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PROBLEM PLASTIC:

How Polyester and PET Plastic Can be Unsafe, Unjust, and Unsustainable Materials

July 2022

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This report is published by Defend Our Health, a U.S.-based nonprofit organization working to create a world where all people have equal access to safe food and drinking water, healthy homes, and products that are toxic-free and climate-friendly.

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EXECUTIVE SUMMARY

We believe that petrochemical plastics are unsafe, unjust, and unsustainable due to their lifecycle impacts. Plastic pollution is much more than a waste problem. Before being thrown away, petrochemical plastics can threaten human health, cause environmental injustice, and fuel the climate crisis.

This report investigates the impacts of one of the most widely-used plastics, known as PET (for polyethylene terephthalate) and as "polyester" in its fiber form. While PET is but one of several problematic plastics, it is emblematic of concerns that may exist with all petrochemical plastics.

We chose to closely examine PET (including polyester) because of its major production volume, its reliance on toxic chemicals and plastic additives that can threaten human health, and the mismanagement typical of the end of PET products' short life-cycle. Like other petrochemical plastics, PET can also contribute to environmental racism and increases greenhouse gas emissions. While chemistry and other details vary, many, if not most, petrochemical plastics implicate similar concerns.

PET is the most common material used to make plastic bottles, cuddly stuffed toys, and clothing. It can pose hidden health hazards to young children and other consumers. Our investigation of PET found unsafe levels of plastics-related chemicals in some beverages packaged in plastic bottles.

The toxic element antimony is a plastics processing aid used to speed up the final chemical reaction that produces PET resin and polyester fiber. Some of the antimony remains in the final PET product and can make its way into the food and beverages that are packaged in PET bottles and containers. Defend Our Health tested samples of twenty major brands of beverages packaged in PET plastic bottles to evaluate the amount of antimony present in the sampled beverages.

In nearly half of the PET plastic-bottled beverages we tested (40%), the concentration of antimony in the drink itself exceeded 1 part per billion (ppb), the California Public Health Goal for drinking water. Daily exposure above this amount may cause liver disease. Excess exposure to antimony compounds may also increase the risk of cancers, heart disease, and other organ toxicity.

Antimony in 90% of the beverages we tested exceeded 0.25 ppb, a more protective health limit recommended by Defend Our Health to better account for typical daily antimony exposures from other sources.

Higher amounts of antimony leach into food and beverages when PET plastic bottles and food trays are heated, stored, exposed to light, or used to package acidic beverages such as juices and carbonated soft drinks.

Babies and toddlers who suck on soft cuddly toys (such as stuffed animals), blankets, clothing, and other polyester items may also be exposed to unsafe levels of antimony.

PET plastic can threaten children's health because many kids are likely already exposed to unsafe levels of antimony from a combination of sources to which they are routinely exposed. Antimony is added to many other plastic products, including electronics and home furnishings, to enhance the effect of flame retardant chemicals. Those products can release antimony in the home, which builds up in house dust. Toddlers may then ingest household dust containing antimony from frequent hand-to-mouth activity. We calculate that young children are likely exposed to almost three times as much antimony per bodyweight as adults in the U.S.

This concept of "aggregate risk" from total exposure to all sources of a chemical is comparable to filling a bath for your child in the tub. You don't let the faucet run until the tub overflows and then keep adding water. Similarly, antimony exposure from PET plastic and polyester adds to health risks that may be already overflowing, worsening the overall impact.

PET plastic and polyester can contribute to environmental racism and injustice. On a nationwide basis, Latinx and Black consumers are exposed to higher levels of antimony in general than white Americans, and at nearly twice the amount in the highest exposure groups, according to the National Biomonitoring Program.

Production of petrochemical plastics, including PET, is concentrated near lower-income communities and communities of color. Black and Brown residents and poor people, in a greater percentage than the national average, are surrounded by more than twenty petrochemical manufacturing plants that directly supply petrochemicals used in PET plastic production in North America. PET plastics-related chemical plants near communities that are already heavily over-burdened with industrial pollution from many sources manifest an even greater injustice. The majority of PET plastics-related chemical plants in North America are located in Texas, Louisiana, Alabama, South Carolina, North Carolina, and Mexico.

