Plastic & Health

THE HIDDEN COSTS OF A PLASTIC PLANET

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#break free from plastic

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Center for International Environmental Law (CIEL) uses the power of law to protect the environment, promote human rights, and ensure a just and sustainable society. CIEL seeks a world where the law reflects the interconnection between humans and the environment, respects the limits of the planet, protects the dignity and equality of each person, and encourages all of earth's inhabitants to live in balance with each other.

Earthworks is a nonprofit organization dedicated to protecting communities and the environment from the adverse impacts of mineral and energy development while promoting sustainable solutions.

Global Alliance for Incinerator Alternatives (GAIA) is a worldwide alliance of more than 800 grassroots groups, non-governmental organizations, and individuals in over 90 countries whose ultimate vision is a just, toxic-free world without incineration.

Healthy Babies Bright Futures (HBBF) is an alliance of nonprofit organizations, scientists and donors that designs and implements outcomes-based programs to measurably reduce babies' exposures to toxic chemicals in the first 1,000 days of development. HBBF brings together the strongest and latest science, data analysis, critical thinking, performance measurement, campaign talent, communications skills and commitment to collaboration.

IPEN brings together leading public interest groups working on environmental and public health issues in over 100 countries to take action internationally to minimize and, whenever possible, eliminate hazardous, toxic chemicals.

Texas Environmental Justice Advocacy Services (t.e.j.a.s.) is dedicated to providing community members with the tools necessary to create sustainable, environmentally healthy communities by educating individuals on health concerns and implications arising from environmental pollution, empowering individuals with an understanding of applicable environmental laws and regulations and promoting their enforcement, and offering community building skills and resources for effective community action and greater public participation.

UPSTREAM seeks to transform our throw-away society to a culture of stewardship. We envision a world in which plastics and other materials are not designed to be used for a matter of minutes and then thrown away, and we empower business, communities, and people to co-create a brighter future with us.

#breakfreefromplastic is a global movement envisioning a future free from plastic pollution made up of 1,400 organizations from across the world demanding massive reductions in single-use plastics and pushing for lasting solutions to the plastic pollution crisis.

Contents

Acronyms

BBP	Benzyl butyl phthalate
BP	British Petroleum
BPA	Bisphenol A
BTEX	Benzene, toluene, ethylbenzene, and xylene
CDC	Centers for Disease Control and Prevention
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon Dioxide equivalent
decaBDE	Decabromodiphenyl ethers
DEHA	Di(2-ethylhexyl) adipate
DEHP	Bis(2-ethylhexyl) phthalate
DiNP	Diisononyl phthalate
DNA	Deoxyribonucleic acid
ECHA	European Chemicals Agency
EDCs	Endocrine disrupting chemicals
EU	European Union
GIT	Gastrointestinal tract
H_2S	Hydrogen sulfide
HAPs	Hazardous air pollutants
HCB	Hexachlorobenzene
HDPE	High density polyethylene
IPEN	International POPs Elimination Network
LDPE	Low-density polyethylene
LEPC	Local Emergency Planning Committee
MDI	Methylene diphenyl diisocyanate
Mt	Metric tons
NGLs	Natural gas liquids
NIAS	Non-intentionally added substances
NO_x	Nitrogen oxides
OctaBDE	Octabromodiphenyl ethers
OSHA	Occupational Safety and Health Administration
PAHs	Polycyclic aromatic hydrocarbons
PBDEs	Polybrominated diphenyl ethers
PBT	Persistent bio-accumulative and toxic
PCB	Polychlorinated biphenyls
PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
PCTP	Pentachlorothiophenol
PE	Polyethylene
PentaBDE	Pentabromodiphenyl ethers
PET	Polyethylene terephthalate
PFAAs	Perfluoroalkyl acids
PFAS	Per and polyfluoroalkyl substances
PFHxS	Perfluorohexane sulfonic acid
PFOS	Perfluorooctane sulfonate
PHA	Polyhydroxyalkanoate
PLA	Polylactic acid
PM	Particulate matters
PHOA	Perfluorooctanoic acid
POPRC	Persistent Organic Pollutants Review Committee
POPs	Persistent organic pollutants
PP	Polypropylene
PP&A	Polyester, polyamide, and acrylic
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinylchloride
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
RNA	Ribonucleic acid
ROS	Reactive oxygen species
SCCPs	Short chain chlorinated paraffins
SO_x	Sulfur oxides
TNPP	Tris(nonylphenol) phosphite
TRI	Toxic release inventory
U-POPs	Unintentionally produced POPs
UCS	Union of Concerned Scientists
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
VOCs	Volatile organic compounds
μm	Micrometer

EXECUTIVE SUMMARY

Plastic Is a Global Health Crisis Hiding in Plain Sight

Despite being one of the most pervasive materials on the planet, plastic and its impact on human health is poorly understood. Yet exposure to plastic are expanding into new areas of the environment and food chain as existing plastic products fragment into smaller particles and concentrate toxic chemicals. As plastic production increases, this exposure will only grow.

To date, research into the human health impacts of plastic has focused narrowly on specific moments in the plastic lifecycle, from wellhead to refinery, from store shelves to human bodies, and from disposal to ongoing impacts as air pollutants and ocean plastic. Individually, each stage of the plastic lifecycle poses significant risks to human health.

Together, the lifecycle impacts of plastic paint an unequivocally toxic picture: plastic threatens human health on a global scale.

This report provides a detailed overview of the health impacts associated with plastic at every stage of its supply chain and lifecycle, and it reveals the numerous exposure routes through which human health is impacted at each stage. The report details the physical impacts of ingesting, inhaling, and touching plastic, as well as the toxic chemicals associated with those plastic particles, whether chemical additives, processing agents, or byproducts of plastic. This report also reveals that systemic and troubling gaps in our knowledge may exacerbate exposure and risks for workers, consumers, frontline communities, and even communities far removed from the sources of plastic. Despite those gaps, the evidence collected in this report is conclusive that there is an urgent need to adopt a precautionary approach to protect human health from the plastic pollution crisis.

KEY FINDINGS

Plastic requires a lifecycle approach. The narrow approaches to assessing and addressing plastic impacts to date are inadequate and inappropriate. Understanding and responding to plastic risks, and making informed decisions in the face of those risks, demands a full lifecycle approach to assessing the full scope of the impacts of plastic on human health. This includes to ensure that we are not creating yet more and increasingly complex environmental problems in attempts to address this one.

At every stage of its lifecycle, plastic poses distinct risks to human health, arising from both exposure to plastic particles themselves and associated chemicals. The majority of people worldwide are exposed at multiple stages of this lifecycle.

- **Extraction and Transport of Fossil Feedstocks for Plastic**
  The extraction of oil and gas, particularly the use of hydraulic fracturing for natural gas, releases an array of toxic substances into the air and water, often in significant volumes. Over 170 fracking chemicals that are used to produce the main feedstocks for plastic have known human health impacts, including cancer, neurotoxicity, reproductive and developmental toxicity, impairment of the immune system, and more. These toxins have direct and documented impacts on skin, eyes, and other sensory organs, the respiratory, nervous, and gastrointestinal systems, liver, and brain.

Opposite: © Marco Garcia/Greenpeace

- **Refining and Production of Plastic Resins and Additives**
  Transforming fossil fuel into plastic resins and additives releases carcinogenic and other highly toxic substances into the air. Documented effects of exposure to these substances include impairment of the nervous system, reproductive and developmental problems, cancer, leukemia, and genetic impacts like low birth weight. Industry workers and communities neighboring refining facilities are at greatest risk and face both chronic exposures and acute exposures due to uncontrolled releases during emergencies.

- **Consumer Products and Packaging**
  Use of plastic products leads to ingestion and/or inhalation of large amounts of both microplastic particles and hundreds of toxic substances with carcinogenic, developmental, or endocrine disrupting impacts.

- **Toxic Releases from Plastic Waste Management**
  All plastic waste management technologies (including incineration, co-incineration, gasification, and pyrolysis) result in the release of toxic metals such as lead and mercury, organic substances (dioxins and furans), acid gases, and other toxic substances to the air, water, and soils. All such technologies lead to direct and indirect exposure to toxic substances for workers and nearby communities, including through inhalation of contaminated air, direct contact with contaminated soil or water, and ingestion of foods that were grown in an environment polluted with these substances. Toxins from emissions, fly ash, and slag in a burn pile can travel long distances and deposit in soil and water, eventually entering human bodies after being accumulated in the tissues of plants and animals.

- **Fragmenting and Microplastics**
  Microplastics entering the human body via direct exposures through contact, ingestion, or inhalation can lead to an array of health impacts, including inflammation, genotoxicity, oxidative stress, apoptosis, and necrosis, which are linked to an array of negative health outcomes including cancer, cardiovascular diseases, inflammatory bowel disease, diabetes, rheumatoid arthritis, chronic inflammation, autoimmune conditions, neurodegenerative diseases, and stroke.

- **Cascading Exposure as Plastic Degrades**
  Most plastic additives are not bound to the polymer matrix and easily leach into the surrounding environment, including air, water, food, or body tissues. As plastic particles continue to degrade, new surface areas are exposed, allowing continued leaching of additives from the core to the surface of the particle in the environment and the human body.

- **Ongoing Environmental Exposures**
  Once plastic reaches the environment in the form of macro- or microplastics, it contaminates and accumulates in food chains through agricultural soils, terrestrial and aquatic food chains, and the water supply. This environmental plastic can leach toxic additives or concentrate toxins already in the environment, making them bioavailable again for direct or indirect human exposure.

Uncertainties and knowledge gaps undermine the full evaluation of health impacts, limit the ability of consumers, communities, and regulators to make informed choices, and heighten both acute and long-term health risks at all stages of the plastic lifecycle.

- **Hidden Risks**
  Extreme lack of transparency of the chemicals in most plastic and its production processes prevents a full assessment of its impacts. Broad protection of confidential business information and inadequate disclosure requirements play a key role in creating these uncertainties, and they reduce the ability of regulators to develop adequate safeguards; consumers to make informed choices; and frontline and fenceline communities to limit exposure to plastic-related health hazards.

- **Intersecting Exposures and Synergistic Effects Remain Poorly Understood**
  Risk assessment processes fail to evaluate the health effects of cumulative exposure to the mixtures of thousands of chemicals used in consumer goods like food packaging and found in the environment.

- **Plastic in the Food Chain**
  Despite their pervasive presence and potentially significant impacts across an array of pathways, research into the impacts and movement of plastic and microplastics through terrestrial

environments, marine ecosystems, and food chains is limited. The potential transfer of microplastics and associated toxic chemicals to crops and animals demands urgent and sustained investigation.

- **Plastic in People**
  Microfibers and other plastic microparticles are increasingly being documented in human tissues. Until these impacts are better understood, we should adopt a precautionary approach to limit the production and use of these persistent contaminants.

Reducing toxic exposure to plastic will require a variety of solutions and options because plastic has a complex lifecycle with a diverse universe of actors.

- **Putting Human Rights and Human Health at the Center of Solutions**
  At every stage of the plastic lifecycle and across those stages, solutions should be guided by the respect for the human rights to health and to a healthy environment. Despite remaining uncertainties, existing information about the severe health impacts of the plastic lifecycle justifies the application of a strong precautionary approach to the lifecycle of plastic and the overall reduction of plastic production and uses.

- **Recognizing the Suite of Interacting Exposures**
  Health impact assessments that focus solely on the plastic components of products while ignoring the thousands of additives and their behavior at every stage of the plastic lifecycle are necessarily incomplete.

- **Making the Invisible Visible**
  Addressing plastic pollution will require adapting and adopting legal frameworks to ensure access to information regarding the petrochemical substances in products and processes, as well as increased independent research to fill existing and future knowledge gaps.

- **Building Solutions on Transparency, Participation, and the Right to Remedy**
  In identifying, designing, and implementing possible solutions to the plastic pollution crisis, transparency is key to success. Transparency is required to identify the nature and breadth of exposure to toxic material, as well to assess possible health and environmental impacts of technologies touted as “solutions” to the plastic pollution problem, such as incineration and plastic-to-fuel technologies. Solutions must integrate not only access to information, but also the right to meaningful participation in decision-making about plastic-related risks, and access to justice when harms arise.

- **Think Globally, Acting Everywhere**
  The production, use, and disposal of plastic is interwoven in supply chains that cross and recross borders, continents, and oceans. To date, efforts to address the human health impacts of plastic have largely ignored the global dimensions of the plastic lifecycle and the plastic crisis. As a result, measures that succeed at a local level or with respect to a single product stream are often undermined or offset by the emergence of new plastic, new additives, and new exposure pathways. Until efforts at all levels of government confront the impacts of the full plastic lifecycle, the current piecemeal approach to addressing the plastic pollution crisis will fail.

Thus far, efforts to address the plastic crisis have had limited success. This results from an array of factors: the scale and complexity of impacts, the limitations of risk assessment systems (in particular the combined effects of chemical substances and the limited exposure data), long and complex supply chains, formidable financial stakes in maintaining the status quo, and an industry in denial of the health impacts. Yet while the economic interests of the plastic industry are indeed enormous, the financial costs to society are even more so.

The findings of this report are clear. Even with the limited data available, the health impacts of plastic throughout its lifecycle are overwhelming. Many actions and solutions are needed to confront this threat to human life and human rights. To be effective, they must ultimately reduce the production, use, and disposal of plastic and its associated toxic chemicals.

CHAPTER ONE

Introduction

Despite being among the most pervasive materials on the planet, the nature, origins, impacts, and diversity of plastic remain poorly understood by the majority of people. In the most general terms, plastics are synthetic organic polymers—giant synthetic molecules comprised of long chains of shorter molecules—derived primarily from fossil fuels. For the sake of simplicity, when this report refers to plastic, it refers to an array of polymers and products with different chemical compositions. That ability to form long unbroken molecular chains is key to plastic's utility, ubiquity, and durability, allowing plastic resins to be pressed, rolled, stretched, and extruded into every conceivable shape. This versatility has made plastic an inescapable part of our material world, flowing constantly through our lives in everything from plastic bottles, bags, food packaging, and clothing to prosthetics, car parts, and construction materials.

The use of plastic as a substitute for traditional materials, and as the basis for new categories of materials, has grown exponentially since the end of World War II, when plastic producers sought new consumer markets for materials made and production facilities built to support the war effort.

A recent analysis of all plastic ever made estimates that the global production of plastic has increased from 2 million metric tons (Mt) in 1950 to 380 million Mt in 2015. By the end of 2015, 8,300 million Mt of virgin plastic had been produced. Significantly, roughly two-thirds of all plastic ever produced has been released into the environment and remains there in some form—as debris in the oceans, as micro- or nanoparticles in air and agricultural soils, as microfibers in water supplies, or as microparticles in the human body. Indeed, plastic is now so ubiquitous in the environment that its presence can be used to identify the age and character of the sedimentary deposits in which it is buried. In other words, plastic is a key geological indicator of the "Plasticene Epoch,"[1] an era often termed the Anthropocene, the geological age in which humans have come to significantly impact terrestrial ecosystems.[2]

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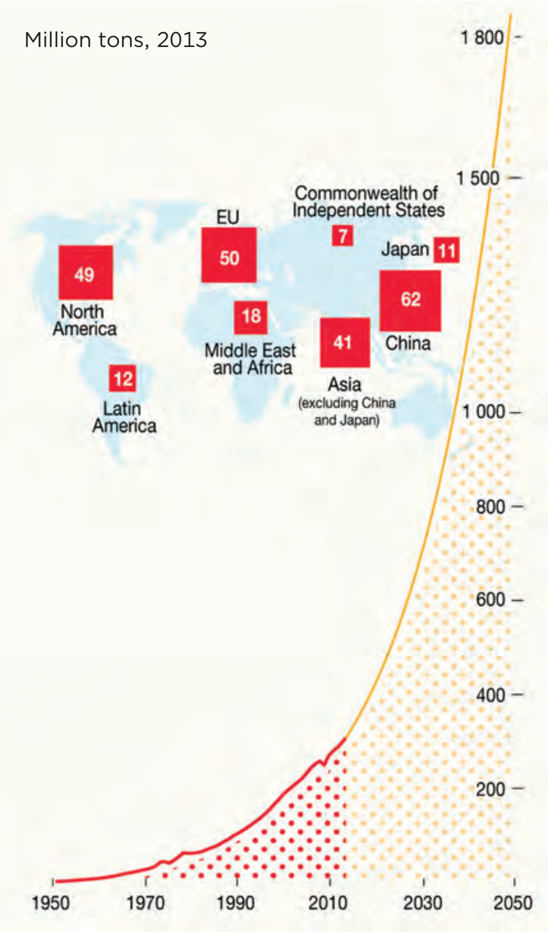
The rise in plastic production, use, and consumption has raised concerns about potential impacts on human health and the environment since at least the 1970s and with growing frequency and urgency in the last two decades.[3] For most of this period, attention has focused on human health exposures to specific plastic precursors or additives, and among specific populations, for example, workers exposed to benzene, infants exposed to phthalates and other plastic additives, or consumers exposed to bisphenol A in food packaging.

This rise in concern continues to coincide with escalating plastic production and use. More than half of all plastic ever created was produced in the last 15 years, and the scale of production grows every year. This growth is poised to accelerate even further, driven by the boom of inexpensive shale gas from fracking, which has made

Opposite: © Les Gibbon/Greenpeace

FIGURE 1

Global Plastic Production and Future Trends



Source: Maphoto/Riccardo Pravettoni plus a link to *http://www.grida.no/resources/6923*

primary feedstocks for plastic cheap and abundant.[4] Based on current investment projections, estimates indicate that production of ethylene and propylene, the two main precursors used for the production of plastic, will increase by 33-36 percent—approximately 100 million Mt—by 2025.[5]

While concerns over the impacts of plastic have been (and sometimes continue to be) denied or downplayed, the scale and urgency of the plastic pollution crisis has unified a global community to undertake legal, scientific, and advocacy initiatives around the world to address it. Successful initiatives include legal bans of plastic bags and bans of single-use plastic products, zero-waste cities initiatives, beach cleanups, research into new technological solutions to deal with waste, and proposals to use international legal frameworks to address plastic pollution globally. Many of these efforts are driven by the visible, tangible imperative to rid our oceans and other ecosystems of plastic pollution.

To date, discussions of the health and environmental impacts of plastic have usually focused on specific moments in the plastic lifecycle: during use and after disposal. However, the lifecycle of plastic and its related human health impacts extends far beyond these two stages in both directions: upstream, during feedstock extraction, transport, and manufacturing, and downstream, when plastic reaches the environment and degrades into micro- and nanoplastics. Increasing research and investigation are providing new insights into the hidden, pervasive impacts of micro- and nanoplastics on human health and the environment.

Nearly all plastic produced today (more than 99 percent) is manufactured from fossil fuel feedstocks (primarily ethylene and propylene, derived from natural gas liquids, or from naphta, a byproduct of crude oil refining; more recently, propylene has also been derived from coal). The true story of the plastic lifecycle thus begins at the coal mine, wellhead, or drill pad, when the fossil fuels that will become plastic begin their journey into the economy and the human environment.

This report consolidates the best available, and previously disparate, research into the human health impacts of plastic throughout its lifecycle to provide a composite understanding of the full range and scale of the health crisis posed by the plastic supply chain and its manufacture, use, disposal, and presence in the environment. The report is broken out into the following chapters:

EXTRACTION AND TRANSPORT

Fossil fuels are extracted from wellheads or drillpads and then transported by pipeline or rail to refineries and processing plants.

REFINING AND MANUFACTURE

Through processing in refineries and crackers, these feedstocks are transformed into the polymers that form the foundation of the plastic economy. Those virgin polymers are in turn combined with a broad range of petrochemical additives to bestow upon the plastic resin specific characteristics such as making it transparent colored, soft, hard, and/or flexible, or to give it properties that make it impermeable to light

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or oxygen, prevent bacterial growth, etc. and that turn it into products for use in all sectors of activity.

CONSUMER USE

During the use phase, wear and tear causes some of those products, such as tires or textile fibers, to degrade and shed micro- and nanoplastic particles and fibers in the environment,[6] or to leach toxic additives, such as through domestic dust and from food packaging into food.

WASTE MANAGEMENT

At the end of their life, which can range from being very short for plastic food packaging and all single-use products to much longer as in the case of construction materials, all plastic products become plastic waste. As of 2015, of the approximately 6,300 Mt of plastic waste generated, around 9 percent had been recycled, 12 percent incinerated, and 79 percent accumulated in landfills or the natural environment.[7] Even the small proportion of plastic that is indeed collected is industrially processed and causes impacts on human health and the environment.

The true story of the plastic lifecycle begins at the coal mine, wellhead, or drill pad, when the fossil fuels that will become plastic begin their journey into the economy and the human environment.

