The Perils of Plastic

Tracking environmental, climate and human impacts of plastic production, use and disposal

UCLA Luskin Center for Innovation

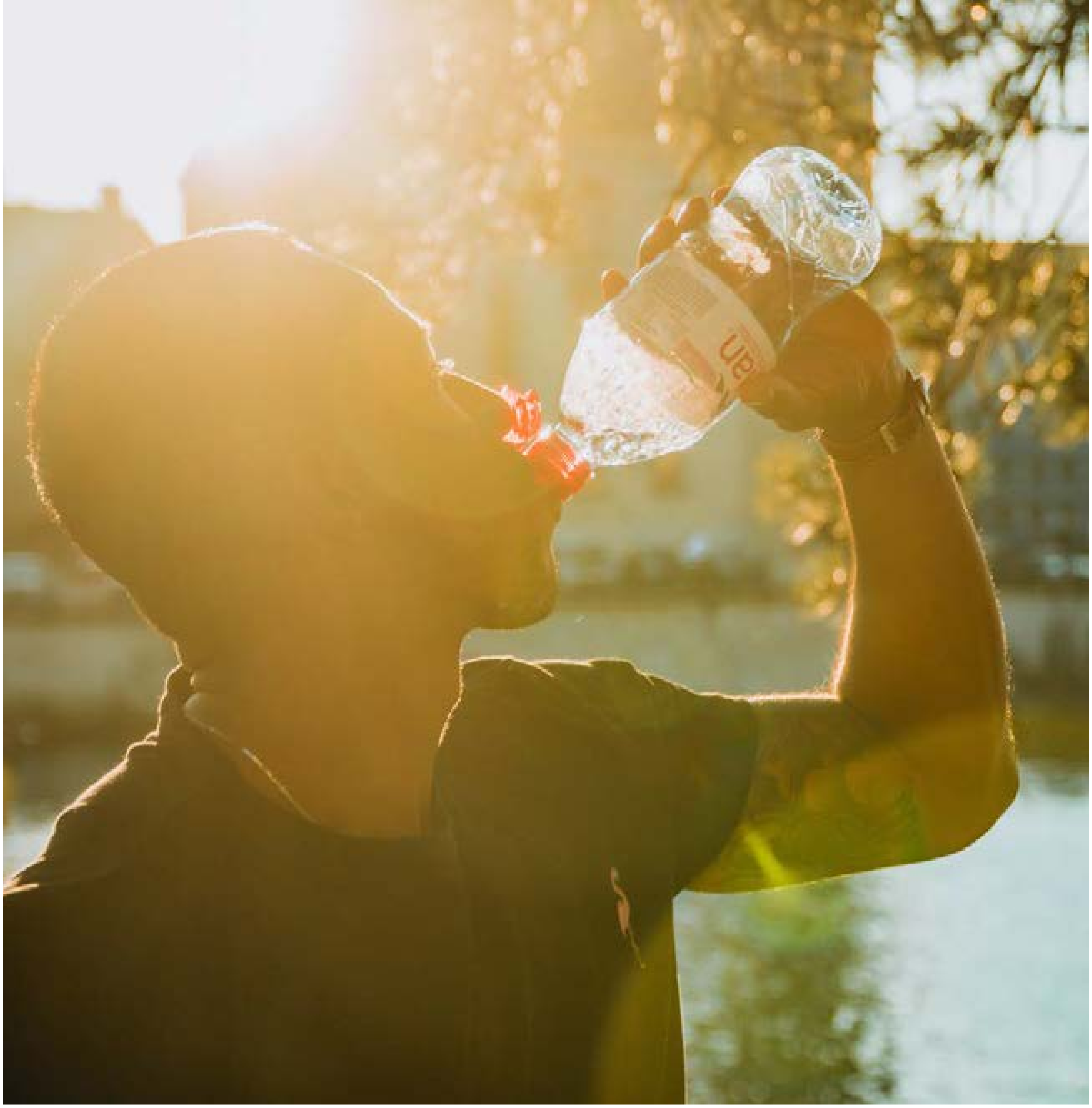

Photo: Peggy and Marco Lachmann-Anke

EXECUTIVE SUMMARY

Although plastic pollution has been an issue of concern for decades, the need for urgent action to curb the impacts of plastic has been accentuated in recent years. Recognition of plastics' contribution to climate change and newfound concerns about globally pervasive microplastics have highlighted the widespread impacts plastic has on the global environment and human health, and have buoyed efforts by activists, stakeholder groups, and legislators to institute systemic solutions.

California historically has been a leader in this effort, as it has on many environmental issues. However, much of the activity in the state has been at the local level, where challenges related to economies of scale and jurisdiction limit potential benefits. Leaders in the California legislature have recognized the need for comprehensive action that builds upon these efforts.

