other chemicals that do not contribute to its structure, but instead confer properties such as color, texture, or durability. 1hese are called *additives,* and their particular combinations, which vary from batch to batch during production, are closely guarded trade secrets. Many legal additives in plastics are acknowledged as being toxic, such as lead, cadmium, phthalates, organotins, and tricresyl phosphate. In the case of plastic marine debris, we need to know the fate not only of the polymer, but also of its monomers and additives.

Chanbasha Basheer and colleagues bought seafood from a market in Singapore (2004). They tested five samples each of prawn, crab, blood cockle, wbite dam, squid, and a pelagic species of fish, *Decapferus russelli,* for BFA, the building block of polycarbonate plastic. BFA was present in *every* sample, at levels that ranged from 13 to 213 parts per billion (ppb) wet weight, with the highest levels found in the crabs. We can begin to comprehend this ratio of concentration through analogies: one part per billion as one pancake in a stack 4,000 miles high, or three seconds in a century. Though these are infinitesimally tiny amounts, a concentration of BFA in the six to ten ppb range or even less has been shown to have adverse effects (Feretz et al. 2014). As endocrinologists know, the effective dose of many pharmaceuticals falls into this low-dose range (for example, the NuvaRing contraceptive acts at o.o35 ppb, while an inhaler can relieve an asthma attack with a puff of 2.1 ppb of Albuterol®). Moreover, we are likely also exposed to BPA through other activities, such as touching cash register receipts made with a BPA or BPS (its chemical cousin), or eating canned food (in the U.S. many food containers are lined with BPA). Basheer et al. (2004) wondered whether the BPA was finding its way into seafood through the seawater. They tested six seawater samples at twenty-eight locations both near shore and offshore that represented diverse uses (industrial zones, beaches, marinas, etc.). The highest concentration they found, however, was only 2-47 ppb, much lower than that in the seafood. Does this mean that BPA is persistent enough to bioaccumulate? Or could it be that marine creatures had ingested plastics that were releasing BPA?

To make matters worse, petroleum-based substances like plastics be have in a curious way when placed in water. They actively seek out other petroleum-based compounds, with which they form nearly inseparable bonds. This property is called lipophilicity *(lipo-* meaning oily or fatty, and *-philicity* meaning love or attraction). Thus petroleum-based plastics hecorne magnets for the trace residues of pesticides such as DDT and its breakdown products that linger in the environment. Another class of oily industrial chemicals that adsorb to marine plastics is polychlorinated biphenols, or PCBs. Though their production was banned in the US in 1979, they turn up mysteriously now and again in things dyed orange and yellow (http://www.scientificamerican.com/ article/yellow- pigments-in -clothing and-paper-contain -long-banned -chemical). Another are phenanthrenes, part of a class of combustion byproducts collectively called polycyclic aromatic hydrocarbons, or PAHs.

Japanese scientist Yukie Mato and her team collected nurdles (pre consumer plastic beads that are melted and shaped into roughly the size and shape of lentils) by hand from three beaches, and scooped floating nurdles from a canal using a stainless steel net (2001). They sorted the nur dles by resin type to find the polypropylene pellets (polypropylene is used for example in yogurt tubs). They measured how much DDE (a metabolite of DDT, an insecticide), PCBs, and nonylphenol (an endocrine-disrupting surfactant, which we will cali NP for short) the pellets contained. They learned that nurdles in the ocean had soaked up so much of these chemicals that they contained up to one million times more of each contaminant than the seawater itself. This is likely because persistent organic pollutants (or

POPS, including DDE, PCBs, and NPs as studied by Mato) are lipophilic. Mato's team wondered if the nurdles might have had these contaminants in them before they fell into the ocean, so examined "virgin" nurdles from a plastics factory and found they did not contain any DDE, PCBs, or NP. Just to be sure, they put new nurdles into a fine mesh stainless steel basket and dangled them in Tokyo Bay for six days, then tested them again. Now ali the nurdles had high levels of DDE, PCBs, and NP, demonstrating that plastics are binding to chemicals already in seawater and concentrating them.

Emma Teuten and her colleagues took this line of investigation a step further, documenting not only how plastics soak up poisonous chemicals but also how they release them into the food chain (2007). They first studied how much phenanthrene (a hazardous połycyclic aromatic hydrocarbon that serves as a model for other POPs) each of three types of plastic (polyethylene, polypropylene, and polyvinyl chloride) could absorb from seawater. Ali three absorbed much more than did natural sand or pebbles. Then they placed lugworms (*Arenieola marina)* in sand that was contaminated with phenanthrene; some of the lugworms also had plastic added to their sand. Adding just one microgram of polyethylene per gram of sediment dramatically increased the amount of phenanthrene the lugworms accumulated. A complementary study by the University of Exeter has shown that elevated levels of plastics cause lugworms to eat less and to suffer from reduced energy levels (Browne et al. 2013).