PLASTIC IN THE ENVIRONMENT

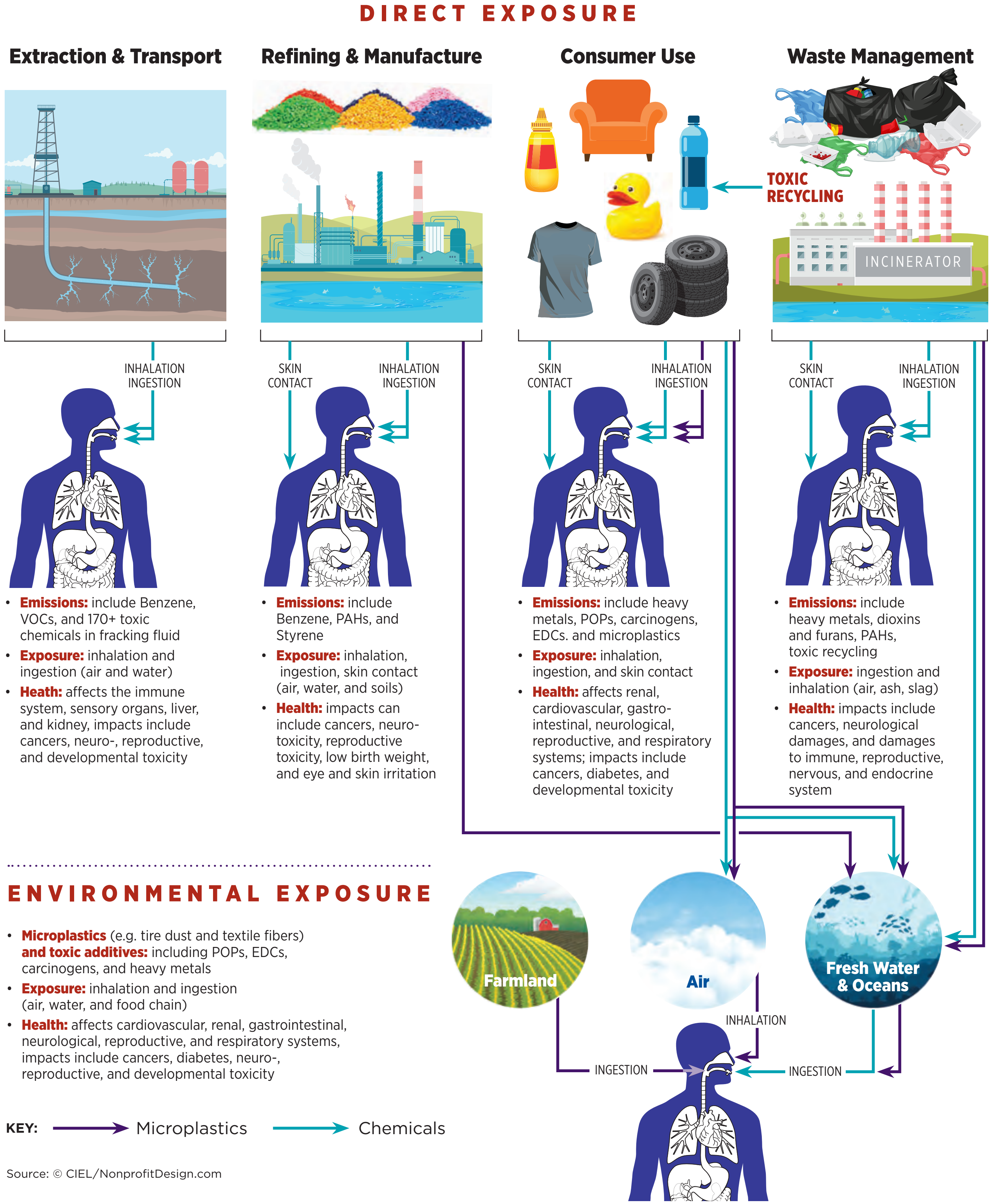
Once plastic reaches the environment in the form of macro- or microplastics, it slowly fragments into smaller particles, where it contaminates all areas of the environment (air, water, and soil), accumulates in food chains, and releases toxic additives or concentrates additional toxic chemicals in the environment, making them bioavailable again for direct or indirect human exposure.[8]

To fully assess the health impacts of our global dependence on plastic, one must therefore not only consider each stage of this lifecycle, but also all possible exposure pathways of the variety of substances used and released throughout the lifecycle. Impacts of any substance on human health will vary depending on the specific route of exposure to the particular substance: **inhalation**—what we breathe, **ingestion**—what we eat and drink, and **skin contact**—what we touch or encounter topically.

FIGURE 2

Plastic & Health: The Hidden Costs of a Plastic Planet

Humans are exposed to a large variety of toxic chemicals and microplastics through inhalation, ingestion, and direct skin contact, all along the plastic lifecycle.



Extraction & Transport

- **Emissions:** include Benzene, VOCs, and 170+ toxic chemicals in fracking fluid
- **Exposure:** inhalation and ingestion (air and water)
- **Heath:** affects the immune system, sensory organs, liver, and kidney, impacts include cancers, neuro-, reproductive, and developmental toxicity

Refining & Manufacture

- **Emissions:** include Benzene, PAHs, and Styrene
- **Exposure:** inhalation, ingestion, skin contact (air, water, and soils)
- **Health:** impacts can include cancers, neuro-toxicity, reproductive toxicity, low birth weight, and eye and skin irritation

Consumer Use

- **Emissions:** include heavy metals, POPs, carcinogens, EDCs. and microplastics
- **Exposure:** inhalation, ingestion, and skin contact
- **Health:** affects renal, cardiovascular, gastro-intestinal, neurological, reproductive, and respiratory systems; impacts include cancers, diabetes, and developmental toxicity

Waste Management

- **Emissions:** include heavy metals, dioxins and furans, PAHs, toxic recycling
- **Exposure:** ingestion and inhalation (air, ash, slag)
- **Health:** impacts include cancers, neurological damages, and damages to immune, reproductive, nervous, and endocrine system

ENVIRONMENTAL EXPOSURE

- **Microplastics** (e.g. tire dust and textile fibers) **and toxic additives:** including POPs, EDCs, carcinogens, and heavy metals
- **Exposure:** inhalation and ingestion (air, water, and food chain)
- **Health:** affects cardiovascular, renal, gastrointestinal, neurological, reproductive, and respiratory systems, impacts include cancers, diabetes, neuro-, reproductive, and developmental toxicity

KEY: → Microplastics → Chemicals

Source: © CIEL/NonprofitDesign.com

It is often argued that a well-developed understanding of the impacts of plastic on human health is hampered by limited information regarding quantification of the cumulative risks of chronic exposure and that there is only limited information about the rates of degradation and fragmentation, leaching of chemicals into the environment, and entry into the food chain.[9] However, while there are indeed knowledge gaps documented in this report, the emerging body of research has served to debunk the historic view of plastic as inert and safe.

Increasingly, the research demonstrates that the same characteristics that make plastic a material with diverse and desirable applications for bettering human life, i.e. lightweight and incredibly durable molecular bonds, render them a widely dispersed, ubiquitous, and persistent threat to human health and the ecosystem upon which we rely.

Increasingly, the research demonstrates that the same characteristics that make plastic a material with diverse and desirable applications for bettering human life, i.e., lightweight and incredibly durable molecular bonds, render them a widely dispersed, ubiquitous, and persistent threat to human health and the ecosystem upon which we rely. Similarly, the breadth of research identifying negative human health impacts of many of the plastic additives is conclusive that there are significant risks to human health and a precautionary approach is warranted.

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CHAPTER TWO

Extraction and Transport

Ninety-nine percent of plastic is derived from fossil fuels.[10] Plastics can be and are made from every kind of fossil fuel. The earliest hydrocarbon plastic—including once-ubiquitous nylons—were derived from coal, and coal continues to be a significant source of plastic production in some areas, including China. Shortly before World War II, the development of polymers from oil feedstocks skyrocketed. When the war ended, plastic producers sought and created new uses and markets for plastic resins and plastic products. Since then, plastic has been produced from a mix of oil, gas, and to a lesser extent coal, depending largely on the availability and cost of key feedstocks.

In the United States, oil and gas drilling began in the early 1900s[11] using conventional drilling, which consists of drilling a vertical well. Later processes introduced unconventional drilling, in which a well is drilled vertically and then horizontally for more than two miles. The advent of new hydraulic fracturing technologies at the turn of the 21st century enabled access to natural gas reserves that were previously unavailable for exploitation. Together, unconventional drilling and hydraulic fracturing have led to a massive oil and gas boom between 2006 and 2015, which has, in turn, fueled a plastic production boom. As extraction methods and locations have expanded, so have the release of toxic chemicals into water, air, and food, leading to massive public health risks.

Often referred to as fracking, hydraulic fracturing is a pressurized process in which underground rock formations (shale) are cracked, or fracked, to release trapped oil and gas. Fracking uses a mixture of chemicals, sand, and fresh water to prop open cracked shale rock. This causes oil and gas to flow out of the drilled well, as well as other "flowback" liquids, such as the water, sand, and chemicals used to drill the well, in addition to hydrogen sulfide (H_2S) and various hydrocarbons,[12] including benzene, toluene, ethylbenzene, and xylene—a group called BTEX.[13]

Oil and gas extraction occurs in five stages:[14]

1. More than one million gallons of water, sand, and chemicals[15] are hauled to inject into the well
2. Pre-production: Well pad is prepared, drilled, and fracked, including by injection of plastic pellets coated with lightly radioactive material[16]
3. The pressurized mixture causes the shale to crack while sand props open the cracks and allows oil and gas to flow into the well
4. Production: active extraction of oil, gas, and waste fluids
5. Transmission, storage in pits or tank, and distribution of oil and gas
6. Processed water, oil, and gas are hauled to treatment for use

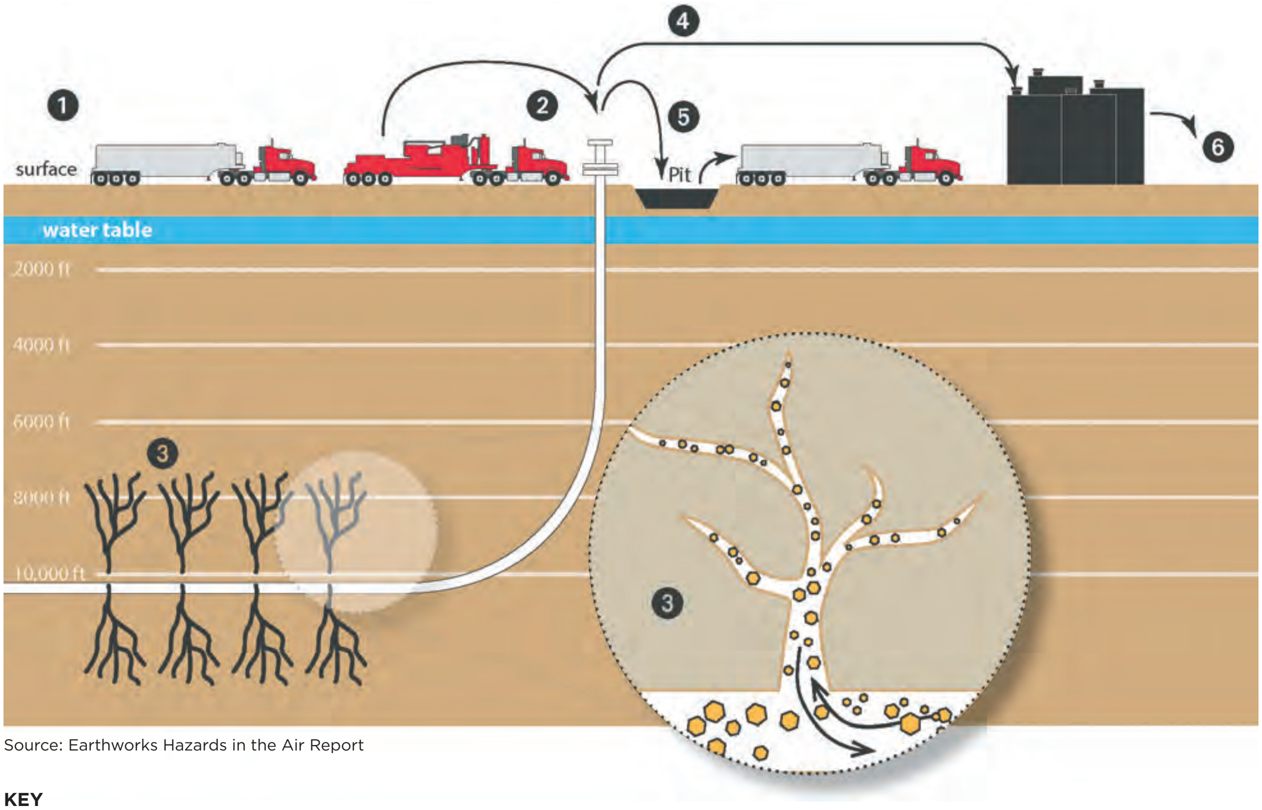
There are two types of fracked gas: wet and dry. Dry gas is mostly methane, while wet gas contains "natural gas liquids" (NGLs) that consist of ethane, propane, butane, and pentane.[17] While all hydrocarbons can be turned into plastic and plastic precursors, ethane is more easily "cracked" into ethylene, one of the primary components of plastic, and it is therefore the preferred feedstock for plastic production.

Due to the fracking boom, there is an abundance of cheap natural gas. "Thanks to the shale gas production boom, the United States is the most attractive place in the world to invest in chemical and plastics manufacturing. It's an astonishing gain in competitiveness," reported the American Chemistry Council in 2014.[18]

Opposite: © iStockphoto/sasacvetkovic33

FIGURE 3

Unconventional Oil and Gas Production



Source: Earthworks Hazards in the Air Report

KEY

- ❶ Water, sand, and chemicals are hauled to the well pad
- ❷ Well pad is prepared, drilled, and fracked
- ❸ Pressurized mixture causes the shale to crack, oil and gas to flow into the well
- ❹ Active extraction of oil, gas, and waste fluids
- ❺ Transmission, storage, and distribution of oil and gas
- ❻ Processed water, oil, and gas are hauled to treatment for use

HEALTH IMPACTS

Air Pollution

In the United States alone, an estimated 12.6 million people live within a half-mile of oil and gas facilities.[19] Research continues to show that oil and gas development creates air pollution, including during production, processing, transmission, and storage.[20] Between 2009 and 2015, 685 peer reviewed studies investigated the impacts of fracking. Of the 46 studies on air quality, 87 percent indicated elevated air pollution emissions.[21]

Air pollution generated during “pre-production,” including drilling, fracking, and flaring—a process used by the industry to burn off excess gases—tends to be well known.[22] Flaring or venting excess gases that are considered waste has increased due to rapid oil and gas expansion[23] and can release toxic chemicals into the air.[24] With 2,300 truck trips required per well to transport water, sand, and other materials, diesel trucks also contribute to air pollution during the pre-production phase.[25] Diesel exhaust from trucks emits toxic chemicals like BTEX and particulate pollution,[26] small particles and liquid droplets that mix into the air. When inhaled, these can lead to cardiovascular disease and respiratory conditions, such as shortness of breath, pulmonary inflammation, and aggravation of asthma symptoms.[27]

Ozone

Air pollution also impacts the health of communities living farther from oil and gas facilities. Oil and gas production emits over nine million tons of methane and other pollutants, like volatile organic compounds (VOCs), each year. VOCs, mixed with oxides of nitrogen (NO_X), when exposed to sunlight, create ozone, or ground-level smog pollution, harmful to human health.[28] Ozone smog resulting from oil and gas pollution has impacted rural communities, andit can spread up to 200 miles from where the pollution is produced.[29]

Chronic exposure to ground-level ozone can impair lung function and lead to asthma and chronic obstructive pulmonary disease. It is particularly damaging to children, active young adults who spend time outdoors, people with existing respiratory conditions, and the elderly.[30] Projections indicate that by 2025, in the US alone, there will be 750,000 summertime asthma attacks in children under the age of 18, more than 2,000 asthma-related emergency room visits, and 600 respiratory-related hospital admissions due to ozone smog from oil and gas pollution.[31]

Frontline Community Impacts

Health impacts to communities living near oil and gas development vary depending on route of exposure (inhalation, ingestion, skin and eye contact, and ears for noise pollution), duration of exposure, dose, mixture of the chemicals, and vulnerabilities such as age, preexisting health conditions, and history of environmental exposures. Harmful pollutants emitted from oil and gas operations can impact the respiratory, circulatory, reproductive, immune, neurological, and digestive systems, in addition to the skin and eyes.[32] Unlike immediate impacts to the skin and eyes that can occur upon contact, other health impacts that are not always evident at the time of exposure can have unpredictable and delayed life-long effects on individuals and their offspring.[33]

Of the 353 chemicals associated with oil and gas production, 75 percent affect the skin, eyes, and other sensory organs, the respiratory system, the gastrointestinal system, and the liver. Up to half of the chemicals could affect the brain/nervous system, immune and cardiovascular system, and the kidneys.[34] Additionally, studies have found that higher concentrations of fracking wells are significantly associated with higher inpatient hospitalization for cardiac or neuro-logical problems.[35]

Mental Health and Human Rights

Although the impacts from oil and gas extraction, transport, and storage on mental health are one of the most underrepresented research areas, studies have found communities living near oil and gas extraction are susceptible to psychological impacts leading to stress, trauma, and powerlessness.[36] Loud noise from fracking and drilling, gas compressors, traffic, and other heavy equipment can cause sleep disturbance, induce stress, and increase high blood pressure, diabetes, heart disease, depression, and learning difficulties in children.[37]

Around the world, community leaders and activists also face threats, harassment, torture, violence, and even assassination for protecting the health and environment of their communities by peacefully opposing new oil and gas extraction projects.[38,39,40]

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Risks to Children, Infants, and Pregnant Women

Studies show that the health risks of vulnerable populations such as children, infants, and pregnant women are particularly high in regions with expansive oil and gas production.[41] Oil and gas drilling and fracking operations use and emit chemicals that are known to disrupt the endocrine system, the collection of glands that produces hormones and regulates everything from hunger to reproduction and influences nearly every cell, organ, and metabolic function.[42] Endocrine disruptors are chemicals that can interfere with the body's endocrine system and negatively impact the developmental, reproductive, neurological, and immune systems. Research links endocrine disruptors to cancer, obesity, diabetes, metabolic diseases, infertility,[43] and increased risk during prenatal and early infant development when organ and neural systems are forming.[44] Thirty seven percent of the chemicals used in fracking are suspected endocrine disruptors.[45] Harm to reproductive and developmental outcomes have been linked to the presence of endocrine disrupting chemicals used in oil and gas development—including benzene, toluene, ethylbenzene, and xylenes.[46]

A British Columbia study found elevated levels of muconic acid—a marker of benzene exposure—in the urine of pregnant women living near fracking sites.[47] Studies in Pennsylvania have found that infants of mothers living near fracking sites have a 40 percent increase risk of preterm birth,[48] and poorer indicators of infant health, and significantly lower birth weights.[49] Colorado-based studies have found higher prevalence of birth defects of the brain, spine, and spinal cord and congenital heart defects,[50] and higher rates of leukemia in children and young adults living in dense oil and gas production areas.[51] Cancer-causing chemicals used in fracking have been found to contaminate both the water and air of nearby communities that could increase the risk of childhood leukemia.[52]

Water

Harmful chemicals used in fracking can enter drinking water resources—from spills, improper handling of wastewater, or faulty infrastructure—and lead to negative impacts on human health. Forty of 58 peer-reviewed studies of water quality near oil and gas production sites (69 percent) show evidence of water contamination associated with oil and gas production.[53] In just four US states—Colorado, New Mexico, North Dakota, and Pennsylvania—6,648 fracking-related spills were recorded from 2005-2014.[54]

Fracking wastewater is a blend of the water used to frack, salts, toxic chemicals, organic matter, and naturally occurring radioactive material.[55] Wastewater poses threats to drinking water sources and local ecosystems, in particular through:

- wastewater spills;
- injection of wastewater into wells that leak into groundwater resources or injection of wastewater directly into groundwater resources;
- dumping of improperly treated wastewater; and
- Dumping or storing of wastewater in unlined water pits, resulting in leakage into groundwater.[56]

The United States Environmental Protection Agency (USEPA) has identified 1,606 chemicals associated with fracking, including 1,084 chemicals used to frack and 500 chemicals detected in wastewater. Of these, 173 chemicals are known to cause health impacts if ingested, including:

- Cancer,
- Neurotoxicity,
- Immune system effects,
- Changes in body weight and blood chemistry,
- Liver and kidney toxicity, and
- Reproductive and developmental toxicity.[57]

Pipelines

The US oil and gas boom has led to a dramatic increase in the buildout of natural gas pipelines in the country. Pipelines are needed to transport natural gas from extraction to refineries, ports, and consumers.[58] Currently, there are an estimated three million miles of pipelines transporting natural gas around the US.[59] Gathering lines move gas from the well to a transport line, which moves the gas to another "mid-stream" line or directly to market.

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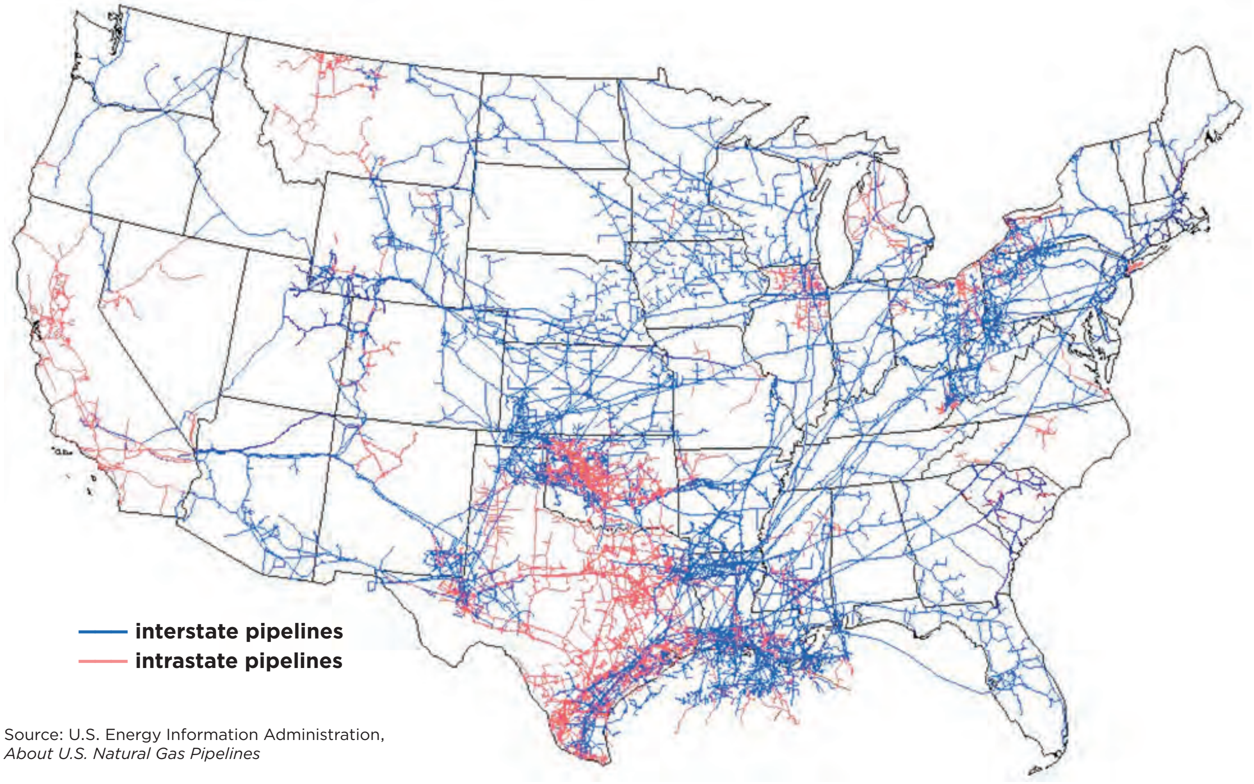
FIGURE 4

Three Million Miles of Gas Pipelines in the US



Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

Although pipelines are buried, they not only pose threats to underground waterways but also to people and natural habitats aboveground. Pipelines are fragile, prone to freezing, corrosion, breaking, and leaking. Between 2010 and 2017, in the US alone, pipeline incidents killed 100 people, injured 500, caused the evacuation of thousands, and leaked more than 17 billion cubic feet of methane. Flowlines, used to carry oil, gas, or wastewater, were responsible for more than 7,000 spills, leaks, and accidents since 2009,[60] further increasing human and environmental exposure to known toxic chemicals and related human health impacts.