Almost all petrochemical plastics, including PET, are unsustainable materials. More than 99% of PET plastic is made from non-renewable fossil carbon extracted from the earth by drilling and fracking for crude oil and natural gas. Greenhouse gases emitted by the production and disposal of petrochemical plastics are fueling the climate crisis.

Most PET plastic is used only once and then thrown away. Only about 11% of the PET and polyester produced has ever been recycled, and nine times out of ten it is recycled for just one more use. Although the recycling rate for plastic bottles has grown to almost 30%, two-thirds of all PET takes the form of polyester fiber. Less than 1% of clothing, where polyester dominates, is ever recycled. Most PET recycling simply turns plastic bottles into lower quality polyester fill, a phenomenon known as "down-cycling."

The petrochemical plastics industry profits from this extractive, one-time use model, and encourages ever-increasing plastics demand. The industry has grown exponentially since 1950, and recent petrochemical industry growth projections indicate plastics production will double by 2040.

Texas City petroleum refining & petrochemical manufacturing center | Jim Evans, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

Two proposed new chemical plants would worsen the adverse impacts of PET plastic

The proposed Corpus Christi Polymers plant in Texas would increase PET plastics production capacity in North America by nearly 25%, producing 1.1 million tons per year. A joint venture between three large existing PET producers – Indorama Ventures of Thailand, Alpek of Mexico, and Far Eastern New Century from Taiwan – this would be the largest PET plant in the world. Much delayed already, the plant could go online in 2024.

The proposed Formosa Plastics chemical plant planned for Welcome, St. James Parish, Louisiana would produce 1.6 million tons per year of monoethylene glycol (MEG), a building block chemical essential for PET production, as well as massive amounts of polyethylene plastic. Globally, 80% of MEG is used to make PET plastic and polyester.

Local residents and health advocates have vigorously opposed the siting of this chemical plant as environmentally racist and a threat to public health. Formosa's operations would drive up emissions of cancer-causing ethylene oxide, a byproduct of MEG production. Construction of this plant is on hold pending completion of a federal Environmental Impact Statement that must consider the cumulative impacts and environmental injustice faced by local residents from the many existing industrial polluters in "Cancer Alley".

Petrochemical pollution from PET and other plastics can and must be stopped

Preventing plastic pollution must begin at the source. Elimination of unnecessary uses and substitution with safer, more sustainable solutions should be the top priority. Recycling is a stopgap measure that alone cannot solve the plastic problem.

Corporate and government leaders, responding to demands from organized consumers and voters, should undertake a series of immediate and longer-term actions to prevent petrochemical plastic pollution. With the end goal in mind, these actions – many of which have been endorsed by scientists and market leaders – should include:

- ***By 2040, the use of virgin fossil PET plastic and polyester should be phased out***
- ***By 2030, replace 50% of PET bottles and packaging with reusable and refillable systems***
- ***By 2030, substitute 50% of virgin polyester with recycled clothing or natural fibers***
- ***By 2030, replace 50% of PET with 100% non-toxic biobased PET or bioplastics such as PEF***
- ***By 2025, meet the industry's Recycled Polyester Challenge to increase the recycled content of polyester to 45% (on the path toward achieving a 90% share by 2030)***
- ***By 2025, meet the industry pledge to eliminate unnecessary and problematic plastic materials (e.g. opaque or pigmented PET plastic bottles, and PETG in rigid packaging)***
- ***By 2025, assess the hazards of all chemical substances used or produced to make PET***
- ***By 2024, eliminate chemicals of high concern as PET plastic additives and processing aids***
- ***By 2023, end all use of antimony and cobalt compounds in PET plastic and polyester***

Through such actions, we can effectively transition away from dependence on PET and other petrochemical plastics in favor of safer and more just and sustainable materials and other solutions that meet the needs of society with less risk of harm to people and the planet.