To support these actions, this brief provides a high-level overview of the multifaceted impacts created by plastic over its entire lifetime. Herein we discuss the three stages where plastic creates harmful effects:

PRE-USE HARMS occur as a result of extracting and refining the fossil fuel materials from which plastic is made and from manufacturing plastic itself

USE HARMS occur directly as a result of intended product use

POST-USE HARMS occur when plastic material reaches the end of its life cycle and is disposed of, whether through the intentional processes of recycling, incineration, or landfilling; or improperly into the environment.

Researchers at the UCLA Luskin Center for Innovation identified impacts at each of these stages through an extensive review of academic research, government resources, stakeholder publications, and journalistic articles. The result is a picture of pervasive impacts on the global community and environment accompanied by widespread, acute impacts on peoples and areas most impacted by fossil fuel industry operations. Each stage of the plastic life cycle manifests impacts in one or more of the following categories:

CLIMATE IMPACTS resulting from emissions of carbon dioxide and other, more potent greenhouse gases

ENVIRONMENTAL IMPACTS, which take various forms including toxic air pollution, soil and water contamination, geological disruption, and damage to ecosystems and wildlife

HUMAN HEALTH IMPACTS, including increased risk of cancer, respiratory and cardiovascular disease, reproductive health harms, neurological damage, and various conditions arising from exposure to pollutants and toxic chemicals.

ECONOMIC IMPACTS related to the direct and indirect costs of plastic waste management and cleanup.

It is important to underscore plastic's role as a fossil fuel product, one which relies on the continued extraction and refining of petroleum. This means that the plastics and fossil fuel industries are inextricably linked, and that plastic manufacturing therefore shares responsibility for the ongoing damage caused by fossil fuel operations. The amount of global oil production going toward plastics is only expected to increase in coming years.[1] Devising a comprehensive strategy to reduce the impact of these products requires recognizing that their footprint extends well beyond plastic straws and cups seen as litter by Californians every day; plastic has and will continue to deeply affect communities throughout the state and across the globe in ways both well documented and others we are just beginning to comprehend.

Perils of Plastics

TRACKING THE ENVIRONMENTAL AND HUMAN IMPACTS OF PLASTIC PRODUCTION, USE AND DISPOSAL

PRE-USE HARMS

(Production, from raw materials to final product)

ENVIRONMENTAL IMPACTS

- Extracting fossil fuels, the raw materials that make up plastic, contaminates soil, pollutes air and water, and can even increase earthquake risk.
- There is a risk of catastrophic failures at drill sites and during transportation.
- Toxic chemicals used in the production process can be released into the environment through chemical fires, spills, and toxic gas emissions.

CLIMATE IMPACTS

- Methane, a potent greenhouse gas, leaks from oil and gas wells during production.
- Flaring, land disturbance and energy consumption all lead to more emissions.

HUMAN HEALTH IMPACTS

- Communities near fossil fuel extraction sites are exposed to pollution, which can cause harmful — and often life-threatening — health conditions.
- Health concerns associated with fossil fuel extraction particularly affect oil and gas workers and communities living near oil and gas developments
- Exposure to styrene and other dangerous chemicals causes health issues for workers in plastics manufacturing.
- Health impacts are unevenly distributed, posing equity concerns.

USE HARMS

(Food packaging and more)

HUMAN HEALTH IMPACTS

- Plastics often contain harmful chemicals, such as styrene and BPA, that leach from containers into food, particularly at high temperatures and for higher-fat foods.
- These chemicals can interfere with hormonal systems, contributing to reproductive issues, obesity, developmental and neurological problems, and kidney and prostate disease, as well as increasing the risk of some cancers.

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TRACKING THE ENVIRONMENTAL AND HUMAN IMPACTS OF PLASTIC PRODUCTION, USE AND DISPOSAL

POST-USE HARMS

(Landfills, incineration, and litter)

ENVIRONMENTAL IMPACTS

- Plastic breaks down into microplastics — tiny particles that pollute water and air.
- Increased plastic waste drives demand for new landfills, which lead to odors, smoke, litter, chemical leaching, and other local pollution.
- Incineration produces local air pollution, which disproportionately harms low-income households and communities of color.
- Plastic pollution harms wildlife when animals eat it accidentally, get trapped in netting, and are affected by chemicals leaching from plastic.
- Plastic containers may transport invasive species through ocean flows.

CLIMATE IMPACTS

- Plastic produces potent greenhouse gas emissions when exposed to sunlight, as it degrades in landfills, and especially when it is incinerated.

HUMAN HEALTH IMPACTS

- Pollution causes a wide array of health problems.
- Living near landfills increases the risk of several dangerous health conditions.
- People may ingest plastic through contaminated food, such as fish that consumed plastic pollution.
- Exposure to microplastics through breathing, drinking, eating may cause health issues.

ECONOMIC IMPACTS

- Plastic waste management raises cost for recycling and waste operators.
- Cities and coastal areas face costs associated with cleanup of plastic pollution and lost tourism revenue.
- Tourists face increased costs if they must travel further to avoid contaminated areas.

RECYCLING
A SOLUTION FOR POST-USE HARMS?