Pipeline air emissions are another public health concern. Pipelines emit methane, ethane, benzene, toluene, xylene, carbon monoxide, ozone, and other pollutants.[61] Compressor stations, which pressurize natural gas to ensure a regulated and continuous flow through pipelines,[62] create additional air emissions, as well as noise pollution. Due to minimal and varying pipeline regulations, damaged or old pipelines increase the risk of fugitive emissions and incidents.[63]

Before plastic reaches consumers, and long before it reaches the environment, severe human health effects are evident in the first stages of the plastic lifecycle: fossil fuel extraction and transport. Thus, the toxic impacts of plastic must be understood starting at the wellheads, where the basic feedstock of plastic is extracted. To reduce the public health risks associated with plastic, it is key to reduce the production of oil, gas, and plastic.

> Before plastic reaches consumers, and long before it reaches the environment, severe human health effects are evident in the first stages of the plastic lifecycle—fossil fuel extraction and transport. Thus, the toxic impacts of plastic must be understood starting at the wellheads.

CHAPTER THREE

Refining and Manufacture

The refining and manufacture of plastic significantly impacts human health. In particular, fenceline communities located in close proximity to production sites and workers employed in the production facilities are acutely impacted. Fenceline communities, as used in this report, are neighborhoods that are impacted due to their close proximity to extractive industry infrastructure that extract, processes, stores, and transports chemicals, toxins, and other hazardous materials. These communities face the daily threat of toxic exposure, potential incidents/accidents, or death. Typically, they are communities of color and low-income and marginalized communities. As such, they are generally viewed as areas of least resistance, where it is likely that people will not have the ability and resources to challenge industry, even when those industries are likely to negatively impact their environment and health. Fenceline communities are disproportionately affected not only by toxic exposure but also by environmental degradation, food insecurity, poor education, and inadequate healthcare, along with a number of other challenges prevalent in low-income areas. These impacts are only exacerbated by poor governance and poor communication with fenceline communities.

Notably, fenceline communities face not one, but rather multiple pollutant sources. One factory or refinery often paves the way for more production facilities and refineries, as well as other related infrastructure. They are often built in close proximity to one another due to the related nature of some industrial processes (for example oil and gas refining and plastic production), economies of scale, and the existing infrastructure, such as a shipping channel.

BOX 1

Shelter-in-Place Incidents

Accidents or incidents are also referred to as shelter-in-place incidents, which draw their name from the action that has to be taken. In these instances, minimizing risk requires people to "shelter-in-place" by taking shelter or refuge in an interior room of a home or other structure that has no or few windows and to remain in those shelters until local authorities indicate that it is safe to go outside. See Emergency Action Plan, Shelter-in-Place, Occupational Health and Health Administration, *https://www.osha.gov/SLTC/etools/evacuation/shelterinplace.html*.

HUMAN HEALTH IMPACTS OF CHEMICALS INVOLVED IN PLASTIC PRODUCTION

While research is still needed on various aspects of the human health impacts of the plastic production process, including the carcinogenic properties of some of the chemical substances involved, many of the chemicals released have myriad impacts already known to be harmful to humans.

Hazardous Air Pollutants

According to the USEPA, hazardous air pollutants, also known as air toxics, are classified as pollutants when they are known or suspected to cause cancer, reproductive and birth defects, or other serious adverse human and environmental effects.[64] Under the US Clean Air Act, the USEPA is required to regulate emissions of 187 hazardous air pollutants.

Opposite: © iStockphoto/George Clerk

© iStockphoto/Joyce Marrero

Plastic production results in the release of many of those substances, as many of the chemicals integral to producing plastic are hazardous air pollutants. For example, a report by the Union of Concerned Scientists (UCS) reviewed the most dangerous hazardous air pollutants present daily in the Houston, Texas, community of Manchester (see Box 3). Four of the six pollutants examined are related to plastic production: 1,3 butadiene, benzene, styrene, and toluene. Many of these chemicals, as well as others released through the production of plastic, pose an especially serious threat to human health because they have a variety of impacts, including cancer, and can be difficult to detect, as some are colorless and tend to have mild to no odor. Below is a non-comprehensive list of some of the worst chemicals used and released during plastic production.

1,3-BUTADIENE

1,3-Butadiene, a flammable, colorless gas with a mild gasoline-like odor, is used as a chemical intermediate and as a monomer to make rubber, plastic, and other polymers.[65] Both short-term and long-term exposure to this pollutant can lead to negative health impacts. Short-term exposure can cause irritation of the eyes and throat, headaches, fatigue, decreased blood pressure and pulse, central nervous system damage, and unconsciousness. Long-term exposure can cause cancer and increase the likelihood of leukemia.[66] For example, a University of Texas Medical Branch study reported that children living within two miles of the Houston Ship Channel, which is home to numerous industrial plants, had a 56 percent increased risk of developing acute lymphocytic leukemia than children who lived more than ten miles from the channel.[67] The same study acknowledged that children living in regions with higher 1,3-butadiene emissions from petrochemical facilities were found to have higher rates of both lymphatic leukemia and acute myeloid leukemia.[68]

BENZENE

Benzene, a flammable, colorless liquid with a sweet odor, is used as a chemical solvent to help form the monomers from which to make plastic resins, nylon, and synthetic fibers.[69] Benzene is released in many ways, including through industrial solvents, emissions from burning coal and oil, and tobacco smoke.[70] Like 1,3-butadiene, exposure to benzene can have severe health impacts. In fact, since the end of the nineteenth century, benzene has been known to be a powerful bone marrow poison.[71] Short-term exposure to benzene causes headaches, tremors, drowsiness, and dizziness, and exposure to high levels of benzene can even lead to death within several minutes or hours.[72] Longer, or a lifetime of, exposure can cause wide-ranging health impacts from anemia to leukemia.[73] Additionally, studies have shown that in communities where benzene is released into the air by industrial plants, there are higher instances of some blood cancers, specifically non-Hodgkin lymphoma.[74] Women exposed to a high density of benzene through air pollution can also experience specific reproductive health impacts, including irregular menstrual cycles and underdeveloped ovaries.[75]

STYRENE

Styrene, a highly explosive colorless liquid, is used in the production of polystyrene plastic and resins.[76] It can be released into the air and can migrate into food (and then be ingested) from polystyrene packaging. Limited exposure to styrene can cause irritation of the lungs, eyes, nose, and skin. High exposure can cause changes in vision, slowed reaction times, problems maintaining balance, and even cancer.[77]

TOLUENE

Toluene is a colorless liquid with a sweet odor. It is used both to produce other chemicals, including benzene, and in the production of polymers such as polyethylene terephthalate (PET), a key component of plastic bottles and nylon, among other products.[78] Toluene is released into the air during polymer production, through its use as a solvent, and during use of products containing toluene.[79] Short-term exposure to low or moderate levels of toluene can cause fatigue, weakness, memory loss, nausea, and appetite loss. Long-term exposure can cause irritation of the eyes or lungs, headaches, and dizziness. Toluene may also affect the nervous and reproductive systems and cause developmental problems in children.[80]

ETHANE

Ethane, a byproduct of natural gas extracted through fracking, is used for plastic production through its conversion into ethylene. Ethane crackers are industrial facilities built to convert ethane obtained from natural gas extraction into ethylene to use in producing plastic. Ethane itself is a hydrocarbon, and the production of ethylene results in the emission of sulfur dioxide, nitrogen oxides, and VOCs, which combine to create ozone in the presence of sunlight, as well as particulate matter, lead, and carbon monoxide. Additionally, hazardous air pollutants including acrolein, benzene, and volatile organic compounds may be released. These bring with them a variety of health impacts, including eye and throat irritation, nausea, headaches, and nose bleeds at low levels and more serious kidney, liver, and central nervous system damage at high levels. They have also been linked to allergies and respiratory problems such as asthma, and some are known or suspected carcinogens.[81]

PROPYLENE AND PROPYLENE OXIDE

Propylene, a colorless gas with a faint petroleum-like odor, is a chemical intermediate in the production of plastic (including carpet fibers) and fine chemicals.[82] Exposure to propylene in moderate amounts can cause dizziness, drowsiness, and unconsciousness.[83] Propylene oxide, a highly flammable, volatile, colorless liquid, is used in the creation of polyurethane plastic and other polyethers.[84] Propylene oxide has been classified as a probable human carcinogen. Through short-term exposure, it can cause eye and respiratory tract irritation and is a mild central nervous system depressant.[85]

> Many of these chemicals, as well as others released through the production of plastic, pose an especially serious threat to human health because they have a variety of impacts, including cancer, and can be difficult to detect as some are colorless and tend to have mild to no odor.

POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

More than 100 chemicals are classified as PAH, and are found in coal tar, crude oil, creosote, dyes, pesticides, and plastic.[86] PAHs are recognized environmental toxicants and can also have negative health impacts. In a 2018 study conducted by Texas A&M, PAHs were present near household entrances in industrial areas, and three of the USEPA-listed PAHs have been linked to plastic production including anthracene, phenanthrene, and pyrene. This study found 19 of 61 PAHs in the homes sampled, including 16 on the USEPA's priority list and seven probable human carcinogens.

Exposure pathways for the PAHs linked to plastic production (including anthracene, phenanthrene, and pyrene) include respiratory passages, skin contact, and ingestion. In a high-exposure setting, laboratory animals, including pregnant mice, exposed to PAHs through ingestion and inhalation experienced reproductive problems, tumors, low birth weight, and birth defects. Humans exposed to anthracene experience headaches, nausea, loss of appetite, and inflammation or swelling of the stomach and intestines. In addition, anthracene delays human reaction time and can cause feelings of weakness. Acute exposure can cause skin damage, including burning or itching sensations, and the build-up of fluid in body tissue.[95] When exposed to high quantities of phenanthrene through food, skin, and air, mice experienced reproductive problems, low birth weight, and birth defects. This was also accompanied by skin and immune system damage.[96] Mice that were fed pyrene developed nephropathy, a kidney disease that can end in kidney failure and changes in blood, decreased kidney weight, and increased liver weight.

BOX 2

Case Study: Emissions from One Proposed Plastic Production Plant

Plastic production facilities release many toxic substances in day-to-day activities. For example, Shell is currently constructing an ethane cracker in close proximity to the Marcellus Shale natural gas deposits in Pennsylvania, an area of increased fracking[87] It is designed to produce plastic from the ethane created as a byproduct of fracking. This one facility is projected to emit a wide range of chemicals that will negatively impact human health, including tons of nitrogen oxide, carbon monoxide, filterable particulate matter, large particulate matter, fine particulate matter, sulfur oxides, volatile organic compounds (VOCs), hazardous air pollutants (HAPs), ammonia, and carbon dioxide equivalents.[88] As Table 1 shows, this single ethane cracker facility would substantially contribute to air pollution in the region as it plans to emit significant amounts of toxic chemicals in close proximity to nearby fenceline communities. Not only will it emit HAPs, including benzene and tolulene, which can cause cancer and birth defects,[89] but also it will emit VOCs, which can react with the simultaneously released nitrogen oxides to create ozone smog that can impede people's ability to breathe, especially those with asthma,[90] and particulate matter, which can also cause cancer.[91]

The ethane cracker's success is linked to the influx of related industries and technology, indicating industrial buildout will likely follow.[92] While plastic production creates its own specific harms and threats to the health of fenceline communities, these can be, and often are, exacerbated by the presence or expansion of related industrial processes that also pose significant threats. Additional petrochemical plants are planned for the area, and it is likely that plastic-producing plants would follow to take advantage of the infrastructure already in place to support them.[93] The pollution statistics omit other pollutant sources, like trucks, that increasingly will be needed to transport products.[94] Thus, the health risks fenceline communities face from the development of this single ethane cracker will only grow.

Both fenceline communities and workers are vulnerable to PAH exposure. According to a report released by the German Environmental Agency,[97] some PAHs are "persistent, bioaccumulative, and toxic (PBT) pollutants."[98] In 2000, the USEPA stated that PBT pollutants are "highly toxic, long-lasting substances that can build up in the food chain to levels that are harmful to humans and ecosystems,"[99] meaning that they have a very long lifespan and potentially have a wide reach. It is difficult to reduce PBT risks because they are able to travel long distances, move easily from air to water or land, and remain in people and the environment for generations. Currently there are 16 PBTs recognized by the USEPA,[100] although it is looking to list five additional substances, four of which are related to plastic production: decabromodiphenyl ethers (decaBDE); pentachlorothiophenol (PCTP); phenol, isopropylated, phosphate (3:1); and 2,4,6-tris(tert-butyl) phenol.[101] Additionally, four of the current 16 have been linked to plastic production: benzo (g,h,i)perylene,[102] lead,[103] mercury,[104] and tetrabromobisphenol A.[105] Some PBT pollutants have a wide range of adverse effects on human health, including damage to the nervous and reproductive systems, and others have been linked to developmental problems and cancer.[106]

Despite these known risks, data on air, water, and soil contaminants that affect fenceline communities and workers in the plastic industry remains incomplete. Furthermore, there is a profound lack of information about cumulative impacts and exposure.

CHEMICAL CLUSTERS AND RISK OF ACCIDENTS

As noted earlier, and as evidenced by the projected emissions from Shell's planned ethane cracker in Pennsylvania, fenceline communities are particularly vulnerable to the impacts of plastic production. They face daily exposure to a variety of toxic chemicals at much higher levels than communities located far from industrial sites. Additionally, they are at constant risk of increased exposure from incidents and accidents, a risk that grows as the number of industrial plants for plastic production, and associated industries, grows.

Events such as catastrophic industrial fires, explosions, and chemical releases are surprisingly common. For example, in 2013, an ExxonMobil refinery and chemical plant in Louisiana reported 76 incidences in a single year, an average of more than six per month.[107] Among the top chemicals released were propylene, ethylene, and benzene, all of which are related to plastic production. These incidents, as well as the emissions estimates from Shell's planned ethane cracker, demonstrate the inherent ongoing risks for fenceline communities. These risks will only increase as plastic production expands. Like Shell, ExxonMobil is investing in new and expanded production. For example, ExxonMobil has invested US$ 6 billion to expand its 36-year-old plastic, refining, and chemical plant as part of its "Growing the Gulf Initiative."[108] Through this expansion, millions of gallons of gas will be transported through hundreds of pipelines to be stored in underground salt domes in Mont Belvieu, a city

TABLE 1

Shell Facility's Potential to Emit

Air Contaminant	**Facility-wide Emission Rate** (Tons Per Year)
Nitrogen Oxides (NO_x)	348
Carbon Monoxide (CO)	1,012
Filterable Particulate Matter (PM)	71
PM10 (Large)	164
PM2.5 (Fine)	159
Sulfur Oxides (SO_x)	21
Volatile Organic Compounds (VOCs)	522
Hazardous Air Pollutants (HAPs)	30.5
Ammonia (NH3)	152
Carbon Dioxide Equivalents (CO_2e)	2,248,293

SOURCE: PA Bulletin Doc. No. 15-558a.

© Les Stone/Greenpeace

roughly 30 miles east of Houston, Texas, built on a mountain of salt and haunted by the dangers posed by vast quantities hydrocarbons stored underground.[109] The area is already home to 125 storage caverns holding millions of barrels of hydrocarbons and quickly filling with ethane and other natural gas liquids. From Mont Belvieu they will be transported to ExxonMobil's Baytown plant, which will produce an additional 3.3 billion pounds of ethylene. Both plants employ 7,500 people, and ExxonMobil estimates that with contractors and others that number will grow to 15,000. This increased workforce, like numerous fenceline communities, will be exposed to inherent health risks.

> The problems fenceline communities face are further exacerbated by the frequent lack of access to information about the risks they face and by the barriers to raising concerns with companies or local officials. Access to information about toxic chemicals is essential to evaluate risks, mitigate harm, and participate in decision-making.

Community Engagement and Access to Information

The problems fenceline communities face are further exacerbated by the frequent lack of access to information about the risks and by the barriers to raising concerns with companies or local officials. Access to information about toxic chemicals is essential to evaluate risks, mitigate harm, and participate in decision-making.[110] Both states and businesses have obligations to ensure communities' right to information, especially related to toxic chemicals they may be exposed to and the risks that those chemicals may pose.[111]

Even when attempts are made to improve information sharing, implementation faces other hurdles. One attempt to standardize engagement, protect communities' right to know, and develop strategic plans is the USEPA's initiative to establish Local Emergency Planning Committees (LEPCs).[112] However, instead of increasing communication and access to information, LEPCs have often only added a bureaucratic layer (and lengthy response times) to communication between residents and agencies. An investigative report by the *Houston Chronicle* found LEPCs were not doing the minimum required—informing communities about the potential chemicals that could be released in the production of plastic and related products[113]—much less the critical work of helping develop emergency response plans. The LEPCs' ability to act in an emergency has been hampered by a lack of dedicated funding, as well as other resources and necessary tools, such as consultants, data, support staff, hazmat training, and equipment.[114] This lack of support, structure, and regular communication[115] limits communities' ability to develop and implement response plans, with dire consequences. In February 2017, a chemical plant leak in Alabama released 738 pounds of chlorine gas. Inadequate disclosure and preparation meant that the plant failed to warn nearby residents, and first responders were deployed directly into the cloud of noxious gas.[116]

Thus, a stated intention to provide access to information alone does not adequately engage and protect communities from toxic risks posed by plastic production. Measures to ensure the right to information and participation must be adequately resourced and implemented to be effective.

External Factors: Extreme Weather Events

Extreme weather events exacerbated by climate change, which the plastic industry helps fuel, will only increase, further complicating fenceline communities' exposure to toxic chemicals. The landfall of Hurricane Harvey in Houston, Texas, in 2017 is a prime example. Harvey dropped an entire year's worth of rainfall in three days. The hurricane affected fenceline communities that not only faced the tremendous amounts of rainfall and its associated problems, but also a severe increase of toxic exposure. In the week following Harvey, oil refineries and chemical plants released one million pounds of dangerous air pollutants into neighboring communities, including benzene, 1,3-butadiene, sulfur dioxide, and toluene, among others.[117] A hurricane-related explosion at Arkema, a chemical storage and chemical processing plant in Crosby, Texas, resulted in 21 people seeking medical attention, 15 of whom were first responders, and 7 of whom filed a lawsuit against Arkema for gross negligence and bodily injury. Following exposure to the fumes and smoke from the plant, "[p]olice officers were seen doubled over vomiting, unable to breathe. Medical personnel, in their attempts to provide assistance to the officers, became overwhelmed and they too began to vomit and gasp for air."[118] Residents of nearby

© Bob McMillan/FEMA

communities were forced to evacuate their homes for a week.

THREATS TO WORKERS IN THE PLASTIC INDUSTRY

The daily safety and health risks associated with plastic production, as well as incident/accident risks, not only impact fenceline communities, but also the people who work in the plants. Workers risk injury and death and face short- and long-term health risks due to their increased exposure to toxic chemicals. However, the reality of these risks is not always apparent. Requirements related to "acceptable limits" of air toxics and reporting rules for injuries and deaths often misrepresent the real risks of working in the plastic production industry. For example, in the US, injuries and deaths are only attributed to companies when they are suffered by official employees. As a result, evaluations of facility safety records are misleading as they omit data on thousands of contract workers, who often perform the most hazardous jobs. For example, all 15 workers killed in an accident at a British Petroleum (BP) facility in Texas City, Texas, were employed as contractors. As a result, their deaths are not attributed to BP in Occupational Safety and Health Administration records.[119]

> The daily safety and health risks associated with plastic production, as well as incident/accident risks, not only impact fenceline communities, but also the people who work in the plants. Workers risk injury and death and face short- and long-term health risks due to their increased exposure to toxic chemicals.

Further, workers are also exposed to numerous toxic chemicals in the production process, and when they report symptoms, they are rarely validated through company or government meter readings. But as with safety risks, even official

BOX 3

Case Study: Manchester/Harrisburg, Texas

As evidenced in studies by UCS and Texas A&M, which reviewed various chemicals, both hazardous air pollutants (HAPs) and PAHs, present in and around households in Manchester/Harrisburg, Texas, the community of Manchester/Harrisburg is a prime example of a fenceline community in the United States. Manchester is part of the city of Houston, home of the largest petrochemical complex in the United States and one of the largest in the world. This includes a wide variety of industries, including plastic-producing facilities and oil and gas refineries, which use their byproducts for plastic production. Houston is the largest US city without any zoning regulations—the intentional designation of areas for specific purposes and uses (i.e., residential area, industrial corridor), which means there is no regulatory structure or restriction as to where industrial buildings can be constructed. As plastic production increases, so will the production of essential plastic feedstocks and the related release of toxic chemicals. The lack of zoning regulation means this toxic impact will likely be borne by nearby communities.