Because "polycyclic aromatic hydrocarbons" and "DDE" are not household words, this phenomenon does not have the impact outside the scientific community that it deserves. I wondered if a similar process might be happening with a more familiar contaminant: mercury. The saving grace for our seafood seemed to be that mercury in its most toxic form is not particularly lipophilic. However, mercury *is* attracted to *mercaptans* (the Latin name indicates how sulfur molecules draw mercury and hold it captive). I decided to investigate whether these sulfur molecules could attract and bind mercury even when they themselves are already bound to another material My proof of concept pilot study found that this was indeed the case. Styrene-butadiene block copolymers, used in automobile tires, contain these sulfur molecules as a residue of a particular type of vulcanization process. When pieces of this plastic were dropped into a seawater solution spiked with methyl mercury, it only took three days for the plastic bits to soak up over 70 percent of the mercury. If we were somehow able to submerge these particles in the ocean and then remove and dispose of them safely, we would be essentially purifying sea water. However, since the only ways plastic marine debris leaves the ocean are by washing up on shore (unlikely for materials this dense) or by being ingested and passing into the marine food web, the net effect is not removal of mercury, but its *concentration* in our seafood.

But how do fish come into contact with automobile tires? Off the Atlantic coast of Florida, two million used tires were spread on the seafloor in what Goodyear proclaimed was an ecologically friendly solution to the problem of old tire disposal, since on land tires tend to fill with rainwater and breed mosquitoes, when buried they have a tendency to resurface, and when burned they release toxic chemicals. So "artificial reefs;' Goodyear reasoned, would provide a habitat for marine species, just as had been proposed for other artificial reef material such as scuttled ships, subway cars, and more recently, "Reef Balls"(including some made of PVC or concrete mixed with cremated human remains!). This is a classic case of one "solution" generating more problems.

II. From Washing Machine to Gyre

Plastics are paradoxical. Though in many cases they are designed to be discarded after a single use, they may outlast life on earth. No one actually knows how long it will take plastics to break down-or if they ever will (giving rise to the slogan, "Like diamonds, plastics are forever"). Unless it has been incinerated or digested by microbes, every piece of plastic ever made is still with us-or in some cases, *in* us. The conventional wisdom holds that if we. "manage" our plastic properly, we will be able to maximize its benefits and minimize its risks. The truth is, we do not yet know how to contain our plastic trash, much less to detoxify it.

Much of what is "responsibly" tossed into recycling bins still finds its way out again. Light plastics such as Styrofoam® and SaranWrap® tend to blow out of open curbside receptacles, from the trucks that transport them, or from the facilities that receive them. Moreover, since these remnants have so little monetary value, there is little incentive to design and implement infrastructure that would prevent such loss. Since plastics do not break down in landfills, sooner or later their resting places will be disturbed, whether by storms or curious creatures. Incineration, meanwhile, transforms plastics into new molecules, some of which are unfortunately even more hazardous.

Many well-intentioned people have with great intelligence and creativity devoted themselves to figuring out how to scoop up and re-purpose plastic debris. Various innovative technological fixes are being proposed, such as sweeping up larger pieces in the ocean with a giant trawl and melting them down for conversion into fuel or into new plastics. However, even if all the plastic in the oceans *were* cleaned up tomorrow, at the rate we are redepositing them, it wouldn't take us more than a few years to replace what had been cleaned up. I am drawn instead to trying to understand how we can stem the tide of garbage in the first place. First we must understand where it comes from.

In one sense, since all plastic is made by factories, it is all land-based. But those of us in the marine conversation field point out that 20 percent of debris is sea-based. It is now illegal to toss plastic overboard from ships, but we can confirm only the accidental spills. Cargo containers are not infrequently lost from freighters during storms. In one famous incident in 1992, a ship spilled nearly thirty-thousand Friendly Floatee toys. A citizen science project directed by Curtis Ebbesmeyer used these rubber duckies to study oceanic currents in the Pacific (see http:/ /beachcombersalert. org/Rubber Duckies.html). The intentional disposal of plastic at sea, on the other hand, like other illegal activities, is hard to quantify. Dutch researchers have caught some ships shredding their plastic trash and mixing it with food waste before sending it illicitly overboard. According to some informants, the Italian mafia makes a lucrative business of disposing of society's toxic waste, including plastics, the disposal of which is more strictly regulated in the European Union. They charge their customers a fee for taking away their waste, which they then load onto ships and sink offshore, entitling them to insurance reimbursement (see e.g. http://www.spiegel.de/ international/ europe/ anger-rises- in-italy-over-toxic-waste-dumps- from the-mafia-a-94363o.html).