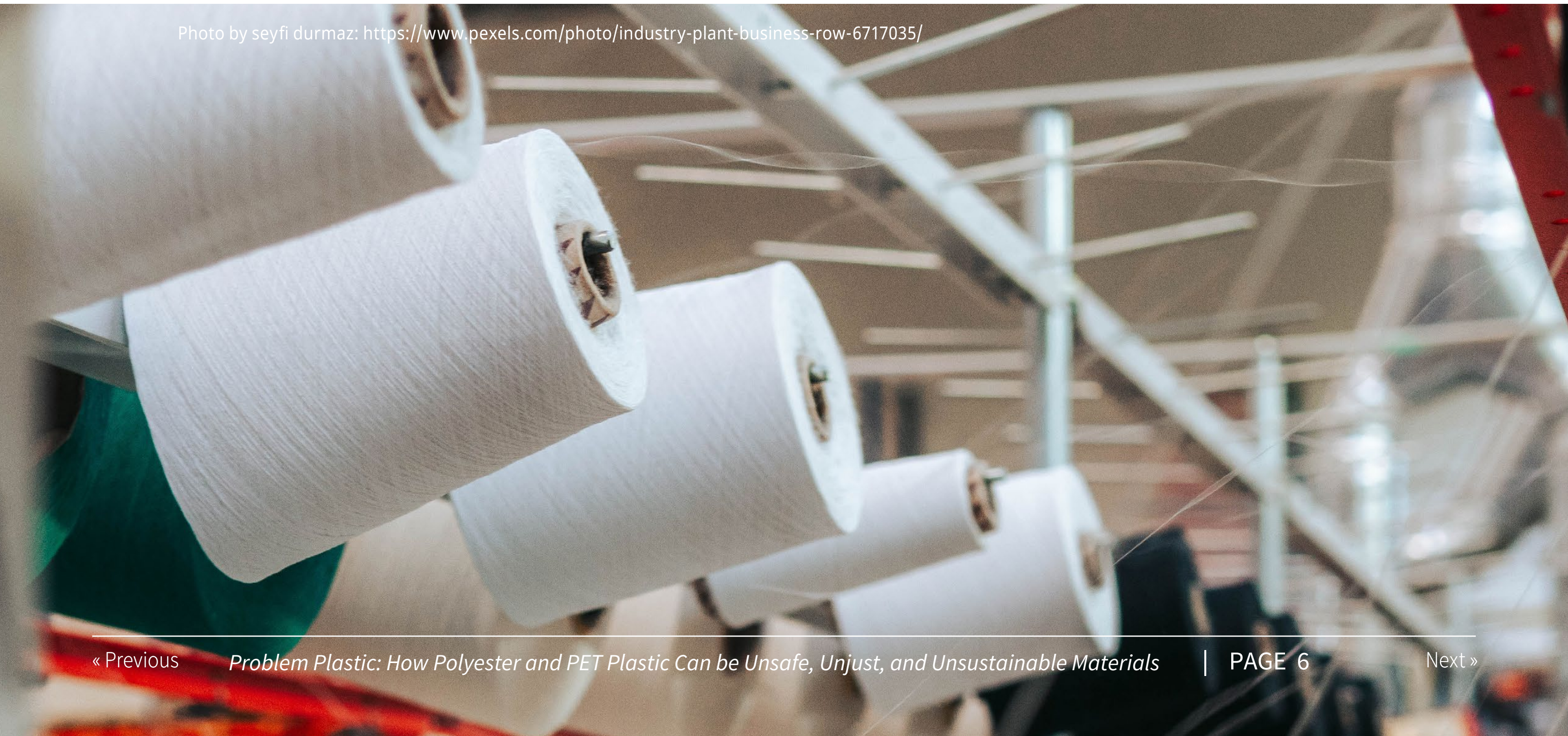

Photo by seyfi durmaz: https://www.pexels.com/photo/industry-plant-business-row-6717035/

Problem Plastic? Polyester and PET

PLASTIC POLLUTION IS IN OUR HOMES AND BODIES

Common plastic products made of **PET and polyester often contain antimony** that disproportionately harms the health of babies, children, and people of color. Everyday products made with antimony include many cuddly toys, soda and water bottles, and polyester clothing.

Your plastic bottle is more than just plastic. It's a mix of all sorts of chemical additives and toxic byproducts, many of which can escape from the plastic. PET, also known as polyester, often contains **antimony, a toxic metal**. Health authorities try to limit our exposure to antimony, but too much is escaping from the plastics all around us.

PET plastic and polyester contribute to environmental racism and injustice. Nationwide, Latinx and Black consumers are exposed to higher levels of antimony than white Americans.

Why is PET harmful?