Ninety percent of residents in Manchester/Harrisburg live within one mile of a chemical facility.[120] The most recent census and demographic data from the American Communities survey indicate that the community is 97 percent people of color. Within a one-mile radius of Manchester/Harrisburg, there are 21 toxic release inventory (TRI) facilities, eleven large quantity generators of hazardous waste, four facilities that treat, store, or dispose of hazardous waste, nine major dischargers of pollutants, and eight major water discharge facilities.[121] A City of Houston Department of Health and Human Services report found that cancer was the second leading cause of death for community members in Manchester/Harrisburg. All but two cancer-related deaths were attributed to bronchus-lung cancer. Additionally, eight percent of live births in Manchester/Harrisburg were low birth weight, which is a significant factor to infant mortality and an indicator of adverse health problems, including mental development, cerebral palsy, and respiratory, vision, and hearing problems.[122] The USEPA's EJSCREEN ranks Manchester/Harrisburg as having a cancer risk rate in the 90–95 percentile, which is a higher cancer rate than the majority of the country.[123]

Four of the largest emitters in the area include Valero Energy Partners LP[124] and Valero Refining-Texas LP Houston Refinery,[125] which include propylene as one of their primary products.[126] Propylene is used as a chemical intermediate in the production of plastic, fine chemicals, and carpet fibers.[127] This facility is located in the center of Manchester/Harrisburg, directly across the street from the main public park and immediately adjacent to residential housing, places of worship, two schools, and one early childhood development center serving the 8,747 children under age five who live within a three-mile radius. Next to Valero is Contanda Chemical storage facility with its 100 steel drums, which range in size from holding 226 to 74,475 barrels of product, with a current total terminal capacity of 2,214,066 barrels.[128] A new storage terminal is expected to be operational in 2021 and provide up to three million barrels of additional capacity and a deep-water ship dock. This 350-acre site on the Houston Ship Channel was established through an agreement with the Port of Houston to support the growing petrochemical and refined products industry.[129]

EcoServices Operation Corp.[130] and Huntsman International LLC[133] release a total of 25 carcinogens from their Manchester/Harrisburg facilities. The Ecoservices facility is located next to JR Harris Elementary, which has a student population that is 98.2 percent Hispanic, 89 percent economically disadvantaged, and 62.6 percent children who are learning English for the first time.[132] Though Ecoservices is primarily a sulfuric acid plant, it also processes products that aid in plastic and polymer production, such as zeocros (plastic stabilizers), polyolefin catalysts (silica used in polyethylene, polypropylene, and other polymer production), and thermodrop (thermoplastic pellets) as well as a variety of other products.[133]

In August 2018, LyondellBasell invested US$ 2.4 billion to construct the world's largest propylene oxide and tertiary alcohol plant in the same area. Propylene oxide, a potential carcinogen, is used in the creation of polyurethane plastic and other polyethers.[134] This expansion accompanies a recently completed ethylene expansion[135] facility along the Houston Ship Channel and Texas Gulf Coast as the company increases its ethylene capacity in the US by two billion pounds. Eleven miles away, LyondellBassell is constructing a plant with an output of 900,000 metric tons of polyethylene per year.[136]

Less than a mile south of Manchester/Harrisburg is Flint Hills Resources, which manufactures olefins and polymers, including polypropylene, ethylene, expandable polystyrene, and chemical grade propylene.[137] In December 2018, INEOS, a large plastic manufacturer, completed their acquisition of Flint Hills Resources.

The presence of so many plastic-related industrial facilities demonstrates how residents of Manchester/Harrisburg, like other fenceline communities, face significant risks, including risks from incidents or accidents. According to Earthjustice, the "EPA has not released any information about the total deaths, injuries, shelter-in-place, or evacuation orders resulting from these or other incidents over the past year" in Texas, though Earthjustice's tracker reveals that, nationwide, at least 73 incidents occurred between March 14, 2017 (the original date of the Arkema chemical disaster) and November 21, 2018.[138]

Manchester/Harrisburg is only one example of the disproportionate burden of contamination, risk, and mortality that fenceline communities face. They are not alone; similar communities exist along the Gulf Coast of the US and around the world.

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Manchester/Harrisburg is only one example of the disproportionate burden of contamination, risk, and mortality that fenceline communities face. They are not alone; similar communities exist along the Gulf Coast of the US and around the world.

reporting may not provide an accurate picture. The "acceptable exposure limits" may be too high, and these levels do not take into account the cumulative impacts of chemicals on humans.[139]

As noted, workers are exposed to numerous toxic chemicals including carcinogens and endocrine disrupting chemicals (EDCs). In particular, there can be significant impacts on women's health as these chemicals are known causes of breast cancer, and EDCs can impact the reproductive system.[140] Workers are exposed to these chemicals largely through the process of heating materials to make them more pliable for creating plastic products. Chemicals released include hazardous monomers such as vinyl chloride, styrene, acrylonitrile, bisphenol A (BPA), and formaldehyde. These chemicals have been labeled as carcinogens or EDCs, and exposure can lead to mammary gland tumors, liver damage, lung cancer, ovarian cysts, endometriosis, and breast cancer, among others. Further, additives, including plasticizers, flame retardants, and metals, used in plastic production have similar carcinogenic and endocrine-disrupting health impacts. These are further examined in other sections of this report. Diseases resulting from these chemicals are often diagnosed years after exposure and are not reflected in industry reports to the government.


Jabón Líquido
Giselle
Siempre dura más
Ayuda a eliminar
Gérmenes y Bacterias
CONCENTRADO
Nestlé Pure Life
1500 ml
Pasta Mamá
400g
JUMBO
Stevia
Costa Palmeritas
Huerto Canchá
TAMAÑO
AGROSANO
RICA!
Espinaca
ENTREGA NATURALMENTE VITAMINAS Y MINERALES
Experimenta el placer de la comida sana.
PRODUCTO 100% FRESCO
MANTENER REFRIGERADO
500 GRS
SAL FINA
Watt's
100 bolsitas

CHAPTER FOUR

Consumer Use

Whether plastic is only used once—like a polystyrene coffee cup[141]—or is used for years—like the casing around a television[142]—plastic use in consumer goods can have negative impacts on human health.

Mass-produced plastic entered the global market after World War II. A recent analysis of all plastic ever made estimates that 8300 million metric tons of virgin plastic have been produced through the end of 2015.[143] That analysis breaks plastic into three categories: polymer resins, synthetic fibers, and plastic additives. The most prevalent plastic resins are manufactured from polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyethylene terephthalate (PET), and polyurethane (PUR) resins. The most common plastic fibers come in the form of polyester, polyamide, and acrylic (PP&A).[144]

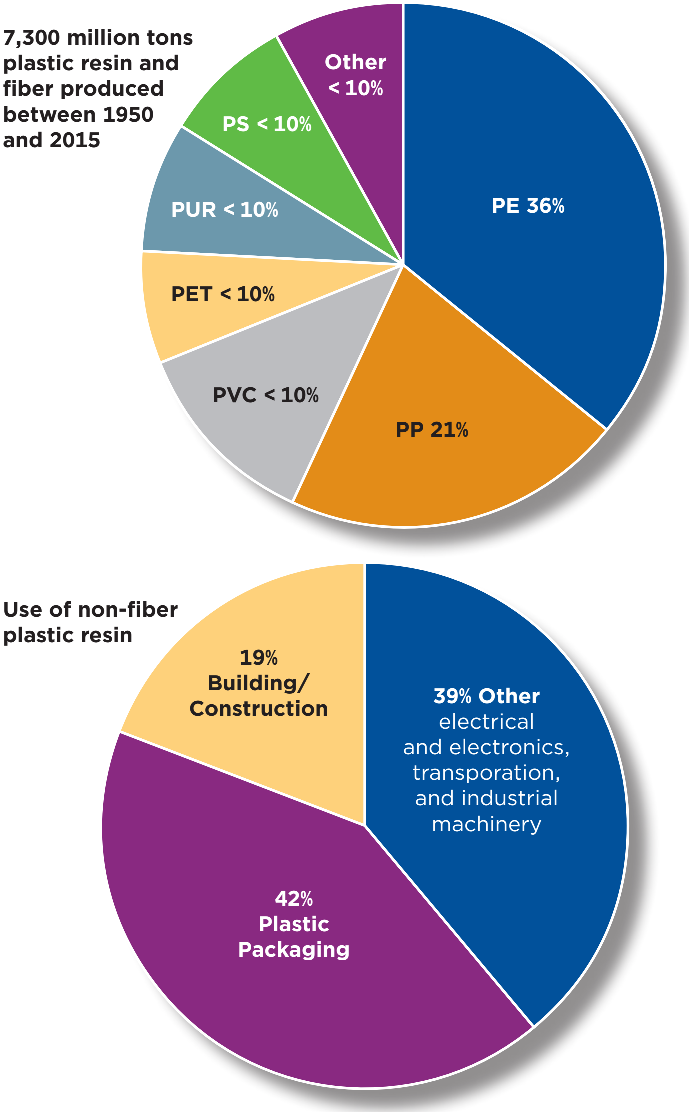
As a result of the global shift from reusable to single-use packaging (including containers), the most significant market for plastic today is packaging and comprises 42 percent of all plastic ever produced.[145] Packaging is also the product with the shortest lifespan. Most plastic packaging leaves the economy the same year it is produced[146] because most it is designed for a single use.[147]

PLASTIC PARTICLES, PLASTICIZERS, AND OTHER CHEMICAL ADDITIVES

When considering the human health impacts of plastic, one must distinguish between the impacts of plastic particles (micro- and nanoplastic particles) entering the human body and the impacts of the chemical additives, plasticizers, and contaminants associated with plastic particles. To date, most of the research on the impacts of micro- and nanoplastic particles has focused on impacts to marine life, while their impacts on

FIGURE 5

Common Plastics and their Uses



Source: Roland Geyer, Jenna R. Jambeck and Kara Lavender, Law, Production, use, and fate of all plastics ever made.

Opposite: © Cristobal Olivares/Greenpeace

FIGURE 6

Main Plastic Resin Types and Applications in Food Packaging

1 PET		Water and soft drink bottles, salad domes, biscuit trays, salad dressing, peanut butter containers
2 HDPE		Milk bottles, freezer bags, dip tubs, crinkly shopping bags, ice cream containers, juice bottles, shampoo, chemical and detergent bottles
3 PVC		Cosmetic containers, commercial cling wrap
4 LDPE		Squeeze bottles, cling wrap, shrink wrap, rubbish bags
5 PP		Microwave dishes, ice cream tubs, potato chip bags, dip tubs
6 PS		CD cases, water station cups, plastic cutlery, imitation "crystal glassware," video cases
6 EPS		Foamed polystyrene hot drink cups, hamburger take-out clamshells, foamed meat trays, protective packaging for fragile items
7 OTHER		Water cooler bottles, flexible films, baby bottles, multi-material packaging

human health have received much less attention. There is emerging data demonstrating the presence of micro- and nanoparticles of plastic (including toxic chemical additives) in the food we eat, air we breathe, and water we drink, raising concerns among scientists about their potential impacts on human health. Though our understanding of the impacts of micro- and nanoparticles of plastic on human health is limited, the emerging body of research is raising fundamental questions about the historic belief that plastic is inert and safe. Increasingly, the research demonstrates that the same characteristics that make plastic a material with diverse and desirable applications for bettering human life, i.e., lightweight and incredibly durable molecular bonds, also make them widely dispersed, ubiquitous, and a potential threat to human life and the ecosystems upon which humans rely.

More research has been conducted on plasticizers and other chemical additives in plastic and their health risks. However, there is still a significant dearth of information on the health impacts of toxic additives, and food packaging chemicals in particular, since only a handful of chemicals in use have gone through a health risk evaluation. A well-developed understanding of the impacts of plastic on human health is further hampered by limited information that quantifies the cumulative risks of chronic exposure.

Plasticizers Used in Plastic and Other Consumer Products

The term *plastic* is used to refer to various types of polymers, which are synthesized from monomers that are polymerized to form macromolecular chains. Plastic can leach unreacted chemical monomers, some of which are hazardous. The plastic that is most hazardous based on carcinogenic monomer release includes: polyurethanes (flexible foam in furniture, bedding, and carpet backing), polyvinyl chloride (pipes, packaging, wire, and cable coatings, the monomer being vinyl chloride), epoxy resins (coatings, adhesives, and composites, such as carbon fiber and fiberglass), and polystyrene (food packaging, CD cases, hard plastic in consumer products, the monomer being styrene).[148] In addition, the hormone-disrupting plasticizer BPA leaches as an unreacted monomer from polycarbonate plastic and epoxy can liners.

A wide array of chemicals and additives may be used in the manufacturing process to create a polymer, including initiators, catalysts, and solvents.[149] Additional chemical additives are used to provide various characteristics including stabilizers, plasticizers, flame retardants, pigments, and fillers. They can also be used to inhibit photodegradation, to increase strength, rigidity, and flexibility, or to prevent microbial growth.[150]

Most of these additives are not bound to the polymer matrix, and due to their low molecular weight, they easily leach out of the polymer[151] into the surrounding environment, including air, water, food, or body tissues.[152] As plastic particles continue to degrade, new surface area is exposed, allowing continued leaching of additives from the core to the surface of the particle.[153]

A global analysis of all mass-produced nonfiber plastic showed that on average they contain 93 percent polymer resin and seven percent additives by mass.[154] Some polymers contain higher concentrations of toxic additives than others. Plasticizers, used to make plastic flexible, often comprise a significant portion of the final product, as much as 80 percent in some products.[155] PVC is the monomer filled with the greatest diversity of additives, including heat stabilizers to keep the polymer stable, and plasticizers, such as phthalates, to make the polymer flexible.[156] PP is highly sensitive to oxidation and therefore contains antioxidants and ultraviolet (UV) stabilizers.

Microplastics that accumulate in the body are a source of chemical contamination to tissues and fluids. A variety of chemical additives in plastic, plastic monomers, and plastic processing agents have known human health effects. For example, several plasticizers, such as bis(2-ethylhexyl) phthalate (DEHP) and BPA, can cause reproductive toxicity. Others, such as vinyl chloride and butadiene, are carcinogens. Benzene and phenol are mutagenic (i.e., they change the genetic material, usually DNA, of an organism, increasing the frequency of mutations).

Some of the most harmful additives include brominated flame retardants, phthalates, and lead heat stabilizers.[157] Yet other harmful chemicals known to leach from plastic polymers include antioxidants, UV stabilizers, and nonylphenol.[158]

BOX 4

Plastic Additives

Additives are added to plastic for flexibility (softeners and plasticizers), durability against heat or sunlight (stabilizers and anti-oxidants), color, flame retardancy, and as fillers. They are an underestimated environmental problem. Among the most hazardous additive types are brominated flame retardants, phthalates, and lead compounds. Some brominated flame retardants like polybrominated diphenyl ethers (PBDEs) structurally resemble polychlorinated biphenyls (PCBs), which are environmental contaminants known to accumulate in the fat tissues of aquatic animals, causing neurotoxic effects and altering the function of thyroid hormones.[159] Other chemicals used as softeners or brominated flame retardants cause birth defects, cancer, and hormonal problems, particularly for women. Once the additives have been released, including through incineration of plastic, they persist in the environment, building up in the food chain.[160]

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TABLE 2

Ranking of Some Plastic Polymer Types Based on Hazard Classification of Constituent Monomers

Polymer	Monomer(s)/additives	Relative hazard scorea	Recycling code	Constituents measured in NHANES?
Polymers with the highest relative hazard scores				
Polyurethane PUR as a flexible foam	Propylene oxide	13,844	6	
	Ethylene oxide			
	Toluene-diisocyanate			
Polyacrylamide PAN with co-monomers	Acrylonitrile	12,379	7	Acrylamide
	Acrylamide			
	Vinyl acetate			
Polyvinylchloride PVC, plasticised	With plasticizer	10,551	3	Benzyl butyl phthalate (BBP)
	Benzyl butyl phthalate (BBP) at 50 wt%			
Polyvinylchloride, PVC, unplasticised		10,001	3	
Polyurethane, PUR as a rigid foam	Propylene oxide	7,384	6	
	4,4’-methylenediphenyl diisocyanate (MDI)			
	Cyclopentane			
Epoxy resins DGEBPA	**Bisphenol A**	7,139	7	Bisphenol A
	Epichlorohydrin			
	4,4’-methylenedianaline			
Modacrylic	Acrylonitrile	6,957		
	Vinylidene chloride			
Acrylonitrile-butadiene-styrene ABS	Styrene	6,552	7	Styrene
	Acrylonitrile			
	1,3 butadiene			
Styrene-acrylonitrile SAN	**Styrene**	2,788	7	Styrene
	Acrylonitrile			
High impact polystyrene HIPS	**Styrene**	1,628		Styrene
Polymers with the lowest relative hazard scores				
Low density polyethylene LDPE	Ethylene	11	4	
High density polyethylene HDPE	Ethylene	11	2	
Polyethylene terephthalate PET	Terephthalic acid	4	1	
Polyvinyl acetate PVA	Vinyl acetate	1		
Polypropylene PP	Propylene	1	5	

Of the thousands of additives used in the synthesis of plastic products, certain plastic types contain more additives than others. The table ranks polymer types based on hazard classifications.

NOTE: Relative hazard score derived from different constituent monomers. Higher ranking = greater hazard.

SOURCE: Adapted from Lithner et al. (2011).

Potential Threats Associated with Accumulated Pollutants on Plastic Particles

Plastic is hydrophobic, meaning it tends to absorb hydrophobic persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs) and PAHs, while circulating in marine waters.[161] The accumulated pollutants can concentrate to as much as 100 times background levels in seawater.[162] Some of these chemicals have been found to desorb into tissues of marine species when ingested.[163] While some recent studies conclude that microplastic ingestion is unlikely to be a significant source of exposure for marine organisms to organic pollutants,[164] a recent study in conditions simulating the digestive environment of warm-blooded organisms (38°C, pH4) showed up to 30 times faster desorption rates than in seawater.[165] Therefore it is likely that in mammals, including humans, the transfer of pollutants from inhaled or ingested plastic debris is more important than originally thought. The overall contribution of plastic debris contaminated with accumulated pollutants to the body burden (the total amount of toxic chemicals in the body) remains unanswered.[166] In light of the projected increase of plastic accumulation in terrestrial and marine environments, a precautionary approach should be adopted while investigating this answer.[167]

Food Packaging Chemicals

Chemicals migrate from packaging into food. It is common, and it is the reason why the US Federal Food Drug and Cosmetics Act defines food packaging chemicals as indirect food additives.[168] Migration of chemicals from food packaging into food and beverages is considered the main source of human exposure to contaminants associated with plastic.[169] Some plastic polymers used for food contact degrade when they come into contact with acidic or alkaline foods, UV light, and heat. Toxic monomers like styrene are released in these conditions.[170] Plastic additives are a diverse group of substances fulfilling various functions. Since they are often not tightly bound to the material, they are another common source of chemicals leaching into food. Non-intentionally added substances (NIAS) such as impurities, side products, and contaminants additionally contribute to the migration or leaching of chemicals. In contrast, a few food packaging chemicals are designed to intentionally migrate out of the package in order to perform various functions, such as preventing foods from spoiling.[171]

BOX 5

The World's Worst Chemicals: POPs

Persistent organic pollutants (POPs) are a class of highly hazardous chemical pollutants that are recognized as a serious, global threat to human health and ecosystems. Because of their risks, POPs are subject to restrictions and bans under the Stockholm Convention on Persistent Organic Pollutants. Short chain chlorinated paraffins (SCCPs), polybrominated diphenyl ethers (PBDEs), nonylphenols, octylphenols, and per- and polyfluoroalkyls substances (PFAS), are plastic additives (softeners and flame retardants) recognized by the international community as POPs.

Specifically, POPs are substances that:

- remain intact for exceptionally long periods of time (many years);
- become widely distributed throughout the environment as a result of natural processes involving soil, water, and, most notably, air;
- accumulate in living organisms, including humans, and are found at higher concentrations at higher levels in the food chain; and
- are linked to cancer, reproductive harm, and other diseases in humans and wildlife.

POPs are widely present in the environment in all regions of the world, and they can move through the food chain and from mother to child. Mothers pass POPs from their own bodies to their offspring. In humans and other mammals, POPs enter and contaminate the fetus while it is still the womb. Infants are further exposed to POPs through breast milk. POPs are most harmful to a developing fetus, causing health impairments such as neurological disorders and deficits, which continue throughout a child's entire life. POPs are also particularly harmful to infants, children, women, the ill-nourished, and those with reduced immune system function, such as people who are sick or elderly.

There is robust medical evidence linking the following human illnesses and disabilities to one or more POP:[172]

- Cancers and tumors, including soft tissue sarcoma, non-Hodgkin's lymphoma, breast cancer, pancreatic cancer, and adult-onset leukemia;
- Neurological disorders, including attention deficit disorder, behavior problems such as aggression and delinquency, learning disabilities, and impaired memory; and
- Reproductive disorders, including abnormal sperm, miscarriages, pre-term delivery, low birth weight, altered sex ratios in offspring, shortened period of lactation in nursing mothers, and menstrual disorders.

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Plasticizers migrate readily into food and beverages. A study of school meals before and after the food was packaged in DEHP and DiNP found that mean phthalate concentrations increased by more than 100 percent as a result of the packaging.[176] The monomer BPA migrates out of polycarbonate bottles into water at levels that increase with heat. Migration of BPA from epoxy-coated cans are of even higher concern.

Chemicals migrating from food packaging and other food-contact materials can be harmful at very low doses. The most well-studied substances include:[173]

- BPA, found in polycarbonate plastics (#7), epoxy resin liners of metal cans, and non-food-related products such as paper receipts;
- Phthalates, a family of chemicals that includes diisononyl phthalate (DiNP) and DEHP, a high-production-volume phthalate plasticizer;
- Di(2-ethylhexyl) adipate (DEHA), a non-phthalate plasticizer and potential carcinogen used in meat wraps;
- 4-nonylphenol, a breakdown product of the antioxidant and thermal stabilizer tris(nonylphenol) phosphite (TNPP) found in some rubber products and polyvinylchloride food wraps;
- Styrene, the monomer used to manufacture polystyrene and polystyrene foam;
- Per- and polyfluoroalkyl substances (PFAS) such as perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), and perfluoroalkyl acids (PFAAs), pervasive chemicals used, among many things, to provide a grease-proof barrier to paper wraps and paper and fiber containers (found in one third of fast food packaging tested in a recent study);[174] and
- Perchlorate, used in various formulations for food packaging, gasket closures, and as an antistatic agent in dry food packaging.