- Recycling is inefficient. It captures only 10 to 15 percent of plastics, and in the long run, most plastic will end up in a landfill or incinerator.
- Recycling an item does not displace its impact — the degraded plastic is usually downcycled.
- Ultimately, recycling is a harm-reduction step rather than a solution.


Photo: Jonathan Chng

INTRODUCTION

Californians have been working to address the challenges of plastic and plastic waste for decades, with local ordinances restricting the use of polystyrene, a type of plastic, being enacted as far back as the late 1980s. Since that time, public awareness of the impact plastic wreaks on the environment — especially in coastal areas and marine ecosystems — has increased substantially, aided by the ongoing work of researchers and activists. More recently this awareness has expanded as the globally pervasive impacts of plastic and plastic waste become so pronounced as to be impossible to ignore. In turn, legislators have been working for years to take comprehensive action at the state level to address the myriad challenges posed by the plastic problem.

This document seeks to clearly enumerate how plastic affects our climate, our environment, our communities, and our health, starting from the point at which the fossil fuel materials from which it is made are first extracted from the earth and ending when plastic is recycled or, much more likely, burned, buried, or littered. Throughout this report we use several interchangeable terms — impacts, harms, damages — to refer to these effects. In all cases, these terms refer to externalities: costs that no one is paying for, and are therefore shared by the people who must bear their burden. In some cases these impacts are global in their reach, as with climate change-causing greenhouse gas emissions or microplastic pollution. Others are more localized, such as local water sources tainted with chemicals or heavy metals from nearby oil extraction.

We explore how these impacts manifest by looking at the life cycle stages of plastic in sequential order. First, we discuss how plastics cause harm before they even reach the consumer ("Pre-Use" harms) by creating demand for fossil fuels and through the manufacturing process itself. Many of these impacts are related to the fact that plastic is a petroleum product, and therefore demand for and consumption of plastics is directly correlated with the effects of fossil fuel extraction and refining operations. These processes contribute to global issues — most notably climate change — but also acutely impact local communities through numerous pollution-related problems. Local pollution, in turn, creates a multitude of human health problems, many examples of which are discussed below.

Photo: Bryant Baker

90%

Amount of global plastic that is not recycled each year.[i]

Problems that arise during plastic item usage ("Use" harms) are relatively few, with most research confined to the potential health risks of using plastics to serve and contain food and beverages. We discuss some of the specific chemicals that have been identified as problematic and the health risks they pose in such contexts.

Last, we address the impacts across three different scenarios for how plastic waste is dis-

[i] Ellen MacArthur Foundation (2017). The New Plastics Economy: Rethinking the Future of Plastics and Catalysing Action. *Ellen MacArthur Foundation and New Plastics Economy.*

posed of (“Post-Use” harms). A small portion of the plastic used each year is recycled, and we discuss some of the factors and challenges that result in recycling not being a more widely practical solution. It is safe to say that, while unequivocally preferable to other outcomes, recycling is a highly imperfect process and should be seen as a tool for minimizing the harms created by plastic waste rather than a long-term solution to the problem. When not recycled, plastic waste is generally disposed of in landfills (including poorly managed and unsanitary open dumps), incinerated, or allowed to leak into the environment.[2] In all three of these cases, plastic waste contributes to climate change and environmental pollution, the mechanisms and pathways of which we discuss below. Also noted are some of the many public health risks and economic costs incurred because of plastic waste and pollution.

It is important to stress that although many different types of impacts are identified herein, this report is not an exhaustive documentation of every way in which plastic is affecting the world. The interrelated issues of petroleum extraction, environmental integrity, and human health are highly complex, and fully exploring them would require much more information than can be contained in this document. Moreover, research in some of these areas, such as the health effects of microplastic exposure, are relatively new and rapidly developing, meaning we do not yet fully understand the totality of plastics’ global impacts.

Photo: Sundry Photography

PRE-USE

Even before they make their way to shelves, warehouses, and restaurants, plastic items have already caused a variety of environmental and health impacts. As fossil fuel products, plastic manufacturing relies on a continuous supply of petroleum. Extracting these raw materials has many negative side effects, as oil and gas operations pollute local communities and environments, harm peoples' health, and contribute to climate change. Producing plastics from these materials adds to these impacts, exposing workers, communities, and the environment to a number of toxic chemicals.

Raw Material Production

Production and consumption of plastics drives demand for the raw material feedstocks from which they are derived, namely, fossil fuels and petrochemicals. Extraction and refining of these materials create significant harms, both in the form of generalized climate-related impacts and more acute, localized effects on the environment and the health of workers and proximate populations.