The issue of "upstream" microplastics debris is much closer to home.

Sixty percent of all fibers used in clothing and accessories are synthetic (Browne et al. 2011). Each time we wash a garment made of polyester, Lycra, nylon, or acrylic it sheds thousands of microscopic fibers. Experiments sampling wastewater from domestic washing machines demonstrated that a single garment can shed more than 1,900 fibers per wash. These are flushed through (usually PVC) outflow pipes with the graywater, and eventually pass through a wastewater treatment plant, because their filters are not designed to capture debris this small. In spite of my fastidious efforts to shop only for clothing made of hemp, wool, organic cotton, and bamboo, some plastic sneaked into my closet. My winter boots and coat are lined with fleece, which is typically made of polyethylene terephthalate, some from reclaimed plastic water bottles. The boots were made water resistant with perfluorinated compounds, another synthetic polymer found in wastewater. My bathing suit includes. Lycra/Spandex, which is a polyurethane-polyurea copolymer. Tightly woven polyester gives my sun-protective jackets and hats their high SPF factor. My vegan shoes are PVC. I have nylon stockings and even an acrylic sweater (it was a gift). And this doesn't count all the plastic buttons!

Personal care products are another household source of plastic micro-debris. The Environmental Protection Agency confirmed that as of 2011, there were more than 2,000 products using polyethylene or polypropylene microbeads on the market in the U.S. These include exfoliating scrubs, lotions, and even some toothpastes (for example, there are approximately 330,000 microbeads present in a large bottle of facial scrub; http://ottawacitizen.com/ news/local- news/ environmentalists-drawing-a-bead-on-microplastics). Activists with the "Ban the Bead" campaign worked with manufacturers and state-level lawmakers to end this practice, which will be phased out by federal law beginning in 2017 (see http://www.sgyres.org/ banthebead/).

In 1997, Charles Moore sailed through a remote spot in the North Pacific called a gyre, and was astonished to find that he was gliding through a plastic soup (2003, 2012). There were pellets and shards, threads and films. Many of the fragments bobbing at the surface or barely submerged were too smali to identify; others were recognizable as having once been pen caps, shopping bags, and bottles. He noted ghost fishing nets and barnacle-encrusted buoys, but they were too heavy to retrieve. Deeply distressed, he struggled to convey the magnitude of his discovery. We now know these areas as "gyres;' a convergence of currents into which much of the ocean's flotsam finds its way. In the gyre's swirls and eddies, the sunlight and the waves slowly break the flotsam into smaller and smaller pieces. We have learned that some of the pieces do leave the gyre- in the stomachs of migratory fish.

Scientists prefer to confront the world in managed, neatly measured increments, so Moore devised a methodology to quantify his discovery. He sailed back to the plastic soup, trailing a Manta trawl behind him. In this long, fine mesh net, held open by metal wings that resemble those of the eponymous Manta ray, he collected the skimmings of the sea. Back at the lab, he and his collaborators dried and weighed the samples. The abundance and mass of neustonic plastic was the largest recorded anywhere in the Pacific Ocean. While plankton abundance was approximately five times higher than that of plastic, the *mass* of plastic was approximately six times that of plankton. This means there are five microscopic plankton for each fragment of plastic garbage, but by dry weight there is six times more plastic than marine life at the surface of the ocean.

Moore's findings represented the highest recorded level of marine plastic to that date (much higher levels have been recorded since).

Other researchers raced to confirm or disprove these numbers. The more measurements taken, the more dismal were the findings. Miriam Goldstein's team found that microplastic (less than five mm) debris in the North Pacific had increased twofold between 1972-1981 and 1999-2010 (see http://www.miriamgoldstein.info/research.html). Another research team cautions, however, that surface measurements significantly underestimate plastic marine debris by a factor of up to twenty-seven due to wind-driven mixing in the upper water column (Kukułka et al. 2012). Ten years after his initial findings Moore estimated there was fifty to one hundred times *more* plastic debris than marine life in the Pacific gyre (2012).