In addition to a lack of testing on most food packaging chemicals and plastic additives, there is little research to shed light on the effects of cumulative exposures from multiple sources. However, a large body of research has demonstrated that chemicals migrate into food from packaging. For example, PVC cling wrap and PVC film leach DEHA into cheese.[175]

Plasticizers migrate readily into food and beverages. A study of school meals before and after the food was packaged in DEHP and DiNP found that mean phthalate concentrations increased by more than 100 percent as a result of the packaging.[176] The monomer BPA migrates out of polycarbonate bottles into water at levels that increase with heat. Migration of BPA from epoxy-coated cans are of even higher concern.[177]

While there are many more scientific investigations demonstrating that chemicals migrate from food packaging, the science on food packaging chemicals barely scratches the surface of the problem. Only a handful of the thousands of chemicals used as additives in food packaging have undergone rigorous testing.[178] At least 175 chemicals that are known to be hazardous (i.e., endocrine disrupters, reproductive toxics, mutagens, or carcinogens) are used in food contact materials in the US and the European Union (EU).[179] Of the 4,000 chemicals approved in the US to be intentionally added in food packaging, only about 1,000 of them have been evaluated for health risks, and even then in a very limited way.[180] In the EU, manufacturers of food packaging and other food contact materials must guarantee the safety of their products, whether any migrating substances have been intentionally added or result from impurities, side reactions, and contaminations (Regulation 1935/2004). However, these non-intentionally added substances are very difficult to assess and are the subject of much debate.[181]

An initiative led by the Food Packaging Forum compiled a database of chemicals associated with plastic packaging for both food and non-food packaging, ranking their human health and environmental hazards. The database currently contains 906 chemicals likely associated with plastic packaging and 3,377 possibly associated chemicals, at least 148 of which were identified as highly hazardous based on several harmonized hazard data sources. These chemicals are used or present in plastic as monomers, intermediates, solvents, surfactants, plasticizers, stabilizers, biocides, flame retardants, accelerators, and colorants, among other functions.[182] A few groups or classes of chemicals were highlighted as presenting a very high level of concern. These include: hazardous metals (banned in the EU and US for packaging), bisphenols, phthalates, and PFAS chemicals.

Two PFAS chemicals are identified in the study: PFOS and PFOA. These chemicals are extremely persistent in the environment and can accumulate in the food chain. They have historically been used in food packaging to create a grease-proof barrier in products such as paper food wraps, fast food packaging, and microwave popcorn bags. As a result of rising global concern about this class of chemicals,[183] the US Food and Drug Administration recently took action to review these chemicals, resulting in the chemical industry's decision to stop using them in food packaging. Instead, these companies have substituted other PFAS chemicals for the same uses,[184] despite concerns expressed by environmental toxicologists that the substitutes also pose significant threats human health.[185] PFOA and PFOS are regulated under the Stockholm Convention on Persistent Organic Pollutants while a third PFAS , perfluorohexane sulfonic acid (PFHxS), is under scrutiny by the Convention's scientific body (the Persistent Organic Pollutants Review Committee, or POPRC). The Organisation for Economic Co-operation and Development (OECD) has identified 4,730 PFAS substances. At its last meeting, the POPRC recommended not using any of the fluorinated alternatives to PFOA and PFOS "due to their persistency and mobility as well as potential negative environmental, health and socioeconomic impacts."[186]

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BOX 6

Sizing It Up

Plastic comes in many different sizes. From nanoparticles to macroplastics, the health impacts and exposure pathways of plastic pollution vary. To date, no international definition of microplastics exists. Macroplastics are generally defined as plastic items larger than 5mm. Microplastics are generally recognized as synthetic organic polymer particles less than 5mm at their longest point. They exist in different shapes and can be spheres, fragments, granules, pellets, flakes, beads, filaments, or fibers. Microplastics can be detected in environmental sampling down to 1 micron in size, but few studies actually identify particles smaller than 50 microns. Nanoplastics are generally defined as 1-100nm.[187]

Macroplastics generally arrive in the marine environment as original consumer products. A recent compilation of the top twenty most common products found in six different international sets of shoreline data characterizes the types of plastic products reaching the environment. Seventy-five percent of the listed items are some type of food and beverage packaging (wrappers, bottles and bottle caps, straws, stirrers, lids, utensils, containers, cups, and plates), while the rest are smoking-related products (cigarette butts, packaging, and lighters) and an assortment of other products including bags, balloons, diapers, condoms, tampons, and six-pack holders.[188]

TABLE 3

Merged National Datasets: The Top 20 Products in Shoreline Data

Plastic Product	ICC	NOAA	MOT	Heal the Bay	COA	Project Aware	Total	Percent
Food Wrappers (candy, chips, etc.)	318,880.0	272.0	16,315.0	307.0	14,827.0	217.0	350,818.0	18.6
Bottle Caps (Plastic)	273,089.0	779.0	11,735.0	27,352.0	2,328.0	205.1	315,488.1	16.7
Beverage Bottles (Plastic)	206,993.0	122.0	7,809.0	6,297.0	5,508.0	289.0	227,018.0	12.0
Bags (Plastic)	157,702.0	39.0	6,970.0	5,249.0	7,871.0	313.0	178,144.0	9.4
Straws, Stirrers	125,635.0	172.0	4,645.0	4,026.0	8,102.0	165.0	142,745.0	7.5
Lids (Plastic)	75,921.0	186.9	409.0	5,829.5	15,347.0	57.9	97,751.2	5.1
Utensils	42,599.0	33.0	1,848.0	47,133.0	1,864.0	352.0	93,829.0	4.9
Cigarette Butts*	51,550.5	25.3	2,337.9	6,775.9	643.0	9.1	61,341.7	3.2
Take Out/Away Containers (Foam)	41,805.0	102.9	537.7	17,696.0	548.0	8.3	60,697.8	3.2
Take Out/Away Containers (Plastic)	49,973.0	123.0	37.0	5,624.0	1,021.7	9.9	56,788.6	3.0
Cups, Plates (Plastic)	48,559.0	14.6	732.6	1,862.2	1,766.0	9.6	52,943.9	2.8
Cigar Tips	41,211.0	47.0	328.0	6,243.0	2,351.0	16.0	50,196.0	2.6
Cups, Plates (Foam)	42,047.0	12.4	4,495.7	690.0	2,021.0	8.3	49,274.5	2.6
Tobacco Packaging/Wrap	33,434.0	82.3	604.5	352.0	694.0	19.0	35,185.8	1.8
Balloons	23,492.0	19.0	1,442.0	5,263.0	480.3	13.0	30,709.3	1.6
Other Plastic Bottles	17,548.0	62.0	1,578.0	4,769.6	1,429.0	9.0	25,395.6	1.3
Cigarette Lighters	10,750.0	24.0	676.5	10,750.0	405.0	3.0	22,608.5	1.2
Personal Care Products (Condoms & Tampon Applicators)	11,555.0	37.4	827.5	2,213.2	1,875.1	14.0	16,522.2	0.8
6-Pack Holders	8,224.0	3.0	180.0	641.0	130.0	10.0	9,188.0	0.4
Diapers	3,938.0	12.5	276.8	2,150.6	82.0	7.0	6,466.9	0.3
Total	**1,584,905.5**	**2,169.3**	**63,785.2**	**161,223.9**	**69,293.0**	**1,735.1**	**1,883,112.0**	**100**

* Counts of cigarette butts were divided by 20 to represent packs rather than individual cigarettes.

Microplastics that enter the environment are either primary or secondary microplastics. Primary microplastics are generally described as microplastics produced as original products in microsizes, whereas secondary microplastics are the degradants of larger consumer items.[189] Primary microplastics include pre-production plastics in the form of powders and pellets (<5mm in size) that are used in the manufacture of plastic consumer products. These microplastics are released from processing and transport facilities, mainly due to poor housekeeping practices during their transfer from rail, truck, and storage sites into processing facilities.[190] Other primary microplastics include microbeads used in personal care products, such as hand cleaners, facial scrubs, and toothpaste. The United States, Canada, Australia, the United Kingdom, New Zealand, Taiwan, and Italy have all banned microplastics in personal care products.[191] Personal care products tested have contained between 0.05 and 12 percent microplastic particles.[192] Primary microplastics are also used in a variety of industrial applications, including in fluids used in oil and gas drilling and other types of extraction, as abrasives in air blasting to remove paint from boat hulls, and in cleaning engines and metal surfaces.[193]

Secondary microplastics are degradants of the types of macroplastic products found in shoreline and litter studies, such as the top 20 items listed in B.A.N. List 2.0. Based on a recent International Union for Conservation of Nature study, synthetic textile fibers and particles from car tire abrasion are the two main sources of primary microplastic in the ocean.[194]

Nanoplastics are increasingly used in products such as paints, adhesives, pharmaceuticals, and electronics, and in 3D printing.[195] These then become primary products entering the environment. Similarly to microplastics, secondary nanoplastics also result from further environmental degradation of microplastics.

Human Body Burden

While the examples discussed previously of chemical migration from packaging into food and beverages confirm that plastic and food packaging are sources of human exposure to numerous toxic chemicals, human biomonitoring is considered the best method to precisely determine actual levels of exposure. It measures the chemicals, their metabolites, or specific reaction products in urine or blood.[196]

Many of the chemicals used in food packaging are also used in a wide array of other consumer products. Most people are exposed without their knowledge or consent because chemicals in plastic and packaging do not appear on ingredient lists.

The Centers for Disease Control National Health and Nutrition Examination Survey conducted one of the most comprehensive surveys of a population's chemical exposure in 2009–2010. It found BPA in 92 percent of the urine samples from children (at least six years old) and adults in the United States.[197] Ten of the 15 phthalates were detected in virtually all of the samples,[198] as were PFOA and perchlorate,[199] and 4-nonylphenol was found in 51 percent of people tested.[200] Other studies have demonstrated that BPA in human blood and other tissues is common.[201]

Many of the chemicals used in food packaging are also used in a wide array of other consumer products. Although biomonitoring data does not reveal how much of the presence of a specific chemical in the human body is the result of exposure to plastic or packaging, it does confirm that human populations have significant and increasing body burdens as a result of exposure to many toxic chemicals. Most people are exposed without their knowledge or consent because chemicals in plastic and packaging do not appear on ingredient lists.

TABLE 4

Common Toxic Chemical Additives to Plastic

Toxic Chemical Additive	Products in Which They Can Be Found	Health Impact
Acrylonitrile	Drinking cups, acrylic carpet and other textiles, plastic furniture, 3-D printing, automotive parts, and appliances.	Carcinogen
Bisphenol A	Polycarbonate plastics, plastic tableware, dental fillings, and lenses for glasses. BPA is also used to make epoxy resins that are used as coatings in lids of glass containers and in the linings of aluminum cans. BPA is also used to coat some thermal papers.	BPA is an endocrine disrupting chemical. Breast cancer, prostate cancer, endometriosis, heart disease, obesity, diabetes, altered immune system, and effects on reproduction have all been tied to BPA's ability to disrupt the normal functioning of endocrine systems. In young children, BPA exposures before and after birth are linked to changes in brain development and behavior.
Cadmium	Used as a colorant and stabilizer in plastic.	Lung cancer, endometrium, and bladder and breast cancer have been associated with cadmium. Cadmium can also damage the body's cardiovascular, renal, gastrointestinal, neurological, reproductive, and respiratory systems.
Flame retardants	Plastic-based home furnishings (foam, upholstery, curtains and blinds) and electronics (computers, laptops, phones, televisions, and household appliances).	Some flame retardants are endocrine disrupting chemicals. Studies have also linked flame retardants to thyroid disruption, impacts on fertility and the functioning of the immune system, and harm to the development of babies' brain and nervous systems both before and after birth. Several flame retardants are banned from production or use under the Stockholm Convention because they pose an unmanageable threat to human health and the environment.
Lead	Lead is used as plastic stabilizers and has been found in plastic jewelry,[1] vinyl raingear,[2] lunchboxes,[3] and vinyl window blinds.	In children, lead can cause reduced growth both before and after birth, decreased IQ and increased attention deficit and problem behaviors. In adults, lead exposures are linked to decreased kidney function and increased risk of hypertension, nerve disorders, and memory problems.[4] There is no safe level of exposure to lead.
Perfluorinated Substances (PFAS)	Grease and stain repellant in plastic-based fabrics used for raingear, upholstery, and carpeting, and as a plastic coating on cookware.	PFOA and PFOS are linked to human diseases including pregnancy complications, low birth weight, testicular and kidney cancer, and thyroid problems. The Stockholm Convention POPRC recommended not using any of the fluorinated alternatives to PFOA and PFOS, *"due to their persistency and mobility as well as potential negative environmental, health, and socioeconomic impacts."*
Phthalates	Plasticizer used to make plastic soft and pliable.	Phthalates are endocrine disruptors. They harm the reproductive and nervous systems, especially in children before and after birth. Deformities of the penis and learning and behavior problems are all associated with phthalates exposure.[5] Studies have also shown that the higher the levels of phthalates are in a home, the more likely children in that home are to have asthma or other respiratory conditions.[6]
Styrene (also known as Vinyl Benzene)	Polystyrene plastics and expanded polystyrene.	Carcinogen
Vinyl Chloride	PVC: plastic furniture, carpet backing, packaging or wall covering.	Liver cancer
SCCP	Plastic consumer product, children's products.	SCCPs adversely affect the kidney, liver, and thyroid, disrupt endocrine function, and are believed to be human carcinogens.[7]

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2 Center for Environmental Health, *Lead in Children's Raingear*, *https://www.ceh.org/campaigns/legal-action/previous-work/childrens-products/lead-in-childrens-raingear*.

3 Center for Environmental Health, *Lead in Lunchboxes*, *https://www.ceh.org/campaigns/legal-action/previous-work/childrens-products/lead-in-lunchboxes*.

4 National Institute of Environmental Health Sciences, Lead (October 12, 2018), *https://www.niehs.nih.gov/health/topics/agents/lead/index.cfm*.

5 Coalition for Safer Food Processing and Packaging, *The Everywhere Chemicals in Your Food*, *http://www.kleanupkraft.org/#info*.

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ROUTES OF HUMAN EXPOSURE TO MICROPLASTIC PARTICLES

The evidence that humans are increasingly exposed to microplastics is mounting. Recent reports suggest that microplastics are entering the human body through the water we drink, food we eat, and air we breathe. In 2018, a study from the Medical University of Vienna and the Environment Agency of Austria analyzed stool samples from participants across Finland, Italy, Japan, the Netherlands, Poland, Russia, the United Kingdom, and Austria. Every sample tested positive for the presence of microplastics and up to nine different types of plastic resins were detected. On average, the researchers found 20 microplastic particles per 10g of stool. The study demonstrated that plastic reaches the human gut and that all food chains are likely contaminated.[202] Increasing evidence that human food and water sources are contaminated with microplastic will continue to shed light on the routes of exposure. Specific routes of exposure related to the environmental contamination of food chains and their impacts on human health are examined in more detail in Chapter 6.

Drinking Water as a Source of Human Exposure to Microplastics

A recent study by *Orb Media* made headlines when it concluded that microplastics contaminate tap water around the world. Researchers at Fredonia State University of New York analyzed 159 tap water samples from 14 countries, half from developed and half from developing nations. Of these samples, 81 percent showed particles ranging from 0 to 61 particles per liter. The results included an overall average of 5.45 particles per liter, with the US having the highest average (9.24 particles per liter) while EU nations had the four lowest averages. Water from more developed nations had a higher average density (6.85 particles per liter) while the average density from developing nations was lower (4.26 particles per liter). Ninety-eight percent of particles were fibers.[203]

When *Orb Media* ran a subsequent study of bottled water with the same researchers, it found twice as much plastic in bottled water compared to the previous study on tap water.[204] The study tested 259 bottles from 19 locations across 11 leading brands and found microplastic particles in 93 percent of the samples, with an average of 325 plastic particles per liter. The tests revealed an average of 10.4 plastic particles per liter, nearly double the average of the tap water study.


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The evidence that humans are increasingly exposed to microplastics is mounting. Recent reports suggest that microplastics are entering the human body through the water we drink, food we eat, and air we breathe.

While the tap water study showed 83 percent contamination with 98 percent of the particles being microfibers, the bottled water revealed 93 percent contamination with only 13 percent of the particles being categorized as microfibers. The plastic identified in the bottled water samples included polypropylene, nylon, and PET. The majority (65 percent) of the microplastics were identified as fragments, indicating a different source of contamination from the tap water, which the authors suggest may be related to the packaging. Of the particles larger than 100 μm, polypropylene was the most common (54 percent) polymeric material, consistent with the most common plastic used for bottle caps. Nestle Pure Life water, purchased on *Amazon.com*, had the highest average microplastic densities at an average of 2,247 particles/L.[205]

TABLE 5

Average Microplastic Densities in Consumer Products

			Average microplastic densities (MPP/L)				
			NR + FTIR confirmed particles	NR tagged particles	Total		
Brand	**Lot**	**Purchase Location**	**(>100 μm)**	**(6.5-100 μm)**	**Average**	**Minimum**	**Maximum**
Aqua	IB 101119	Jakarta, Indonesia	6.68	30.4	37.1	3	133
Aqua	BB 311019 08:11 PSRL6	Bali, Indonesia	10.5	695	705	1	4,713
Aqua	BB 311019 09:50 STB1	Medan, Indonesia	6.93	397	404	0	3,722
Aquafina	Oct0719 0121PF100375	Amazon.com	14.8	237	252	42	1,295
Aquafina	BN7141A04117	Chennai, India	11.6	162	174	2	404
Bisleri	HE.B.No.229 (BM/AS)	Chennai, India	18	808	826	39	5,230
Bisleri	MU.B.No.298 (MS/AD)	Mumbai, India	8.85	204	213	2	1,810
Bisleri	SO.B.No.087 (AS/LB)	New Delhi, India	0.57	3.15	3.72	0	32
Dasani	Oct 0118NHBRB	Amazon.com	14.6	150	165	85	303
Dasani	P18NOV17CG3	Nairobi, Kenya	6.28	68.3	74.6	2	335
E-Pura	17.11.18	Mexico City, Mexico	22.3	664	686	11	2,267
E-Pura	14.10.18	Tijuana, Mexico	7.76	12.2	20	3	92
E-Pura	09.08.18	Reynosa, Mexico	0.21	37.1	37.3	0	149
Evian	PRD 03 21 2017 14:02	Amazon.com	26	171	197	126	256
Evian	PRD 05 24 17 11:29	Fredonia, NY, USA	1.51	56.7	58.2	0	256
Gerolsteiner	07.142018 2 07.07.2017	Fredonia, NY, USA	14.8	1,396	1,410	11	5,106
Gerolsteiner	NV No. AC-51-07269	Amazon.com	8.96	195	204	9	516
Minalba	FAB: 211017 09:06SP	Sao Paulo, Brazil	2.56	37.5	40.1	4	199
Minalba	FAB: 160817 15:05SP	Aparecida de Goiania, Brazil	5.3	7.19	12.5	0	47
Minalba	FAB: 091217 16:53SP	Rio de Janeiro, Brazil	5.01	145	150	0	863
Nestle Pure Life	100517 278WF246	Amazon.com	29.8	2,247	2,277	51	10,390
Nestle Pure Life	P: 4/11/17 01:34 AZ	Beirut, Lebanon	11	38.2	49.3	6	153
Nestle Pure Life	730805210A 23:28	Bangkok, Thailand	18	450	468	11	3,526
San Pellegrino	BBE 11.2018 10	Amazon.com	1.68	28.6	30.3	0	74
Wahaha	20171102 1214JN	Jinan, China	9.1	147	156	30	731
Wahaha	20171021 3214GH	Beijing, China	5.53	61.2	66.7	13	178
Wahaha	20171103 2106WF	Qingdao, China	4.4	62.7	67.1	1	165

NOTE: Maximum and minimum densities with the lot are also provided. NR, Nile Red.

The notion that plastic packaging itself may be contributing to bottled water contamination was supported by a 2018 German study of drinking water distributed in plastic bottles, glass bottles, and beverage cartons. The study found small (-50–500 μm) and very small (1-50 μm) microplastics in every type of water.[206] They tested the microplastic content of water from 22 different returnable and single-use plastic bottles, three beverage cartons, and nine glass bottles bought at German grocery stores. This study used micro-Raman spectroscopy, which is capable of detecting smaller particles than in the techniques used in the previous studies. Almost 80 percent of all microplastic particles ranged between 5 and 20 μm (very small) and were therefore not detectable by the analytical techniques used in previous studies. The highest levels of microplastics were found in the returnable plastic bottles (118 ± 88 particles per liter), while the single-use plastic contained 14 ± 14 particles per liter. The microplastic content in the beverage cartons was 11 ± 8 particles per liter and 50 ± 52 particles per liter for glass bottles.

Most of the particles in water from returnable plastic bottles were identified as consisting of polyester (primary polyethylene terephthalate PET, 84 percent) and polypropylene (PP; 7 percent). This is not surprising since the bottles are made of PET and the caps are made of PP. In water from single-use plastic bottles, only a few micro-PET-particles were found. In the water from beverage cartons and glass bottles, microplastic particles other than PET were found, for example polyethylene or polyolefins. The authors suggest this can be explained by the fact that beverage cartons are coated with polyethylene foils and caps are treated with lubricants. The authors conclude that the packaging itself may release microparticles.[207]

Toxicity of Microplastic Particles to Cells and Tissues

Compared to chemicals used in plastic, less is known about the toxic effects of plastic particles in the human body. A recent review of potential health risks of microplastic particles listed concerns that microplastics entering the human body could lead to inflammation (linked to cancer,

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BOX 7

Children's Toys Contain Toxic Plastic Softeners

SCCPs are used as a flame retardant in PVC plastic, rubber, and carpeting. Other uses include a plasticizers in paints, adhesives, and sealants. SCCPs above permitted levels have been found in children's products such as toys, stickers, clothing, sports gear, childcare articles, and kitchen utensils.

A 2017 survey[208] of children's products in ten countries conducted by IPEN, Alaskan Community Action on Toxics, and ARNIKA found widespread contamination of SCCPs, which adversely affect the kidney, liver, and thyroid, disrupt endocrine function, and are believed to be human carcinogens.[209]

Shortly after the release of the study, SCCPs were added to the Stockholm Convention for global elimination. Due to heavy industry lobbying, the resulting ban included loopholes to allow for continued use of SCCPs in the production of plastic, which demonstrates the inadequacy of current global regulatory frameworks to address toxic plastic additives.

According to a recent scientific paper,[210] "no other persistent anthropogenic chemical has been produced in such quantities [as SCCPs]" and there is some indication that production is increasing. Considering SCCPs' demonstrated long-range transport and ability to accumulate, as well as industry's intensive lobbying to continue its use as a plastic additive, human and environmental exposures are likely to increase.