THE CLIMATE AND EMISSIONS IMPACTS from extraction and refining of plastic feedstocks are significant. In the United States, the recent natural gas boom has created a shift in favor of natural gas liquids as the source for ethylene — a precursor for several types of plastic resins that collectively account for approximately 65% of global plastic production.[3] Although touted in the past as a cleaner alternative to oil extraction, recent scrutiny has indicated that leakage rates and emissions of methane — a highly potent greenhouse gas — are significantly higher than originally estimated, erasing much, if not all, of the purported emissions advantage for natural gas compared to oil.[4,5] Additional emissions result from other activities associated with natural gas extraction like flaring, associated energy use, and land disturbance.[6] The result is that as of 2015, the Center for International Environmental Law estimated that 9.5 million to 10.5 million metric tons of CO_2-equivalent (CO_2e) was emitted as a result of extracting and transporting fossil fuels for plastic production.[7] The same study estimated that the remainder of the globe (where oil is the primary source material) produces approximately 10 times those emissions — about 108 million metric tons CO_2e — to fuel the plastics industry.[8] Moreover, these figures are likely to grow absent corrective action, as industry projections suggest that by 2050, 20% of global oil production will go toward plastics.[9]

LOCAL ENVIRONMENTAL IMPACTS also occur as a direct result of oil and natural gas extraction. A 2019 review of studies by University of Southern California researchers identified myriad environmental harms from fossil fuel extraction operations across the globe, affecting air, water, and soil quality, as well as the health of local flora and fauna.[10]

Fossil fuel extraction produces many air pollutants, including high-profile hazardous substances such as benzene, particulate pollution, and sulfuric acid.[11] Notably, volatile organic compounds emitted as a result of extraction operations (including benzene, formaldehyde, and hydrogen sulfide) may contribute to the formation of ground-level ozone — a highly harmful air pollutant and contributor to climate change.[12] Flaring practices also create air pollution, especially via the emission of sulfur dioxide.[13] In addition to direct harmful health impacts (discussed below), sulfur dioxide is a precursor to other sulfur oxide compounds, which are linked to flora damage, particulate pollution, and acid rain.[14] Extraction operations also present significant risks for soil contamination, exposing ecosystems and persons to a variety of harmful impacts. Such contamination can occur as a result of everyday operations, transportation of fuels or industrial fluids, or equipment failures and accidents such as pipeline leaks. As a result, studies have found soils in oil fields and near extraction sites to contain significantly higher concentrations of

Photo: Mikes-Photography

0.9%

Portion of all plastic ever produced that has been recycled more than once.[ii]

petroleum hydrocarbons, polycyclic aromatic hydrocarbons, heavy metals, and naturally occurring radioactive materials than other areas.[15] Collectively, these pollutants pose a major threat to ecosystems, as many of these compounds are toxic or carcinogenic and can damage ecosystems via acute harms to microbial populations and wildlife.[16] Furthermore, some of these toxins — such as the heavy metal cadmium — have the potential to bioaccumulate, creating compounding, long-term ecological damage.[17]

Relatedly, fossil fuel extraction contaminates bodies of water both through direct pollution and as a secondary effect of soil contamination. Spills of pollutant-laden wastewater from oil and gas operations are common, with tens of thousands of documented instances in the United States in recent years resulting in the uncontrolled release of hundreds of millions of gallons of wastewater.[18] In addition to being highly saline, extraction wastewater often contains a plethora of toxic industrial chemicals, creating a potent ecological threat in the aftermath of a spill.[19] Aquatic environments are especially vulnerable; documented impacts include mortality spikes in fish populations, endocrine disruption, and potential long-term contamination of waterway sediments.[20] Surface waters and wells near extraction sites have also been found to be more saline and to have higher concentrations of petroleum hydrocarbons, polyaromatic hydrocarbons, arsenic, and manganese, indicating a degradation of water quality.[21] These risks extend to underground aquifers; international studies have identified instances in which the use of injection wells — the practice of disposing of wastewater by injecting it underground — and other sources have contaminated groundwater water supplies.[22] One 2013 study found that water wells near the Barnett Shale formation in North Texas had become highly contaminated with arsenic and other pollutants.[23] At the same time, shale oil operations consume huge amounts of local water resources — hundreds

[ii] Geyer, Roland, Brandon Kuczenski, Trevor Zink, Ashley Henderson (2015). Common Misconceptions about Recycling. Journal of Industrial Ecology 20(5), 1010-1017. https://doi.org/10.1111/jiec.12355.

of billions of gallons annually across only a few U.S. states.[24] This is especially problematic for areas at risk of or already experiencing water stress, a category within which between 31% and 44% of the world's shale deposits fall.[25] Hydraulic fracturing (fracking) oil and gas extraction operations — an exploitation strategy that has expanded greatly in North America in the last two decades — have also been linked to earthquakes. Underground injection of fluids and wastewater can destabilize the geology of the surrounding area, and as a result there has been a notable increase in earthquakes near fracking sites in Canada and several U.S. states.[26,27]

Beyond the everyday impacts, fossil fuel extraction poses risks related to catastrophic failures occurring at drill sites (e.g. the Deepwater Horizon disaster), with pipelines, and during shipping. Such accidents typically release large volumes of oil and toxins into the environment, leading to ecological damage and wildlife mortality with impacts that persist for years.[28,29,30] Additionally, there is evidence that chemical dispersants used to clean up oil spills in the wake of accidents may also be harmful to wildlife, compounding the environmental damage done by the initial event.[31]