Meanwhile, researchers have begun documenting abundant plastic debris outside the five oceanic gyres, from the Great Lakes to Antarctica. One team found a concentration on average of more than 43,000 micro-plastic particles, including microbeads per square kilometer in the Great Lakes, which increased ten-fold near major cities (Eriksen et al. 2013).

III. **Learning to Love Trash**

The ever-increasing abundance of plastic trash in land, sea and bodies is, fundamentally, a spiritual problem. Plastics habituate us to accept unhealthy relationships-and not only because our use of them is so typically fleeting. The foundation of a healthy relationship lies in a celebration of the Other's unique and intrinsic value; disposable plastics, however, are by design both fungible and instrumental.

We tend to project what we loathe onto trash, and then hold to the fantasy that by throwing away what is used,, and/or dirty,, we will ourselves be purified. I contend that this relationship to disposables habituates us to project a similar shadow onto other people, thus dehumanizing them.

I have been wrestling for years with the memory of watching an infant die at the hands of the Kenyan police for the "crime" of being homeless. Their justification was: "We're cleaning up the streets. These people are garbage:' The idea that people are disposable is reinforced by slurs like "trailer trash" or "poor white trash:' The salient question, then, is how to unlearn this form of oppression.

At a class on environmental racism I taught at the Servant Leadership School in Washington, D.C. a few years ago we talked a lot about trying to love trash. I related a story of a client at an AIDS service organization who, after being estranged for decades from his family, was finally invited home to share Thanksgiving dinner. When he arrived, full of hope for a renewed connection, he was directed to sit outside on the back steps and to eat from disposable dishes while the rest of the family shared a meal on china around the dining table. We discussed how Jesus would have interacted with this modern -day leper, and reflected on times when we felt treated like garbage, or treated another person as if they were disposable. Then we each committed to choosing a piece of litter from the street to bring home to put on an altar. For one week, we would spend time contemplating what is beautiful and holy in it. After the week was up, I invited each person to share how this practice affected their prayer life. We found this exercise stirred up powerful, inexplicable, raw emotions, and many of us were nudged to get back in touch with people from whom we've been estranged. We then created a ritual together to bless our garbage. We each shared how special our piece of litter had become a piece of ourselves we gathered to bless.

There is a connection between how we treat objects, how we view our selves, and how we treat each other. My ecotheology of zero waste affirms that all that is has intrinsic value and is good. Everything that is belongs and contributes. By disposing of any part of the whole, we are all diminished. Everything and everyone, no matter how broken, is needed to re-member the body of Christ. As Jesus said to the authorities of his time:

> Have you never read in the Scriptures: "The stone the builders rejected has become the cornerstone; the Lord has clone this, and it is marvelous in our eyes"? (Matt 21:42 citing Psalm 118:22; see Acts 4:11)

I see a parallel between this reference to the reclamation of material refuse and Jesus' other teachings concerning the reversal of social position ("the last will be first"), the centrality in God's plan of those on the margins, and the leadership of those who have been rejected. Conversely, throwing something away reinforces the mentality of a linear progression from birth to death, foreclosing the possibility of resurrection.

If we choose zero-waste as a spiritual discipline, we affirm that which is life-giving instead of toxic. We practice finding beauty, utility, and worth in the world around us and in each other. We call into being a world that is not a wasteland. And it is at the bioregional scale that we can most practically manage (and take responsibility for) our "garbage-shed:'

An apple producer in British Columbia has recently marketed pre-cut, genetically modified apple pieces (no doubt wrapped in plastic) because "in a convenience-driven world, a whole apple is too big of a commitment" (http://greenecountynewsonline.com/2015/os/o6/do-you-have-difficulty committing-to-an-apple/). The temptation of such a "better apple" seems to me to be a parable of Eden's Fall. With our earth groaning under the toxic pressure of trash-especially plastics-we can no longer claim ignorance of the consequences of, nor displace blame for, eating *this* apple. As seductive as it may seem, we must wean ourselves off of disposable culture, and muster a commitment not only toward whole apples, but to a zero-waste world. [1]

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Two useful websites are http:l lzerowasteinstitute.org/ and http:l *lwww.ze* rowasteeurope. e*ul* 2015*l*o3*l* zero-waste-a- key- solution-for-a-low- carbon -economy*l.* Two popular practical household guides on zero waste are Johnson (2013) and Korst (2012); on plastics specifically SanClements (2014) and Freinkel (2011); on the waste crisis in general Humes (2013) and Palmer (2005).

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