Jumprope purchased in Japan contains 19,808ppm of SCCPs

© IPEN

heart disease, inflammatory bowel disease, rheumatoid arthritis, and more), genotoxicity (damage to the genetic information within a cell causing mutations, which may lead to cancer), oxidative stress (leading to many chronic diseases such as atherosclerosis, cancer, diabetes, rheumatoid arthritis, post-ischemic perfusion injury, myocardial infarction, cardiovascular diseases, chronic inflammation, stroke), apoptosis (cell death associated with a wide variety of diseases including cancer), and necrosis (cell death associated with cancer, autoimmune conditions, and neurodegeneration). Over time, these effects could also lead to tissue damage, fibrosis, and cancer.[211]

All plastic contains reactive oxygen species (ROS), or free radicals, which are unstable molecules that contain oxygen and easily react with other molecules in a cell. A build-up of free radicals in cells may cause damage to DNA, RNA, and proteins, and can lead to cell death.[212] Photodegradation of plastic or interactions with metals can lead to free radical formation. Damage associated with free radical formation can lead to cardiovascular and inflammatory disease, cataracts, and cancer.[213]

Inflammation appears to be the main response to micro- and nanoplastics entering the gastrointestinal tract (GIT) or the pulmonary system.[214] The literature reviewing the effects of plastic particles released into the body from degraded plastic prosthetic implants indicates that inflammation is a notable outcome of plastic particles crossing the respiratory or GIT epithelium.[215] PE and PET particles resulting from wear have been observed to move around the body, traveling through the lymph system, and to the liver and spleen. PE wear particles accumulate in the lymph nodes surrounding joint replacements and can be so abundant that they completely replace the lymph nodes, resulting in severe inflammation. Similar reactions can occur with ingested or inhaled microplastics if they are capable of crossing the epithelia.[216]

Uptake and Translocation Across the Gut

Micro- and nanoplastics can travel across the gastrointestinal tract in marine organisms, such as crabs[217] and mussels,[218] but fewer studies are available for mammals.[219] Based on the study of pharmaceutical drug delivery systems and the migration of nanopolymers from packaging materials into food, scientists believe that the ingestion and inhalation of micro- and nanoplastic particles could result in particles reaching various

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parts of the body and having a variety of impacts.[220] Ingestion can lead to uptake and translocation of plastic particles in the gastrointestinal tract, inhalation can lead to translocation to the lungs, and particles may also enter the circulatory system.[221]

Size of particles, surface charge, and hydrophilicity are factors that influence translocation. The current consensus seems to be that particles smaller than 1μm will translocate across the gut wall and potentially penetrate deeper into systemic circulation.[222] Various nanomaterials have moved from the gut into the circulatory system and become deposited into the liver and spleen.[223] Based on in-vitro studies, patients with inflammatory bowel disease are likely to show higher levels of absorption into colon and mucosal tissue compared to healthy controls.[224] Nano- and microparticles can translocate across living cells to the lymphatic or circulatory systems,[225] possibly accumulating in secondary organs,[226] or degrading the immune system and health of cells.[227] Microplastics' presence can induce intestinal blockage or tissue abrasion in earthworms and sea bass.[228] One study of human cells demonstrated that microplastics can cause cell toxicity.[229]

What happens when micro- and nanoparticles enter the circulatory system from the gut is not well understood, however it is clear that factors such as size, surface charge, porosity, and the physiologic condition of the individual are considered important.[230] A range of toxic effects may occur as micro and nanoplastic particles interact with cells and tissues, and accumulate in the major organs, but more research is needed.

All plastic contains reactive oxygen species, or free radicals, which are unstable molecules that contain oxygen and easily react with other molecules in a cell. A build-up of free radicals in cells may cause damage to DNA, RNA, and proteins, and can lead to cell death.

Research shows that humans are exposed to a variety of microplastics and toxic chemicals through the use of plastic consumer objects and plastic packaging. While there are still a number of knowledge gaps, available data clearly indicates an abudance of severe impacts on human health.

CHAPTER FIVE

Plastic Waste Management

The constant rise in global production and consumption of plastic has substantially outpaced all existing waste treatment methods. Contrary to common belief, only a small fraction of plastic waste is economically or technically viable to recycle. Between 1950 and 2015, approximately 4,900 million tons or 60 percent of all plastic ever produced had been discarded and was accumulating in landfills or in the natural environment.[231] Of that waste, 60 percent entered the environment (either via landfill or marine and terrestrial litter) 12 percent was incinerated, and only 9 percent was recovered for recycling.[232] Struggling to manage the ever-increasing amount of plastic waste, some cities and governments, influenced by a strong lobby of waste management corporations, are turning to waste incineration. One its surface, incineration may seem like a viable quick-fix, with “waste-to-energy” or “plastic-to-fuel” promising not only to reduce the volume of waste, but also to generate energy. The nature of all incineration technologies is the same, however, as that of burning waste in an open area (open burning). Despite use of the different terms used and regardless of the composition of the waste, incineration and open burning turns one form of waste into other forms of waste, including toxic emissions and toxic ash.

Emissions from waste incineration include metals (mercury, lead, and cadmium, among others), organic compounds (dioxins like polychlorinated dibenzo-p-dioxins, PCDD) and furans, PAHs, VOCs, and other POPs, including polychlorinated dibenzofurans (PCDF), PCBs, and hexachlorobenzene (HCB),[233] acid gases (including sulphur dioxide and hydrogen chloride), particulates (dust and grit), nitrogen oxides, carbon monoxide, and carbon dioxide (CO_2).[234] Smoke and particulates emitted from burning plastic and other waste can

BOX 8

Open Burning of Trash Around the Globe

Open burning of waste is defined as combustion of unwanted combustible materials such as paper, wood, plastic, textiles, rubber, waste oils, and other debris either in nature or in open dumps, where pollutants are released directly into the air.[235] Open burning can also include incineration devices that lack emissions control, including fire stoves. This practice is frequently used in developing countries[236] and rural areas, especially in communities with limited access to affordable fuels and organized waste management systems. Around 2.8 billion people—over a third of the global population—rely on open fires or simple stoves fueled by kerosene and solid fuels, including wood, coal, and waste, for cooking and heating. According to the World Health Organization’s Guideline for Indoor Air Quality, this results in approximately 4.3 million premature deaths from respiratory and cardiovascular diseases, lung cancer, stroke, chronic obstructive pulmonary disease, and pneumonia.[237] There is also evidence of links between household air pollution and low birth weight, tuberculosis, cataract, and nasopharyngeal and laryngeal cancers.

One study found open burning releases as much as 29 percent of global anthropogenic emissions of small particulate matter, 10 percent of mercury emissions, and 40 percent of PAHs.[238] Burning plastic can pose a serious health threat, with PVC contributing to high dioxin emissions.[239] This persistent, bio-accumulative toxin can spread into the air and land, affecting nearby plants and animals. Open burning can also cause wildfires, with their related deaths and injuries.[240] The United Nations Environment Programme defines open burning as an environmentally unacceptable process that can lead to unintentional formation and release of persistent organic pollutants, and it advises the cessation of open and other uncontrolled burning of waste, including burning of landfill sites.[241]

Opposite: © Nandakumar S. Haridas/Greenpeace

trigger respiratory health problems, particularly among children, the elderly, people with asthma, and those with chronic heart or lung disease,[242] while PCDF and PCBs are known carcinogens and emitted metals are known neurotoxics. The toxins from emissions, fly ash, and bottom ash in the burn pile can travel long distances and deposit on soil and water, eventually entering human bodies after being accumulated in the tissues of plants and animals in the food chain.[243]

WASTE-TO-ENERGY

Commercial trash incinerators burn waste (paper, plastic, metals, and food scraps) under more controlled conditions than open burning, yet still generate air pollutants, bottom ash, fly ash, combustion gases, wastewater, wastewater-treatment sludge, and heat. Some incinerators use refuse-derived fuel produced from various types of wastes, while others combust mixed wastes in traditional incinerators, usually referred to as mass burn incinerators. The latter burn waste at temperatures above 1,000°C. When waste is burned using coal or biomass at non-traditional incinerators such as cement kilns, coal plants, and industrial boilers, the process is referred to as co-incineration.

The toxins from emissions, fly ash, and bottom ash in the burn pile can travel long distances and deposit on soil and water, eventually entering human bodies after being accumulated in the tissues of plants and animals in the food chain.

The euphemisms frequently used by the waste incineration industry, such as “waste-to-energy” and “energy from waste,” broadly include thermal processes, like mass burn incineration and gasification, as well as non-thermal processes like anaerobic digestion and landfill-gas recovery. In this report, “waste-to-energy” refers to the incineration of waste including mass burning, co-incineration, and refuse-derived fuel, while other forms of thermal processing, such as gasification, pyrolysis, and plasma are addressed separately under the category of “plastic-to-fuel.”

Waste Incineration Industry Targets Asian Markets for Growth

Use of incineration varies widely across the globe. In Europe, there are almost 500 incinerators, and 41.6 percent of plastic waste is being incinerated as of 2016.[244] In 2016, 231 incinerators were reported to be operating, with another 103 being built or planned in China.[245] Other more heavily industrialized regions have lower rates of incineration: in the United States, only 12.5 percent of municipal solid waste is incinerated, and only one new US incinerator has been constructed since 1997. The waste incineration industry estimates that the industry will grow steadily at a compound annual growth rate of over five percent. By 2025, waste generation is projected to double to over six million tons generated per day, creating vast growth potential for the incineration industry.[246] Betting on government initiatives in China, India, Thailand, and Malaysia, the incineration industry has targeted Asian markets for above seven percent growth.[247] However, incineration is highly controversial in many countries, and recent attempts to build new incinerators have led to opposition, including in China, India, the Philippines, Indonesia, Vietnam, Malaysia, Thailand, South Africa, Ethiopia, Spain, UK, Puerto Rico, Mexico, Argentina, Chile, and Brazil.

ENVIRONMENTAL HEALTH IMPACT OF WASTE INCINERATION

Toxic Emissions from Burning Plastic

Waste incineration industries claim that incineration using highly advanced emission control technologies provides clean energy that reduces climate impacts and toxicity. However, extensive evidence demonstrates the harmful short- and long-term effects of waste incineration’s emissions and byproducts.

Air emissions associated with waste incineration include: metals (mercury, lead, and cadmium), organics (dioxins and furans), acid gases (sulphur dioxide and hydrogen chloride), particulates (dust and grit), nitrogen oxides, and carbon monoxide.[248] Workers and nearby communities can be directly and indirectly exposed to these toxic emissions through inhaling contaminated air, touching contaminated soil or water, and ingesting foods that were grown in an environment polluted with these substances.[249] These toxic substances pose a threat to vegetation, human and animal health, and the environment, and they persist and bio-accumulate through the food chain.[250] Burning plastic also increases the fossil content of the energy mix and adds greenhouse gas emissions to the atmosphere.

In some countries, newer incinerators apply air pollution control technologies, including fabric filters, electrostatic precipitators, and scrubbers. The filters do not prevent hazardous emissions, such as ultra-fine particles that are unregulated and particularly harmful to health,[251] from escaping into the air.

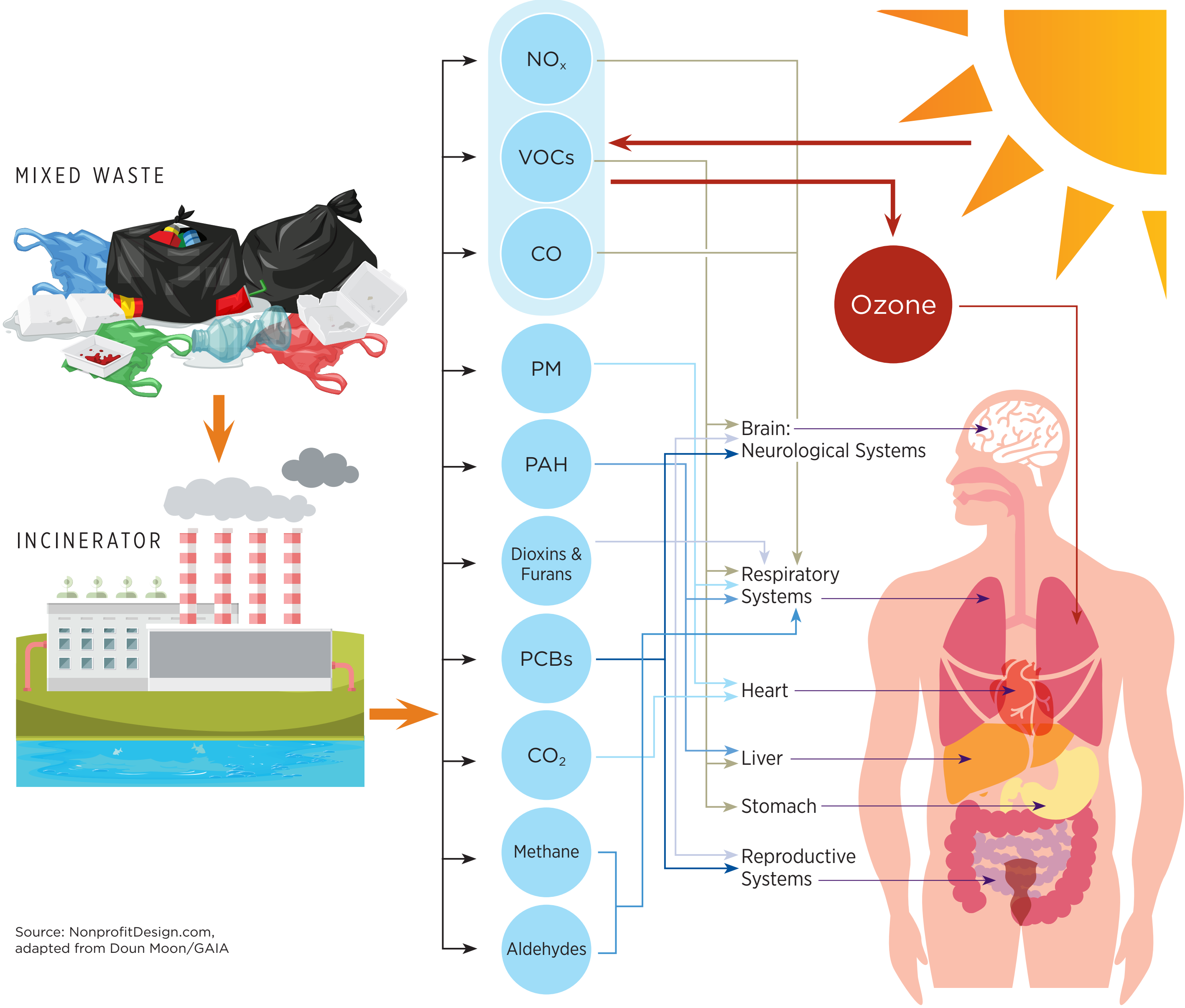
Malfunctions also tend to occur when the facility starts up and shuts down, or when the composition or volume of the waste changes, and these system failures result in greater emissions compared to normal operating conditions.[252] It is estimated that in 2015, these kinds of airborne particulates caused the premature deaths of over four million people worldwide.[253] Incinerators are also disproportionately built in low-income and socio-politically marginalized communities, burdening them with toxic ash and air pollution, noise pollution, and accidents.[254]

Toxic Byproducts of Incineration on Land and Water

In addition to toxic air emissions, incineration technologies produce highly toxic byproducts at various stages of thermal processing. Pollutants captured by air filtering devices are transferred

FIGURE 7

Toxic Exposure from Incineration



Source: NonprofitDesign.com, adapted from Doun Moon/GAIA

© iStockphoto/ReneDya

BOX 9

Ash Mismanagement Cases around the Globe

Even though the incineration industry claims to be “pollution-free,” incinerators have mismanaged highly toxic ash in several cases. In 2015, Sweden was found to have dumped highly toxic fly ash on a small island in Norway for five years, creating risks of heavy metal leakage into the Oslo fjord and explosions on the island.[255] In China, a study reported that incineration ash was dumped in unequipped landfills due to a shortage of landfills for toxic waste.[256] Tests of massive quantities of ash dumped by Covanta in Butte County, California, found high levels of dioxin in 2012.[257] More recently, an expansion plan for an ash landfill in Massachusetts faced a lawsuit for failing to meet the permit requirements of the Board of Health. The Massachusetts Cancer Registry reported that people living in the nearby community experienced higher rates of brain, bladder, and lung cancer than normally expected.[258]

to the byproducts of incineration, such as fly ash, bottom ash, boiler ash (also known as slag), and wastewater treatment sludge.[259] Bottom ash comes from the furnace and is mixed with slag. Fly ash is particulate matter in flue gases containing hazardous components, such as dioxin and furans, and are emitted from the stack. The toxicity in fly ash is greater than bottom ash because they are small particles that are readily wind-borne and more likely to leach.[260] At municipal waste incinerators, the more efficient the air pollution control system, the more toxic the ash is.[261]

Incineration produces ash that becomes a new waste disposal problem. Ash may end up in many places: landfills (ash landfills, hazardous waste landfills, and municipal waste landfills), mixed with cement, deposited in caves or mines, or dumped on open lands, agricultural lands (sometimes mislabeled as fertilizer), and islands and wetlands. The metals and organic compounds in ash can leach (e.g., dissolve and move from the ash to rain and other water that mixes with ash) and migrate into groundwater or nearby surface water, further expanding the cycle of toxic exposure of human beings. In addition to threatening water supplies, incinerator ash can affect human health through direct inhalation or ingestion of airborne or settled ash.[262]

Waste incineration ash residues are a serious threat to both local and global environments, as well as human health. They contain high quantities of unintentionally produced highly toxic persistent organic pollutants (U-POPs), including ones listed under Annex C of the Stockholm Convention (dioxins, furans, PCBs, and hexachlorobenzene), which are carcinogenic, mutagenic, and/or harm reproductive health.[263] The ash also contains heavy metals including arsenic, barium, cadmium, chromium, copper, molybdenum, nickel, lead, tin, antimony, selenium, and zinc, which originate from plastic and hazardous households waste.[264] These are known to cause heavy metal poisoning through industrial exposure, air or water pollution, and ingestion.

PLASTIC-TO-FUEL

Gasification, pyrolysis, and plasma arc—often clustered as "Plastic-to-Fuel"—aim to reduce the volume of waste by converting it into synthetic gas or oils, followed by combustion. They are classified as a form of incineration in the United States and in Europe because the process involves thermal treatment of waste and combustion of the produced gases.[265]

- **Gasification:** Thermal conversion of carbon-containing materials at temperatures of 540°C–1,540°C, with a limited supply of air or oxygen.[266] Gasification produces contaminants and syngas composed of carbon monoxide, hydrogen, and carbon dioxide, which require advanced pollution control.[267] Air emissions, slag, fly ash from air pollution control equipment, and wastewater are byproducts of gasification, similar to waste incineration.[268]

- **Pyrolysis:** Thermo-chemical decomposition of organic material, at elevated temperatures without oxygen. Pyrolysis occurs at temperatures above 400°C in an oxygen-free atmosphere.[269] Syngas produced during the reaction is generally converted to liquid hydrocarbons, such as biodiesel. Other byproducts are usually unconverted carbon and/or charcoal and ash, in which heavy metals and dioxin are consolidated.[270]

- **Plasma Arc:** A plasma torch provides supplemental heat from 2,200°C–11,000°C to create syngas and heat.[271] The slag produced by this technology is reported to have a risk of leaching heavy metals, such as arsenic and cadmium.[272]

Low Feasibility and Recent Trend of Failures

The plastic-to-fuel market has been growing, with an increasing number of attempts to develop commercial-scale gasification of municipal solid waste. To date, these efforts have been marked by years of delays and high-profile failures due to operational inexperience, high costs, lack of financing, and environmental concerns.[273] A recent study concluded that the thermodynamic viability of municipal solid waste pyrolysis is dubious and the technology poses environmental harm; thus it has yet to be proven as a sustainable waste treatment technology and energy source.[274]

Gasification, pyrolysis, and plasma arc—often clustered as "plastic-to-fuel"—aim to reduce the volume of waste by converting it into synthetic gas or oils, followed by combustion. They are classified as a form of incineration in the United States and in Europe because the process involves thermal treatment of waste and combustion of the produced gases.

Environmental Health Impact

Gasification of waste produces highly toxic carbon monoxide in concentrations far above the fatal dosage.[275] Toxic, acidic, and condensable hydrocarbons (tar) are unavoidable byproducts of gasification, and they are produced in greater quantities when facilities process mixed waste due to difficulties in stabilizing the process.[276] When pressure builds, toxic gas can escape to the air.[277] As stated above, byproducts of pyrolysis and plasma contain concentrated toxins, which can potentially leach into the environment. More generally, thermal processing of plastic waste leads to emissions of persistent organic pollutants (POPs) such as dioxins and PCBs, as well as lead, arsenic, mercury, and other heavy metals from the original components of the plastic waste: polymers derived from oil, gas, or coal that have been combined with toxic additives, such as flame retardants and/or plasticizers.[278]

BOX 10

Toxic Recycling

Recycling materials containing toxic chemicals can contaminate consumer products, leading to a legacy of hazardous chemical exposures and re-releases into the environment. Toxic recycling is an obstacle to a truly circular economy. In the case of POPs, their persistence, toxicity, and ability to contaminate food chains and travel long distances are particular challenges.

IPEN's report *Toxic Loophole: Recycling Hazardous Waste into New Products*[279] found that consumer products, including toys made from recycled electronic waste, are contaminated with toxic chemicals. Product testing showed items on sale in Europe contained restricted or banned polybromodiphenylethers (PBDEs), a group of toxic flame-retardant chemicals found in electronic waste.

Of the 430 plastic products collected, 109 items were identified as likely to be containing flame retardants originating in recycled e-waste. A more detailed chemical analysis of these 109 revealed that:

- 94 samples (86 percent) contained OctaBDE
- 100 samples (92 percent) contained DecaBDE
- The highest measured concentrations of PBDEs were found in children's toys, followed by hair accessories and kitchen utensils. A toy guitar from Portugal had the highest concentration of PBDEs (3318 ppm or 0.3 percent of product weight) three times more than the most conservative limit for this substance in plastic.

PBDEs are known to disrupt human thyroid function affecting the developing brain and causing long-term neurological damage.[280] Research shows PBDE exposure is associated with hyperactivity and poorer attention in children.[281] Contamination of children's toys is especially worrying because of children's propensity to put objects in their mouths and consequently risk ingesting those toxic substances.

If the products analyzed in this study had been made of virgin plastic instead of recycled materials, almost half would not have met the EU Regulation on POPs, which requires that OctaBDE concentrations not exceed the regulatory limit of 10 ppm in articles made of virgin plastic. These different standards for PBDE content in virgin and recycled articles result from weak legislative thresholds for POPs waste, which do not take into account the potential toxicity of waste streams to be recycled. The problem extends far beyond EU borders. As recycling targets are globalized through recycling exemptions for PentaBDE and OctaBDE under the Stockholm Convention, this perpetuates the global toxic legacy of PBDEs' emissions and exposures.