20%

Portion of global oil production projected to go toward plastics by 2050.[iii]

HUMAN HEALTH RISKS also manifest as a result of extraction and refining of plastic feedstocks and are, unsurprisingly, linked to many of the environmental harms detailed above. Much as exposure to toxic and carcinogenic pollutants via air, water, and soil adversely affect flora and fauna, communities living near fossil fuel extraction sites or the corridors along which they are transported are also harmed. Extraction-related pollution (including pollutants identified above) and residing near fossil fuel operations have been linked to a wide variety of health conditions, including (but not limited to) higher risk of numerous types of cancer, bronchial and respiratory conditions, neurological harms, cardiovascular problems, immunological problems, liver damage, and anemia.[32] Studies suggest that some health risks — including cancer incidence, neurological degradation, autoimmune disorders, and kidney disease — are especially elevated for oil and gas workers.[33,34] Other research, including studies focused specifically on California, have found that living near oil and gas developments is associated with a number of harms for pregnant women and their children. These harms include lower birth weights and higher incidence of pre-term birth and congenital birth defects.[35,36,37] Unsurprisingly, oil and gas industry workers are at especially high risk of negative health consequences related to their occupation.[38]

[iii] World Economic Forum (2016). The New Plastics Economy: Rethinking the future of plastics. Accessible at https://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf.

The health issues created by oil and gas operations are further compounded by the equity issues related to geographic concentration of extraction and refining sites. Oil and gas sites historically have been located in or near lower-income communities of color, a trend from which California is no exception.[39] Thus, the most acute burdens of the fossil fuel industry are being placed on peoples who have historically been politically and economically disenfranchised and are least equipped with the resources to cope with said burdens.

Production of Plastics

In addition to the effects of extracting and refining the fossil fuel inputs necessary for producing plastic, the process of manufacturing plastic resins and goods creates its own set of impacts. Most pertinent among these are acute environmental impacts resulting from industrial practices and negative human health effects for workers and populations near manufacturing sites.

The most notable **ENVIRONMENTAL HARMS** arising from plastic manufacturing are linked to toxic chemicals used in the process. Hazards inherent to the industry, such as chemical fires, spills, and toxic gas emissions release harmful substances into the environment. Leaked substances may include benzene, ethylbenzene, ethylene oxide, and nickel.[40] Studies have also found significant levels of polycyclic aromatic hydrocarbons (a fossil fuel-related class of chemicals) in air emissions and soils near plastic production sites, posing a risk to both environmental and human health.[41]

HUMAN HEALTH IMPACTS related to plastic manufacturing have been most well documented among workers exposed to styrene, the primary component of polystyrene plastics and derivative products. A number of occupational studies have found plastics workers to have significantly higher blood styrene levels than the general population, with longer durations of exposure linked to respiratory problems and chromosomal damage.[42] Styrene exposure has also been linked to several types of cancer, including non-Hodgkin's lymphoma, esophageal cancer, pancreatic cancer, leukemia, lung cancer, and prostate cancer.[43,44]

However, styrene is not the sole dangerous chemical to which workers are regularly exposed in the manufacture of plastics. Recent studies have assessed the occupational health impacts of other common chemicals. Among the findings are links between vinyl chloride monomer — used in the manufacture of polyvinyl chloride (PVC) — and incidence of liver cancer in male workers, as well as hormonal disruptions occurring from workplace exposure to diisononyl phthalate (a plasticizer which is added to plastics to make them more flexible).[45,46] Polycyclic aromatic hydrocarbon exposure has also been found to increase cancer risk among people living near plastic production sites.[47]

Photo: Dariia Havriusieva

USE

Plastics are everywhere, being an important material component of everything from food and beverage packaging to consumer goods to major items like cars and appliances. However, this omnipresence means people are exposed to plastic — and the harmful chemicals used to manufacture it — on a regular basis. The area of greatest concern regarding everyday use of plastics is in their application as food service ware or food and beverage packaging. In these contexts, consumers may be exposed to carcinogenic or toxic chemicals that leach into their food and drink, creating long-term health risks.