The environmental safety of the gas produced for sale also remains questionable. When burned, the gas can emit ultrafine particles of nickel, lead, and other toxic metals.[282] Plastic-derived fuel produces higher exhaust emissions compared to diesel, with a higher sulphuric content compared to both gasoline and diesel.[283] Monitoring and implementing stringent air pollution control for these fuels is challenging, when the fuel is sold and distributed to off-site industries for different uses in vehicles and boilers.

Highly flammable gases—hydrogen and carbon monoxide—also create fire and explosion hazards.[284] Startup and shutdown operations, as well as uncontrolled air intake, increase the potential explosion risk.[285] Over a six-year period in Sweden there were 2,865 documented gasifier fires.[286]

OTHER ROUTES AND UNKNOWNS

A number of other technologies or strategies, such as chemical recycling or using plastic waste for road or building materials have been proposed in recent years to deal with plastic waste.

Chemical Recycling

Chemical recycling is defined as chemical transformation of plastic into its basic components for the purpose of reproducing the same materials. While various thermochemical and catalytic conversions of plastic are being explored,[287] many unknowns remain around the toxicity of fugitive emissions from high temperature treatment, management of solvents, affordability of processes, and the efficiency of catalysts. Sometimes the term "chemical recycling" is used to refer to transforming plastic into fuel through combustion, such as gasification and pyrolysis. In such cases, "chemical recycling" poses the same environmental health concerns as waste incineration. Examination of multiple facilities that claim to perform "chemical recycling" reveals that these facilities are actually "plastic-to-fuel" operations.[288]

Waste-Based Road and Building Materials

In recent years, "plastic-to-road" or "Plasphalt," as well as "plastic-to-brick," initiatives have emerged to utilize bottom ash from incinerators for aggregate replacement in base road construction, bulk fill, concrete block manufacture, or concrete grouting.[289]

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- **Plastic-to-brick:** The plastic brick is compressed by two iron rods in a modular brick mold. The molds are filled with an air-tight amount of plastic waste and heated in a solar grill oven for one hour, then cooled immediately with a jet spray.[290]

- **Plastic-to-road:** Collected plastic waste is shredded into a uniform size (2–4 mm) after cleaning. Then the mixture is melted at 160–180°C and blended with hot aggregates and asphalt at a similar temperature.[291]

Although the toxicity of most of new “recycling” methods is yet to be explored, there are known health risks associated with heated plastic, chemical additives, and microplastics. Polymers such as PP, PE, and PS release moderately to highly toxic emissions into the atmosphere when heated, in the forms of carbon monoxide, acrolein, formic acid, acetone, formaldehyde, acetaldehyde, toluene, and ethylbenzene.[292] Given that the estimated 588,000 tons of plastic already used for road markings is unintentionally releasing microplastics through weathering or abrasion by vehicles,[293] the amount of plastic, additives, and microplastics exposed to unintentional losses would only increases with increased use of plastic waste in roads. Building materials raise further questions about emissions of microplastics and associated chemicals during the use and disposal of such materials.

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BOX 11

Waste Pickers at Particular Risk

Waste pickers are exposed to high health risks throughout the waste processing cycle from waste collection to transportation, sorting, washing, heating, and melting of plastic. They face chronic risks, such as respiratory disorders, due to prolonged and frequent exposure to fecal matter, medical waste, and chemically hazardous substances leached in the waste, air emissions, or byproducts during the processing.[294] For the thousands of people, particularly in less developed countries or communities that conduct plastic collection, recycling, and disposal under poor conditions, governments and local authorities should provide proper health care and social protection to ensure their occupational health and safety.[295]


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CHAPTER SIX

Plastic in the Environment

Human civilization is facing a growing burden of plastic pollution. There are myriad sources of plastic in the environment, including industrial and agricultural waste, particulates from car tire wear, dust, landfill, wastewater, and deliberate littering. Plastic disperses readily throughout marine, freshwater, and terrestrial environments into air, soils, rivers, lakes, and the ocean. Not only is it unsightly, but it also could have grave negative consequences for global ecosystems and human health. Plastic debris is ubiquitous, and it has even been found in the deepest parts of the ocean, the 7-mile deep Mariana trench in the western Pacific.[296] The problem is exacerbated by decades of poor waste management coupled with overproduction and consumption of plastic that is used fleetingly. In 2010, between 4.8–12.7 million metric tons of plastic were discharged into the ocean.[297] One study predicts that there may be around 5.25 trillion pieces of plastic debris weighing some 269,000 tons in the ocean, though the figures are almost impossible to verify.[298]

Weathering, such as ultraviolet light, wind, and wave action fragment plastic in the environment into ever smaller micro- and nano-sized pieces (see Box 6 for definitions). Large items of plastic have been found in the digestive systems of many marine species, like whales.[299] Over the past two decades, the consequences of smaller pieces of plastic on microscopic marine organisms have started to surface. Research suggests there are real possibilities that humans encounter microplastic, as these particles have been found in a number of commercially sold fish and shellfish[300] and in street dust samples from urban centers around the world.[301,302,303] Recent unpublished research suggests that microplastics are also found in human feces across the globe.[304]

Microplastics are of particular concern because they have a relatively large surface area and can penetrate deep into an organism and attract (adsorb) or release (desorb or leach) chemical additives or contaminants.[305]

Research shows that plastic debris has direct effects on wildlife, including entanglement, blockages to the digestive system, and toxicological impacts. From a human health perspective, the effects of inhaled or ingested microplastic depend on factors, such as size, chemical composition, and shape, all of which have an impact on whether a particle will be removed from the body or taken in by cells and potentially translocated. The indirect impacts of microplastics on the environment and human health are particularly difficult to determine. Most investigations to date have been carried out in a marine environment, and it is clear that microplastics interact with every part of ecosystems in ways that are yet to be fully understood. Emerging research suggests that, in addition to the human health impacts described below, there may be broad-scale ecological risks associated with plastic pollution that include the health of fish stocks and altering marine carbon storage, which could have long-term effects on food and climate security.[306]

The need to address plastic pollution and its associated uncertainties is undoubtedly urgent, but international policy discussions have only reached the equivalent stage of global climate change talks 27 years ago in 1992; there is a recognized need for global action and a mandate to identify options, but discussions are slow, industry obstruction is high, and concrete commitments are few.[307] In an attempt to control the burden of plastic waste, scientists are calling for international laws to address all stages of the

Opposite: © Marco Garcia/Greenpeace

plastic lifecycle—such as reducing production of polymers and toxic additives, setting up plastic recycling and implementing waste management targets, and moving towards a circular economy.[308,309]

The abundance of microplastics in the environment is expected to increase, and more information is needed to understand how this will affect human health. Research is being published regularly, and laboratory (and field) protocols are under development with the aim of making results more comparable. However, although global regulatory policies are in still development, some medical practitioners are already expressing concerns about the presence of microplastics in food.[310,311]

Scientists predict that if we eat microplastics there could be physical effects and/or toxic effects from chemicals associated with the plastic particles. Considering the multiple routes of exposure to microplastics from air, food, and drink, further research is required to fully understand their effects. Designing robust human health studies to investigate the toxicological impacts of ingesting microplastics is difficult. Large-scale population-based studies will have many confounding factors because we are exposed to a variety of toxic substances in our daily lives, and experimental studies are impractical. Regulation within the European Union exists for certain contaminants, including mercury, pesticides, and certain industrial chemicals in food, but it does not exist for microplastics in seafood intended for human consumption.[312,313] Below is a selection of research that has examined plastic pollution in human food.

BOX 12

The Truth about Bioplastic

Bioplastic—or biopolymers—is distinct from conventional plastic because it is made from renewable plant feedstocks such as corn, cassava, sugar beet, or sugar cane and not petrochemicals. Bioplastic can be as versatile as conventional plastic and is used to manufacture a variety of commercial products. Food-packaging uses include coffee cups, bottles, plates, cutlery, and vegetable bags; medical applications include surgical sutures, implants, and fracture fixation; other commercial applications include fabrics. Bioplastic includes polylactic acid (PLA), plant-derived polyethylene terephthalate (PET), polyhydroxyalkanoate (PHA), and can be mixtures of biopolymers, petrochemical-derived plastic, and fibers.

Bioplastic is not inherently biodegradable. The material used in plant-based PET is indistinguishable from its petrochemical equivalent. Plant-based PET, like petrochemical PET, will not decompose, but it can be recycled with conventional PET. Plant-derived PET thus has the same environmental impact as conventional plastic. PLA is not suitable for home composting; biodegradation requires an industrial composting process that uses high temperatures (>58˚C) and 50 percent relative humidity (most home composters operate at <60˚C and only rarely reach temperatures greater than this).

Pure bioplastic will release carbon dioxide (or methane) and water when it breaks down. However, if additives or toxins have been added during the manufacturing process, as is generally the case, these may be released during degradation. As with fossil fuel-based plastic, chemicals may be added to a bioplastic to add strength, prevent wrinkling, or confer breathability. Further research and lifecycle analyses will help to understand the role and impacts of different bioplastics.

INGESTING PLASTIC

As indicated in Chapter 4, plastic food packaging and drinking water are significant sources of food contamination, through both microplastics and associated toxic chemicals. However, contamination extends beyond packaged food, and natural food chains are also a source of human contamination. Most research to date has focused on seafood, and a number of knowledge gaps remain. More research is needed about both sea- and land-based food chain contamination.

Fish and Shellfish

Plastic is ubiquitous and persistent in air, agricultural soils, freshwater, and marine environments. To date much of the research has focused on the impacts of plastic in oceans. Plastic has been found floating in every ocean and in sediments, including in the deepest part of the oceans.[314] More than 690 marine species, from microscopic zooplankton to vast marine mammals, have been shown to have ingested microplastics. Microplastics have also been found in many commercially important species.[315,316]

In humans, the majority of microplastic ingestion from seafood is likely from species that are eaten in their entirety, such as mussels, oysters, shrimps, crabs, and some small fish. Exposure to microplastics may not, however, be limited to consumption of the aforementioned species—it is possible that other seafood, such as the muscle tissue of fish, could be contaminated either within the organism or during preparation.[317]

Microplastics have been found in the digestive tract of many commercial species, such as Atlantic mackerel (*Scombrus scombrus*), herring (*Clupea harengus*),[318] and plaice (*Pleuronectes plastessa*).[319] Evidence suggests that microplastics can be translocated from the digestive tract to the liver in species such as European anchovies (*Engraulis encrasicolus*).[320]

Studies show that Norway lobsters (*Nephrops norvegicus*), commonly called scampi, and spider crabs (*Maja squinado*) contain microplastics.[321,322] Microplastics are taken up by crabs either through ingestion or by inspiration through the gills.[323] While their gills and digestive tract are removed before eating, they may be present during the cooking process because crabs are cooked whole. Microplastics and any associated chemical contaminants could, therefore, be in the cooking liquid. Microplastics have also been found outside of the digestive tract within the shell and in the muscle tissue of wild tiger prawns (*Penaeus semisulcatus*) and brown shrimps (*Crangon crangon*).[324,325]

Microplastics have been found in wild and farmed mollusks, such as blue mussels (*Mytilis edulis*), clams (*Venerupis philippinarum*), and Pacific oysters (*Crassostrea gigas*), all of which are filter feeders.[326,327,328,329] In contrast to fish, in which microplastics have (to date) largely been found within the digestive tract, microplastics can spread to every tissue in a mussel.[330] One study found microplastics in all samples of mussels purchased from UK supermarkets.[331] Pre-cooked, supermarket-bought mussels contained more pieces of microplastic than live supermarket-bought mussels.

An analysis of four species of dried fish purchased from local markets in Malaysia concluded that people may consume up to 246 man-made particles (microplastics and pigments) per year.[332] The authors conclude that more research is needed on how microplastic particles could confer toxicity.

Seaweed

A laboratory investigation into whether humans could be exposed to microplastics by eating seaweed found that, at high exposure, microplastic particles could stick to the surface of the edible seaweed species *Fucus vesiculosus.*[333] Washing, however, reduced the number of microplastic particles by 94.5 percent.

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Salt

Microplastic particles have been found in commercial table salt derived from sea, lake, and rock salt.[334,335,336,337] However, differences in laboratory methods can make comparing studies difficult, and in the future, standardization should make interpreting the results more straightforward. Samples of both rock salt and sea salt have been found to contain microplastics, which suggests that there is a high background level of plastic contamination in marine and terrestrial environments.[338] Packaged salt and other food products packaged in plastic could become contaminated with microplastics during processing and packaging as well.


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Other Food and Drink

Microplastics are pervasive in terrestrial, as well as marine and freshwater environments.[339] Microplastics have been found to contaminate bottled water,[340,341] tap water,[342] beer,[343,344] honey, and sugar.[345] The origin of microplastic particles is difficult to determine; they may come from environmental sources, including water, waste treatment sludge used as fertilizers, and processing and packaging.

Microplastics in the Food Chain

Microplastics are resistant to degradation. Laboratory experiments have shown that micro- and nanoplastics can be transported from prey to predator and suggest that plastic-associated chemical additives and contaminants could also be passed through the food chain.[346,347] Researchers found that common shore crabs that had been fed plastic-contaminated mussels also ingested the microplastic beads and fibers.[348] One study found that nanoplastics readily travelled through the food chain from an alga (*Chlamydomonas reinhardtii*) to a water flea (*Daphnia magna*) to a rice fish (*Oryzias sinensis*), all the way to the top predator, a dark chub (*Zacco temminckii*).[349] Another study documented how microplastics are transferred from prey to predators in the wild by studying sand eels (*Ammodytes tobianus*) that were found in the digestive tract of both plaice and spider crabs caught in the Celtic Sea.[350]

The complex interactions between marine life and microplastics highlight the multiple pathways and routes through which microplastic could enter the food chain.[351,352,353] Research shows that humans are exposed to microplastics from a diversity of food sources, see Figure 2.

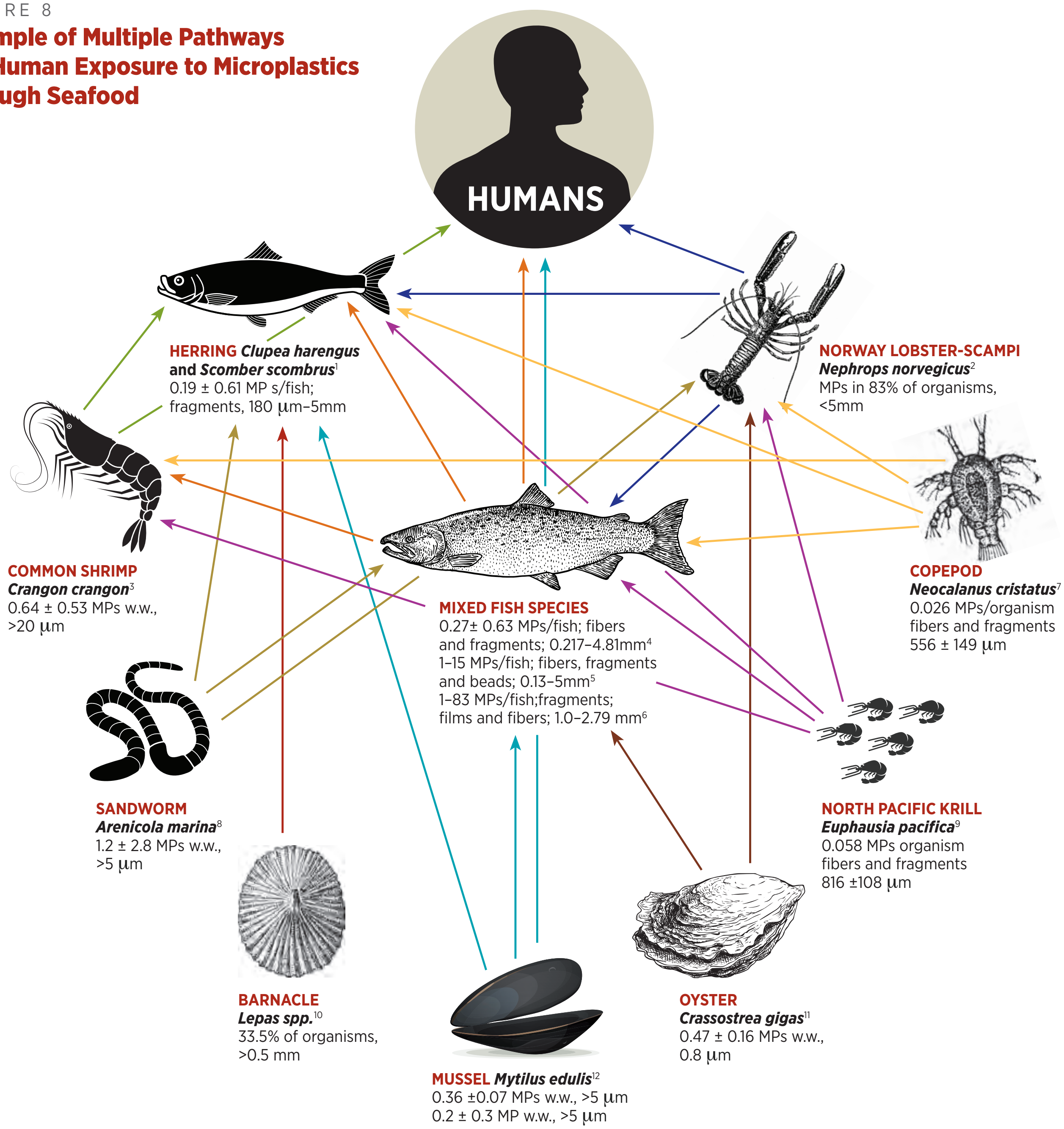
Impact on Human Health

Microplastics can enter the human body by two main pathways: airborne through nasal passages into the lungs and ingestion through the mouth into the stomach.[354] Ingestion of microplastics via food consumption raises health concerns because of the potential translocation of particles from the digestive tract to other tissues and as a delivery mechanism for toxic chemicals.[355,356] Of the chemical additives, phthalate plasticizers, bisphenol A, antimicrobial agents, and polybrominated flame retardants are of particular concern.[357,358] Microplastics contain an average of four percent of additives, but this can vary depending on the plastic type.[359] Existing research shows that plastic additives such as phthalates, BPA, and some flame retardants, are endocrine disruptors and carcinogens. It also shows that plastic can accumulate heavy metals and adsorb toxic contaminants, such as polycyclic aromatic hydrocarbons and organochlorine pesticides from the surrounding water.[360] Plastic exists in dozens of forms, each of which behave differently, degrade at different rates, and adsorb (attract), desorb (release), and leach chemical additives differently. It is important to take into account the manufacture, as well as the absorption and desorption properties, of plastics when considering potential toxicity.[361] The constant fluctuation of chemical exposure—both toxic and non-toxic—throughout the environment means that human and animal exposure will vary. This fluctuation also varies the rate at which microplastics adsorb and desorb chemical contaminants and additives.

Further clues into the impacts of microparticles (including plastic) that enter the human body can be found in medical literature. Once inside the body, microplastic particles can cross biological boundaries. As discussed in Chapter 4, polyethylene particles from artificial joint replacements were found to have translocated to the lymph nodes, liver, and spleen.[362] Studies in the emerging field of pulmonary nanodrug delivery show that nanoparticles of 4 nm, 8 nm, 12 nm, and 16 nm can penetrate lung tissue pulmonary surfactant membrane.[363]

FIGURE 8

Example of Multiple Pathways for Human Exposure to Microplastics through Seafood



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12 193 Van Cauwenberghe, L., Janssen, C., *Microplastics in bivalves cultured for human consumption* 65–70 (Environmental Pollution 2014).

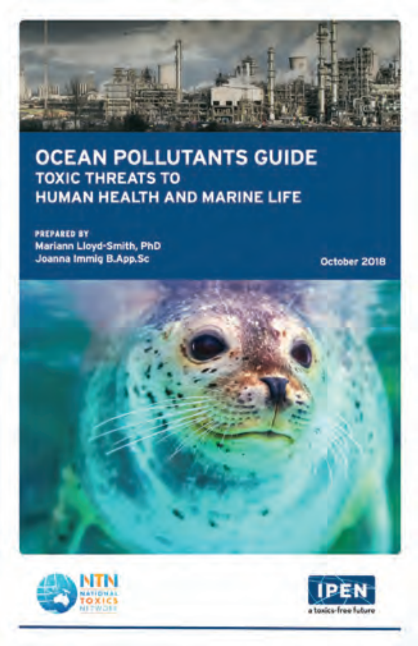
SOURCE: Re-created based on Carbery, M., O'Connor, W., & Thavamani, P., *Trophic transfer of microplastics and mixed contaminants in the marine food web a implications for human health* (Environment International 2018).

Because of ethical issues around human testing, initial work investigating the potential toxicity of microplastics has used laboratory and field studies to evaluate impacts on marine species and small mammals. Fluorescent microscopy has shown that polystyrene microplastics (5 μm and 20 μm) consumed by mice can accumulate in the liver, kidney, and digestive tract.[364]

BOX 13

Invisible Pollutants: No Place is Safe

Despite covering 71 percent of the earth's surface and holding 97 percent of the earth's water, even the most remote parts of the ocean are contaminated by toxic chemical additives used to make plastic. Tiny shrimp in the Mariana Trench are loaded with toxic chemicals, including plastic additives like brominated flame retardants. These contamination levels were considerably higher than those documented in nearby regions of heavy industrialization, indicating bioaccumulation of anthropogenic contamination and that pollutants are pervasive across the world's oceans and to full ocean depth.[365]



OCEAN POLLUTANTS GUIDE
TOXIC THREATS TO
HUMAN HEALTH AND MARINE LIFE

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October 2018

While giant gyres of plastic and soupy layers of microplastics have catapulted marine plastic pollution onto the world stage, invisible and persistent pollutants hitchhiking on plastic have created a toxic timebomb in marine environments.[366] Highly persistent chemical pollutants are already altering the reproduction and behavior of marine animals and impacting their immune systems, threatening their survival by altering their capacity to respond to disease.[367]

No place is safe. Most of the global land surface is connected to oceans via river systems. The toxic legacy of plastic and its associated toxic chemicals hidden in the ocean is part of an inextricably linked global ecosystem that cannot be ignored away.

Microplastics and Toxic Chemicals

The possibility of chemical contaminants from microplastics transferring to humans through food is not fully understood and warrants additional research.[368,369,370] Uncertainties surround the health impacts of microplastic ingestion, and scientists have suggested urgent research be undertaken, particularly on the potential effects to the endocrine system.[371] Humans are exposed to microplastics and associated chemicals that can be toxic even in low doses. Although plastic is only one source of chemical exposure, it could be a significant source for some chemicals.

One research team investigating the potential toxicity of microplastics in mice reported that microplastics may induce changes in energy and fat metabolism, cause oxidative stress, and could be neurotoxic.[372] The study indicates that there is a potential risk to humans from microplastic consumption.

Microplastics and the Potential for Disease

Another health concern relates to bacteria that grow on microplastics. One investigation looked into a bacterium living on the surface of microplastics collected in the North and Baltic seas.[373] The study discovered *Vibrio parahaemolyticus* bacteria on the surface of polyethylene, polypropylene, and polystyrene fragments. The bacterium can cause gastrointestinal illness in humans, and more research is needed to understand whether pathogens on the surface of microplastics consumed by humans may present a serious disease risk.

Ingesting Microplastics

The potential impacts of ingesting microparticles have been studied for decades, but are not yet fully understood because the particles are associated with such a diverse range of additives and contaminants. For example, in tests of rats, dogs, goats, and pigs, polyvinyl chloride particles have been transported from the digestive tract to the lymph and the circulatory systems, bile, cerebrospinal fluid, urine, lungs, and the milk of lactating animals.[374] Evidence so far suggests that the interaction between microplastics and other gut contents, including proteins, lipids, and carbohydrates, is highly complex.[375] The accumulation of microplastics could lead to inflammation, tissue damage, cell death, or carcinogenesis.[376] In addition, there is the potential for toxicological effects from harmful chemicals that leach or desorb from microplastics (see above Chapter 4 on consumer use).

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Given the ubiquitous nature of these particles in our food and the serious risks to human health arising from their ingestion, further study to understand and prevent health risks arising from the consumption of microplastics must be a priority.[377,378,379,380] As laboratory, field research, and large-scale, long-term monitoring studies are conducted and until we know the full nature of the risks, adopting a precautionary approach to reducing ingestion exposure is necessary.

INHALING MICROPLASTIC

The air we breathe is also a source of exposure to microplastics. Although atmospheric fallout of microplastics is an emerging area of research, studies conducted in Paris, France,[381] and Dongguan City, China,[382] have already revealed the presence of microplastics, mostly fibers, in total atmospheric fallout. Within the dense urban area of Paris, researchers discovered indoor concentrations of microplastic fibers ranged between 1–60 fibers/m3 while outdoor concentrations ranged between 0.3 and 1.5 fibers/m3.[383] Exposure to low concentrations of airborne microplastics is expected outdoors due to dilution,[384] and higher concentrations are found indoors due to more immediate contact with sources of microplastics, such as carpets and furniture textiles, and the lack of wind and other dispersal mechanisms.[385] Researchers also consider indoor air exposure more significant because people spend an average of 70–90 percent of their time indoors.[386] The fallout of airborne plastic particles may result in accumulation on the skin and on food, resulting in dermal and gastrointestinal exposure.[387] Based on reported indoor air concentrations and the average volume of air inhaled, researchers postulate that a person's lungs could be exposed to 26–130 airborne microplastics per day.[388]

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Other sources of airborne plastic include plastic and films used in agricultural processes that have degraded,[389] fibers released from clothing dryers,[390] and sea salt aerosol (i.e. caused by wave action).[391] More recently, dust from vehicle tire wear has been acknowledged as one of the main sources of microplastics in the air.[392] Airborne plastic can also be dispersed on global air currents.[393,394]

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Occupational exposure is considered to be even more significant than exposure at home.[395] Workers in the textile industry are exposed to greater concentrations of synthetic fibers for longer periods compared to the rest of the population. The effects of workers' exposure provide insights into the potential human health hazards of increasing exposure to microplastics, particularly fibers. For example, four percent of workers in nylon flock[396] plants in the US and Canada have interstitial lung disease, e.g. scarring of the lung tissue, that induces coughing, dyspnea (breathlessness), and reduced lung capacity.[397]

Toxicity of Inhaled Plastic Particles

Plastic microfibers can lodge deep in the lungs[398] and induce acute or chronic inflammation.[399] Size, shape, and the particle's interaction with different biological structures,[400] as well as concentrations of particles,[401] determine whether or not particles get lodged in the lungs and how long they remain there. Longer fibers are more persistent, and typical pulmonary clearance mechanisms have a harder time ejecting them.[402] Fibers $<0.3\mu m$ thick and $10\mu m$ long are the most likely to be carcinogenic.[403] Fibers of certain sizes and thicknesses have invoked acute inflammatory responses in rats, while shorter but wider ones showed no pulmonary inflammation.[404]

Once inhaled, most fibers are likely to get trapped by the lung lining fluid. Particles $>1\mu m$ passing through the upper airway, where the lung lining is thick (central lung), can bypass the lung lining, allowing for uptake across the bronchial epithelium.[405] The diameter of a microplastic particle may allow it to be deposited deeper in the lung, where it may penetrate the thinner lung lining fluid and contact the epithelium, then translocating via diffusion or active cellular uptake throughout the body.[406]

Other factors that determine the toxicity of fibers in the lungs include concentration, site of deposition, and the potential for chemicals to leach or desorb from the fiber surface.[407] Microplastic is resistant to chemical degradation in human subjects. When inhaled or ingested, it can become lodged or embedded in the lungs or other organs. Inhaled fibers in the malignant lung tissue of patients exhibited few signs of deterioration, indicating that they are bio-persistent, and that plastic fibers can lodge deep in the lungs.[408] Bio-persistence and dose can be risk factors.[409] Inhaled plastic particles have also been associated with oxidative stress and subsequent inflammation, and nanoparticles have caused airway inflammation and intestinal fibrosis.[410]

The health effects associated with inhaled chemical additives and accumulated toxics in plastic particles are not yet clear. *In vitro* (lab-based) research has shown that polymers with additives result in higher toxicity to cells and increased inflammatory response, while *in vivo* (human subjects) did not show any increase.[411] However, certain plastic additives or monomers can migrate out of inhaled or ingested particles into the body[412] or enter air and dust, as in the case of phthalates and BPA.[413] Household dust containing polybrominated diphenyl ethers (flame retardants) released from plastic components of electronics, upholstery, and carpets can reach >90 ng/g dust.[414] It is unclear how PBDE reaches household dust, but one strong suggestion is that PBDEs are released through the normal wear of plastic household products and textiles.[415] Microplastics may also adsorb and release airborne contaminants, just as they do in marine environments.[416]

PLASTIC IN AGRICULTURAL SOILS

Soil is central to food production and safety. Soil determines the composition of human and animal food. It is the interface between land, the aquatic environment, and the atmosphere, and it is affected by many contaminants, including plastic. There is sparse data about the sources and transportation of microplastics within the terrestrial environment.[417] For example, researchers identified the presence of macro- and microplastics contamination on agricultural farmland in southeast Germany, where microplastic-containing fertilizers and agricultural plastic applications had never been used.[418] Recent studies suggest terrestrial plastic pollution may be four to 23 times greater than ocean pollution.[419]

Plastic is widespread in agricultural soils.[420] Sources include agricultural polyethylene sheets (that fragment from weathering), biosolids and sewage sludge (from wastewater treatment plants),[421,422,423,424,425] and grey water (from washing clothes made with synthetic fibers).[426,427]

Sewage entering municipal treatment systems is high in microfibers from textiles, microplastics from personal care products, and degradants of consumer products.[428] Between 80 and 90 percent of microplastics entering treatment systems remain in residual sewage sludge.[429] This sludge is often used as fertilizer in agriculture, resulting in plastic being deposited on agricultural fields where it can remain for long periods of time.[430] To understand the significance of sewage sludge as a source of microplastic pollution, one study estimated that sewage sludge accounts for 63,000–43,000 and 44,000–300,000 tons of microplastics to be added annually to European and US farmland, respectively.[431] Based on a recent study, microplastics can persist in soils for more than 100 years, due to low light and oxygen conditions.[432]

Compost and fertilizers used to supplement soil nutrients are an increasingly significant source of plastic in soil as well. A recent study evaluating organic fertilizers from bio-waste fermentation and household compost found microplastics in all samples. The most abundant types of plastic were those associated with food packaging.[433]

Scientists do not currently fully understand the impacts of plastic in, nor the toxicological and ecological impacts on, agricultural soils. Some studies have identified concerns. Others have highlighted the need for further research to determine how plastic degrades under different environmental conditions (for example in soil versus water) and leaches persistent organic pollutants.[434,435,436,437]

One health concern regarding plastic in soils is the potential transfer of toxic chemicals to crops and animals. The plastic industry is a major source of chemical additives reaching the environment. Some of these additives, including endocrine-disrupting chemicals such as phthalates,[438] polybrominated diphenyl ether (PBDEs),[439] and bisphenol A[440] have been found in fresh vegetables and fruit. Although pinpointing the precise source of a given contaminant is almost impossible, reports of plastic additives and toxic contaminants in vegetables and fruit serve as an early warning that should trigger the urgent implementation of the precautionary principle in order to reduce exposure.

Evidence of the indirect effects of plastic-associated chemicals is emerging in scientific literature. Earthworms that encounter polyurethane particles in soils can accumulate PBDEs.[441] Earthworms are important to maintain healthy ecosystems and soils, particularly in agricultural regions. Worms aerate the soil through burrowing, process detritus, move the soil, and are a key food source for other animals. It is possible that PBDEs could be transferred in worms to other areas of soil and through the food web.

BOX 14

Is Plastic a Persistent Organic Pollutant?

Plastic is not officially recognized as a POP under the Stockholm Convention,[442] but the characteristics of plastic and its chemical additives and contaminants make it potentially as harmful as, and portraying similar characteristics to, officially recognized POPs.[443] These characteristics include:

- **the degradation of persistent plastic into micro- and nanoplastic particles, which facilitates their uptake by marine biota, indicate they accumulate in the food chain;**
- **some chemical additives and contaminants present in plastic polymers have endocrine disrupting properties and may be harmful at extremely low doses; and**
- **there is a “continuous flow of ‘fresh’ plastic waste,” marking a significant persistence in the marine ecosystem.**

Supporting the qualification of microplastics as POPs, the European Chemicals Agency (ECHA) consider microplastics to be similar to PBT/vPvB substances, substances that are persistent, bio-accumulative, and toxic/very persistent and very bio-accumulative. In January, 2018, ECHA proposed restrictions under Annex XV of its flagship chemical regulation REACH.[444] At the time of writing, a decision on this proposal had not yet been adopted.

CHAPTER SEVEN

Conclusions and Recommendations

This report provides a snapshot of current knowledge regarding the array of human health impacts produced throughout the supply chain and lifecycle of plastic. It documents the numerous routes through which human health is impacted at every stage in the plastic lifecycle-from wellhead to refinery, from store shelves to human bodies, and from waste management to ongoing exposure from air pollutants and environmental plastic. This report also reveals systemic and troubling gaps in our knowledge that may exacerbate exposure and risks for workers, consumers, frontline communities, and communities around the globe that are far removed from obvious sources of plastic.

KNOWN KNOWNS

Every stage of the plastic lifecycle poses significant risks to human health, and the majority of people worldwide are exposed to plastic at multiple stages of this lifecycle.

Extraction and Transport of Fossil Feedstocks for Plastic

Fossil fuels such as oil, gas, and coal comprise the primary feedstocks for plastic, constituting more than 90 percent of plastic content. The extraction of oil and gas, particularly the use of hydraulic fracturing to extract natural gas, releases an array of toxic substances into the air and water, often in significant volumes. These toxins have direct and documented impacts on skin, eyes, and other sensory organs, the respiratory system, the gastrointestinal system, and the liver, as well as the brain and nervous systems.[445] Over 170 chemicals used in fracking operations for plastic production are known to cause health impacts, including cancer, reproductive, developmental, and neurotoxicity, and impairment of the immune system.[446] Exposure to such toxins has also been correlated with higher hospitalization for cardiac or neurological problems.[447]

Petrochemical Refining and Manufacture of Plastic Resins and Additives

Transformation of fossil fuel into plastic resins and additives releases carcinogenic and other highly toxic substances into the air, water, and soils, with a range of adverse human health effects. Documented effects of these substances include impairment of the nervous system, reproductive and developmental problems, cancer, and genetic impacts leading to record levels of low birth weight, cancers, and leukemia. Industry workers and communities neighboring plastic production facilities are at greatest risk and face both chronic exposures and the risk of emergency releases. The production of plastic disproportionately impacts the health of poor and marginalized communities, and vulnerable populations within those communities, particularly children and women of reproductive age.

Consumer Products and Packaging

Both microplastics and the associated chemicals in plastic consumer products and packaging have impacts on human health. Use of plastic products leads to ingestion or inhalation of large amounts of microplastic particles and hundreds of toxic substances, the adverse impacts of which include developmental impacts, endocrine disruption, and cancers.

Direct Exposure through Contact, Ingestion, or Inhalation of Microplastics

Microplastics entering the human body can lead to an array of health impacts, including inflammation (linked to cancer, heart disease, inflammatory bowel disease, rheumatoid arthritis, and more), genotoxicity (damage to the genetic information

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within a cell causing mutations, which may lead to cancer), oxidative stress (leading to chronic diseases such as cancer, diabetes, rheumatoid arthritis, cardiovascular diseases, chronic inflammation, stroke), apoptosis (cell death associated with a wide variety of diseases including cancer), and necrosis (cell death associated with cancer, autoimmune conditions, and neurodegeneration). These effects over time could also lead to tissue damage, fibrosis, and cancer.

Cascading Exposures in the Environment and within the Human Body

Most plastic additives are not bound to the polymer matrix and easily leach out[448] into the surrounding environment, including air, water, food, or body tissues.[449] As plastic particles continue to degrade, new surface areas are exposed, allowing continued leaching of additives from the core to the surface of the particle.[450] Several plasticizers, such as DEHP and BPA, can cause reproductive toxicity. Benzene and phenol are mutagenic; they change the genetic material, usually DNA, of an organism increasing the frequency of mutations. Some of the most harmful additives include brominated flame retardants, phthalates, and lead heat stabilizers.[451] Other harmful chemicals known to leach from plastic polymers include antioxidants, ultaviolet stabilizers, and nonylphenol.[452]

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Toxic Releases from Plastic Waste Management

All combustion technologies (including incineration, co-incineration, gasification, or pyrolysis) to eliminate plastic waste result in emissions and releases of toxic metals, such as lead and mercury, organic substances, such as dioxins and furans,[453] acid gases, and other toxics substances to the air, water, and soil.[454] All such technologies lead to direct and indirect exposure to toxic substances for workers and nearby communities, including through inhalation of contaminated air, direct contact with contaminated soil or water, and ingestion of foods that were grown in an environment polluted with these substances. The toxins from emissions, fly ash, and slag in a burn pile can travel long distances and deposit in soil and water, eventually entering human bodies after being accumulated in the tissues of plants and animals.[455]

Ongoing Exposures through Agricultural Soils, Terrestrial and Aquatic Food Chains, and the Water Supply

Once plastic reaches the environment in the form of macro- or microplastics, it contaminates and accumulates in food chains, where it can release toxic additives or concentrate additional toxic chemicals, making them bioavailable again for direct or indirect human exposure.[456]

KNOWN UNKNOWNS

Uncertainties and knowledge gaps undermine a complete evaluation of health impacts, limit the ability of consumers, communities, and regulators to make informed choices, and heighten both acute and long-term health risks at all stages of the plastic lifecycle.

Hidden Risks

Extreme lack of transparency around the chemical composition of most plastic and the production processes through which it is produced prevents the full understanding of exposure and a full assessment of impacts.

This is fueled by the treatment of confidential business information and inadequate disclosure requirements. These gaps reduce the ability of:

- regulators to develop adequate safeguards;
- consumers to make informed choices; and
- frontline and fenceline communities to limit their exposures to plastic-related health hazards and respond properly when emergencies occur.

Details Matter

Communities living near major extraction, production, and waste treatment facilities are at particular risk throughout the plastic lifecycle, but they face systemic and often significant barriers to quantitative and qualitative information about their exposures to toxic and hazardous substances.

Intersecting Exposures and Synergistic Effects Remain Poorly Assessed and Poorly Understood

Plastic risk assessment processes face numerous limitations, particularly in relation to the health effects of the cumulative exposure to the mixtures of thousands of chemicals used in food packaging and other manufactured products.

We Are What We Eat

Despite their pervasive presence and potentially significant impacts across an array of pathways, the distribution, transport, degradation, and impact of microplastics in terrestrial environments remains poorly understood. The movement of plastic and microplastics through marine ecosystems and food chains is only now being researched; and studies of the role of plastic in, and toxicological/ecological impacts on, agricultural soils are in their infancy. The potential transfer of toxic chemicals to crops and animals demands urgent and sustained investigation.

What Becomes of Plastic People?

Microfibers and other plastic microparticles are increasingly being documented in the human bloodstream and human tissues. Until the exact behavior and impacts of plastic microparticles in the human body are better understood, the rising production and pervasive use of these persistent contaminants should be viewed as a significant public health concern.

RECOMMENDATIONS: A LIFECYCLE APPROACH TO PLASTIC ASSESSMENT, MANAGEMENT, AND REDUCTION

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From the siting of facilities, to the testing of new products, to addressing the increasingly diverse manifestations of the plastic crisis, assessments of plastic's impacts to date have disproportionately and improperly focused on a single stage of the plastic lifecycle, and often only a single exposure pathway within that stage. This report demonstrates that each of those stages interacts with others, and all of them interact with the human environment and the human body in multiple, often intersecting, ways.

Taking a Lifecycle Approach

The current narrow approaches to assessing and addressing plastic impacts are inadequate and inappropriate. Understanding and responding to plastic risks, and making informed decisions in the face of those risks, demands a full lifecycle approach to assessing the complete scope of the impacts of plastic on human health.

Recognizing the Interacting Exposures

Health impact assessments that focus solely on the plastic components of products while ignoring the thousands of additives and their behavior at every stage of the plastic lifecycle are incomplete and dangerous.

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Making the Invisible Visible

Addressing plastic pollution will require adapting and adopting legal frameworks to ensure better transparency regarding the presence of petrochemical substances in all products and processes, as well as increased independent research to fill existing and future knowledge gaps.

Avoiding False Solutions to the Plastic Crisis

Plastic represents a wide and diverse universe, with a complex lifecycle involving a wide variety of actors. Reducing toxic exposure to plastic will accordingly require a variety of solutions and options. Adequately addressing the plastic pollution problem and its impacts on human health requires ensuring that we are not creating yet more and increasingly complex environmental problems in attempts to address this one.

Putting Human Rights and Human Health at the Center of Solutions

Solutions at every stage of the plastic lifecycle should respect the human rights to health and to a healthy environment. Despite some uncertainty requiring further independent scientific research, existing information about the severe human health impacts of the plastic lifecycle documented in this report warrant the adoption of a precautionary approach to the lifecycle of plastic and the overall reduction of plastic production and uses.

Building Transparency, Participation, and the Right to Remedy into Solutions

In identifying, designing, and implementing possible solutions to the plastic pollution crisis, transparency is key to success. As indicated above, transparency is required to identify the nature and breadth of exposure to toxic material, as well to assess and prevent possible adverse health and environmental impacts of technologies touted as "solutions" to the plastic pollution problem, such as incineration and plastic-to-fuel technologies. As indicated in a statement of the United Nations Special Rapporteur on Toxic Substances: "The right of victims to an effective remedy, the right to meaningful participation, the right not to be subject to experimentation without consent, the right to the highest attainable standard of health and several other human rights have all been frustrated by large information gaps throughout the lifecycle of substances and wastes."[457]

Think Globally, Act Everywhere

The production, use, and disposal of plastic are interwoven around the world in supply chains that cross and recross borders, continents, and oceans.[458] To date, efforts to address the human health impacts of plastic have largely ignored the global dimensions of the plastic lifecycle. As a result, measures that succeed at a local level or address a single product stream are often undermined or offset by the emergence of new kinds of plastic, new exposure pathways, and new additives. Until efforts at all levels of government recognize the full plastic lifecycle, the current piecemeal approach to addressing the plastic pollution crisis will not succeed.

To date, efforts to address the plastic pollution crisis have had limited success due to an array of factors: the scale and complexity of impacts, limitations of risk assessment systems, unknown cumulative effects and limited exposure data, long and complex supply chains, formidable financial stakes in maintaining the status quo, and an industry in denial of the health impacts. Yet while the economic interests of the plastic industry are indeed enormous, the financial costs to society are no less significant.[459,460]

The findings of this report are conclusive. Even with the limited data available, the toxic impacts of the plastic lifecycle on human health are overwhelming. While many actions will be necessary to confront this threat to human life and human rights, it is clear that urgent, global action is needed to reduce the production and consumption of plastic and associated toxic chemicals.

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459. *See* Teresa M. Attina et al., *Exposure to Endocrine-disrupting Chemicals in the USA: A Population-based Disease Burden and Cost Analysis*, 4(12) The Lancet, Diabetes & Endocrinology 996, 996-1003 (Dec. 1, 2016), *https://www.thelancet.com/journals/landia/article/PIIS2213-8587(16)30275-3/fulltext*.

460. *See* Leonardo Trasande et al., *Burden of Disease and Costs of Exposure to Endocrine-disrupting Chemicals in the European Union: An updated analysis*, 4(4) Andrology 565, 565-72 (2016), *https://onlinelibrary.wiley.com/doi/full/10.1111/andr.12178*.

Plastic & Health

THE HIDDEN COSTS OF A PLASTIC PLANET

Despite being one of the most pervasive materials on the planet, plastic and its impact on human health is poorly understood. Human exposure to it grows with increasing plastic production and use. Research into the human health impacts of plastic to date have focused narrowly on specific moments in the plastic lifecycle, from wellhead to refinery, from store shelves to human bodies, and from disposal to ongoing impacts as air pollutants and ocean plastic. Individually, each stage of the plastic lifecycle poses significant risks to human health. Together, the lifecycle impacts of plastic paint an unequivocally toxic picture: plastic threatens human health on a global scale.

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