The most significant and studied **HUMAN HEALTH CONCERNS** regarding usage of plastic items relate to the use of polystyrene plastics for disposable food service ware items. While the most severe harms of styrene exposure occur in occupational settings — as discussed above — polystyrene containers can leach styrene into food and beverages placed within them, facilitating low-level ingestion of the chemical.[48] Although leaching has been demonstrated for a variety of substances, the greatest amount of leaching occurs at high temperatures and with higher-fat food and beverages — an unfortunate correlation, given the historical popularity of expanded polystyrene food service ware for serving hot beverages and greasy foods.[49,50] Cases where expanded polystyrene is used for food takeout containers that may later be microwaved by consumers at home also pose a risk. Although further study is needed to quantify the health impacts of chronic low-level exposure, styrene's status as a carcinogen makes any use case that causes inadvertent ingestion concerning.[51] Health concerns have also arisen regarding other chemicals present in plastics. The most notable of these are endocrine disruptors: chemicals that interfere with the normal functioning of hormonal systems, thereby contributing to a variety of health problems including reproductive issues, obesity, and developmental and neurological problems.[52] Studies have also found evidence of carcinogenic effects and increased risk of kidney and prostate disease.[53,54] Chemicals in this group include bisphenol-A (BPA), DEHP, and DBP — the first commonly used in polycarbonate plastics and the latter two common plasticizers. The ubiquity of these substances makes exposure and ingestion likely. However, the highly distributed nature of these impacts and the complexities of identifying causality for health conditions make a definitive assessment of the total harms created by these chemicals extremely difficult.

Although further study is needed to quantify the health impacts of chronic low-level exposure, **styrene's status as a carcinogen makes any use case that causes inadvertent ingestion concerning**.

Photo: Tom Fisk

POST-USE

All goods have a finite lifetime, even those made from material as durable as plastic. In some cases, this may be years or decades but more often it is much shorter. Plastic has become the go-to material of choice for many short-lived, disposable applications like throwaway utensils and consumer goods packaging. The constant stream of waste these applications generate means millions upon millions of tons of plastic reach the end of their product life each year and must be disposed of.[55]

Sometimes these materials are properly disposed of and recycled, an outcome that (while imperfect) mitigates some of the damage done by the product's creation. However, this is the exception rather than the rule, as a startlingly small amount — about 10% — of plastic is recycled each year.[56] It is much more likely that plastic waste will either be incinerated, placed into a landfill, or leak into the environment through littering or waste mismanagement. In each of these destinations plastic causes a litany of harms. Among these are contributing to climate change via the production or greenhouse gases; pollution of local air, water, and soils; pervasive ecological harms, especially through lethal effects on wildlife; economic costs to communities and local governments; and a wide variety of human health impacts, the full extent of which ar e still undetermined.

14%

Portion of global plastic waste — approximately 11 million tonnes annually — that is incinerated.[iv]

Recycling

For non-durable and single-use plastics, recycling is the optimal end-of-life disposal outcome (apart from atypical reuse cases by consumers). However, only a small portion of produced plastics are actually recycled. Work by the Ellen MacArthur Foundation and McKinsey & Company estimated that, as of 2013, only 14% of plastic packaging is recycled globally and 10% of material makes its way through the process.[57] Of this, only a small fraction is recycled in a closed-loop fashion such that it can be reutilized for similar purposes. Most recycled material is directed into lower-tier, "downcycled" applications, the ramifications of which are discussed below.[58] The inefficiencies of the recycling process also limit its effectiveness in reducing plastic waste, as studies estimate that the approximately 28% of collected plastic packaging material lost during recycling translates to a 64% loss of material value.[59,60] This confluence of factors — low collection rates, process inefficiencies, and recycling of materials into lower-tier applications — results in very low effective long-term recycling rates. Researchers estimate that, of all plastic produced globally between 1950 and 2015, only 0.9% has been recycled more than once.[61]

For the small portion of plastics that are recycled, the process's limitations and its own set of impacts consign recycling to a harm-reduction role rather than being a solution to the plastic waste crisis. The most important of these limitations is the fact that, in most applications, recycled plastic must be combined with newly produced, or "virgin," plastic to manufacture new items.[62] The reason for this is that the recycling process typically degrades the plastic polymers through the shredding

[iv] Malak Anshassi, Hannah Sackles, Timothy G. Townsend (2021). A review of LCA assumptions impacting whether landfilling or incineration results in less greenhouse gas emissions. *Resources, Conservation and Recycling* 174, 105810. DOI: https://doi.org/10.1016/j.resconrec.2021.105810.

and heating process used to reduce recycled plastic items into versatile pellets. Other issues also include impurities, contamination, and resin mixing that result in weakened, lower-quality material.[63] In cases where products are manufactured with multiple types of plastic resins without end-of-life considerations taken into account, such outcomes are practically unavoidable. This means that recycling a plastic beverage bottle, for instance, does not displace a bottle's worth of new plastic production, and that recycled plastic is often utilized in lower-tier applications, a phenomenon termed "downcycling." Thus, in the long-term, a given amount of plastic material has a finite lifespan for its utility and will almost always inevitably make its way into the environment or be landfilled or incinerated.

Landfilling and Incineration

Plastics that are "properly" disposed of but not recycled are typically either interred in landfills or incinerated. These outcomes create significant impacts in areas including climate, solid waste management, local pollution, and human health

THE CLIMATOLOGICAL IMPACT of plastic disposal can be attributed to the emissions given off from degradation or incineration of the materials. Incineration is believed to create more severe impacts, as burning plastic releases the fossil fuel derived polymers in the material as carbon dioxide.[64] It was estimated that as of 2016, approximately 14% of global plastic production — nearly 11 million tonnes — was disposed of in this fashion, creating a commensurate amount of greenhouse gas emissions.[65] Although incineration of such wastes may be used for electricity generation, this represents only a marginal harm reduction by combusting one form of fossil fuel — plastic — in place of another, such as oil or coal. The value of such offsets only decreases as electricity grids continue to transition to clean, renewable energy.

Greenhouse gas emissions resulting from landfills are not insubstantial, though most studies indicate that emissions from plastic in a landfill are less than those produced from incineration.[66] This advantage may be less than historically estimated, though, as recent research has found that common plastics produce greenhouse gas emissions when degraded by sunlight (discussed in greater detail below).[67]

LOCAL POLLUTION AND ENVIRONMENTAL IMPACTS also arise from both landfills and the incineration of municipal solid waste, with both approaches handling an appreciable amount of plastic waste. Numerous studies have found that plastic in landfills escapes in various forms. Plasticizing chemicals and additives such as BPA and phthalate diester chemicals have been found to leach out of landfilled plastics, contaminating local soil and water sources.[68,69] Recent studies have also found fragmentation of plastic waste in landfills to be a significant source of microplastics — very small plastic particles — that can escape the landfill and make their way into leachate (waste-laden liquid that leaks from landfills), nearby soils, and groundwater.[70,71]

More generally, plastics' slow degradation in landfill settings drives demand for new landfill areas, in turn contributing to the plethora of negative impacts landfills have locally. Landfills have been linked to water contamination, ecosystem damage, habitat destruction, and the presence of toxic substances and heavy metals.[72] Nearby communities may also suffer from foul odors, smoke, or litter from escaped waste.[73] Because landfills tend to be located in or near low-income communities and communities of color, these impacts — along with the economic harms from decreased property values that accompany them — fall hardest on historically disadvantaged and disenfranchised peoples.[74]

Photo: choice76

12,000

Tons of plastic landfilled in California daily.[v]

Incineration of plastic waste produces a large number of harmful air pollutants. These include particulate pollution, halogens, brominated compounds, and heavy metals.[75,76] Of particular concern are chemical such as dioxins and polychlorinated biphenyls (PCBs) which, in addition to being highly dangerous, can persist in the environment and ecosystems for long periods, harming flora and fauna in addition to people.[77]

THE HUMAN HEALTH RAMIFICATIONS of landfilling and incineration of plastics are thus significant. Landfilled plastics contribute to health impacts by driving landfill construction and expansion, exposing more communities to landfill-proximate conditions. Living near landfills increases the incidence of many harmful health conditions, including respiratory disease, gastrointestinal disorders, and several types of infectious disease.[78] Studies have also found landfill health impacts to include reproductive harms, birth defects, and increased risk of numerous types of cancer.[79] However, it is difficult to gauge to what degree these impacts vary by country or region without more research, as few contemporary studies with a focus on the United States or California have been identified.

The pollutants released by incineration of plastics also present a major public health risk, with many being linked to severe medical conditions. Among these are cardiovascular disease, respiratory disease, and lung cancer caused by particulate pollution; neurological harms from heavy metals; carcinogenic and mutagenic impacts from brominated compounds; and increased cancer risk and reproductive health harms attributed to persistent chemicals like dioxins.[80,81] These risks are heightened by the

[v] Vinay Yadav et al. (2020). Framework for quantifying environmental losses of plastics from landfills. *Resources, Conservation and Recycling* 161, 104914. DOI: https://doi.org/10.1016/j.resconrec.2020.104914.

Photo: A Different Perspective

ability of some of these chemicals — notably dioxins and PCBs — to persist and accumulate in the environment, allowing them to contaminate water and food sources.[82]

Finally, plastics contribute to significant solid waste management problems, with more than 12,000 tons being landfilled in California daily.[83] As aforementioned, given the long degradation times for plastic in landfills, this volume of waste is driving demand for new landfill areas as existing space is filled. Additionally, collection and processing of this waste represents a marginal cost on recycling and waste operators, which is in turn passed on to taxpayers via increased waste collection fees or through more expensive contracts for local governments

Waste management systems are also imperfect, allowing plastic waste properly disposed of by consumers to escape into the environment. Plastic waste may escape during transit, processing, or from the landfill itself due to natural occurrences (e.g. wind and rain) or disturbance by animals or people.[84] Estimates of plastic losses from landfills due to mismanagement range from 5% to 47% among various studies, though more research in this area is called for to ensure accuracy.[85] Even under the more conservative scenario, however, it is likely that millions of tons of plastic escape disposal sites and enter the environment annually.[86] Leaked plastics like these add to the litany of impacts resulting from uncontrolled plastic pollution detailed below.

Environmental Pollution

The worst-case scenario for end-of-life plastic is for it to escape into the environment, either due to improper disposal (i.e., littering) or due to waste mismanagement. Although estimates vary, the amount of plastic waste entering the environment annually is measured in the tens of millions of tons.[87,88,89] This type of plastic pollution has historically been the highest profile and most salient with the public, particularly due to the demonstrable harms of plastic waste on marine wildlife and ecosystems. In addition to these, uncontrolled plastic pollution causes climatological, human health, and economic impacts

$500 million

Amount spent by local governments in California on litter cleanup annually[vi]

THE CLIMATE-RELATED IMPACTS of environmental plastic pollution center on how plastic degrades in a natural setting. Although the inert properties of plastic have been a feature important to both its success and the challenges it poses as an environmental contaminant, plastic is not completely immune to the pressures of natural conditions.

In a groundbreaking 2018 study, researchers found that polyethylene — the most commonly used plastic globally — produces the potent greenhouse gases methane and ethylene when exposed to solar radiation.[90] These gases have a heating potential many times that of carbon dioxide, and given the millions of tons of plastic waste entering natural ecosystems each year, plastic pollution represents a potentially significant contribution to climate change.[91] Importantly, the study in question found that emissions from degrading plastic occurred at much higher rates in terrestrial environments versus marine or aquatic ones, meaning plastic pollution that remains on land creates a greater climatological harm than material that makes its way to rivers or oceans.[92] This stands in contrast to the historic focus on the ecological damage plastics inflict on marine and aquatic environments, especially in the public perception. Furthermore, estimates from the Carbon Tracker Initiative indicate that nearly three times as much plastic waste remains on land than enters the oceans, further increasing the potential warming effect of plastic leakage.[93]

THE ECOLOGICAL DAMAGE caused by plastic waste leakage is perhaps the best-studied component of plastics' negative impacts. Plastic waste has contaminated every biome and continent on the planet (Antarctica included), and has become so pervasive that microplastic particles contaminate the air itself.[94] These pollutants inflict many harms on wildlife, especially in aquatic and marine settings where lightweight plastic items may float on the surface or become suspended in the water column. Numerous species of animals — including protected and

[vi] California Recycling and Plastic Pollution Reduction Act of 2020 (n.d.). Retrieved from https://caaquaculture.org/wp-content/uploads/2019/11/Plastics-Initiative.pdf.

endangered species like sea turtles and marine mammals — inadvertently consume these items when they perceive them as food.[95] This can be lethal to wildlife, either in the short term from choking or laceration or in the long term from buildup of indigestible material in the animal's digestive tract.[96,97] Wildlife of numerous types, including birds, snakes, and marine mammals, have been found to become entangled in plastic netting, often with fatal consequences.[98,99,100]

As in other contexts discussed previously, chemical leaching and potential exposures to toxins also pose a risk to wildlife. One area of note is the potential of endocrine disrupting chemicals like BPA to harm amphibians and other water-dwelling species.[101] There are also concerns that plastic debris in the oceans may be colonized by potentially invasive species and transport them to new areas, allowing the newly-introduced species to damage and disrupt local ecosystems.[102]

THE HUMAN HEALTH CONSEQUENCES of pervasive plastic detritus in the world's ecosystems are an area of rapidly developing research, and as such it is difficult to definitively identify what effect plastic pollution has on public health in this context. Though developments are ongoing, two general areas of concern have been identified. First are the potential threats of ingestion of food contaminated with plastics or plastic-related chemicals.[103] Many species of fish and other wildlife that are regularly exposed to or consume plastic debris are targeted for human consumption, providing a potential vector for plastic contaminants to be ingested by people. Second are the as-yet-unknown long-term health impacts of continued exposure to microplastics through breathing, drinking, and eating.[104] Worrisomely, existing research has found that microplastics can damage human cells, and recent research efforts have demonstrated just how pervasive microplastic pollution is within human beings.[105] In March and April of 2022, groundbreaking studies identified microplastic pollution in the bloodstreams of 17 out of 22 people and in the deepest recesses of the lungs in 11 out of 13 surgery patients.[106,107,108,109] Given the scale and nature of exposure affecting people worldwide, aggressive application of the precautionary principle to address these potential harms is appropriate.

Finally, proliferation of plastic pollution creates **ECONOMIC COSTS** for governments and taxpayers. One component of these harms manifests in everyday cleanup costs for city governments, which in California can reach millions of dollars annually for street sweeping and manual litter cleanup.[110] As of 2012, these costs collectively exceeded half a billion dollars across the state.[111] Though no single overarching litter dataset exists, information available from both government and non-governmental organizations has consistently shown that disposable plastic items — especially food service ware — are heavily represented in litter.[112] The presence of plastic waste has also been found to damage tourism and recreation industries in coastal areas, while simultaneously imposing additional costs on visitors and residents who travel farther to avoid polluted areas.[113,114] Moreover, damage to marine ecosystems caused by plastic pollution has been estimated to cost the public the equivalent of $33,000 per ton of waste.[115]

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Disclaimer

The views expressed herein are those of the authors and not necessarily those of the University of California, Los Angeles as a whole.

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