PET Plastic and Polyester are different forms of the same plastic *(polyethylene terephthalate).* Antimony is one of many chemicals used to make PET; some of them are known to be toxic. These chemicals:

⚠ can increase risk of liver and heart disease
⚠ may cause lung and breathing problems
⚠ are linked with cancers
⚠ interfere with endocrine and hormone health

⚠ BABIES & KIDS AT HIGH RISK

Some **children are exposed daily to nearly double the safe limit for antimony** set by the US EPA, and six times the California standard.

How are kids exposed to so much antimony? One reason is likely the **antimony in many plastic products**, including **toys that babies suck on**. And due to their frequent hand-to-mouth activity, they may also ingest antimony shed from everyday plastics into household dust.

⚠ HIGH LEVELS OF ANTIMONY FOUND IN BEVERAGES

We tested drinks in plastic bottles from **Coca-Cola, Pepsi, Keurig Dr Pepper,** and other major brand owners.

🟥🟥🟥🟥⬜⬜⬜⬜⬜⬜

40% **of the PET bottled beverage samples we tested had concentrations of antimony that exceeded the California Public Health Goal for drinking water.** Daily exposure above this amount may cause liver disease.

⚠ ANTIMONY IN POLYESTER CLOTHES

🟥🟥🟥🟥🟥🟥⬜⬜⬜⬜

60% of all clothing currently produced has polyester.

Clothing and textiles can break down with use, which may **shed microplastics and antimony** in our homes, build up in dust, and may enter our bodies when we breathe, eat, and touch things around us.

We're making sure powerful corporations get rid of toxic antimony in their plastic products—it's a first step towards completely phasing out dangerous petrochemical plastics.

Will you join us? Read the report to learn more: https://defendourhealth.org/campaigns/plastic-pollution/problem-plastic/

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CHAPTER 1

Tackling Petrochemical Pollution, One Plastic at a Time

Plastics are found everywhere in our homes and lives. Cheap, light-weight, and functional – petrochemical plastics made from crude oil and natural gas have displaced forest products, natural fibers, and common metals as the raw material of choice for many manufacturers. Plastics dominate much of our materials economy, with widespread use in building products, transportation, appliances, apparel and footwear, consumer goods, packaging, food processing and more.

About 475 million metric tons of plastic were produced globally in 2019. (See Table 1-2). It's hard to fathom the magnitude of such a number. What are some equivalent amounts?

Consider that more plastics are produced in just one year than the total weight of:

- **Every person [2] on Earth, with a global population of nearly 8 billion people [3];**
- **589 Golden Gate Bridges [4]; or**
- **91 Great Pyramids of Giza [5].**

But a one-year snapshot doesn't capture the ever-increasing volume of plastics produced every year, a phenomenon known as exponential growth. Twice as much plastics entered commerce in 2020 than were produced barely twenty years ago; but annual plastics production has increased ten times in less than 50 years and more than 200 times in the last 70 years [6]. If recent petrochemical industry growth projections hold, global plastics production will double again by 2040 [7].

It's no wonder that plastic pollution has reached crisis proportions. About 70% of all plastics ever produced between 1950 and 2015 have become waste while 30% still remain in use; For that wasted plastic, only 9% has ever been recycled (usually only once) with 12% incinerated and 79% of all plastics discarded in landfills and the natural environment [6].

"I want to say one word to you. Just one word. … Plastics!"

– The Graduate, 1967 [1]

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Plastic waste dominates the public and political perception of plastic pollution

All plastic becomes waste over time (Table 1-1). Single-use packaging draws immediate attention for its extreme wastefulness and its large share of petrochemical plastics production. All other uses of plastics also add to the growing mountains of plastic waste every year, just on a more slowly unfolding timescale. Due to high production volumes, plastics used for building and construction materials, clothing and other textiles, and consumer goods, also generate huge volumes of plastic waste.

Most plastic waste is mismanaged. Globally, nearly 20% of single-use packaging and other short-lived plastics are directly discarded to land and ocean, with another 22% of this plastic waste openly burned [8], a major source of dioxins and other highly toxic air emissions [9]. Even "managed" plastic waste creates avoidable environmental impacts, with about 30% of short-lived plastic waste destined for landfills and another 13% to incinerators, both of which pollute surrounding communities.

Gut-wrenching images of sea turtles and birds choking to death from plastic waste have galvanized public outrage and global political response. Although much public attention has been focused on beaches littered with plastic packaging, other forms of plastic waste mismanagement also result in tragic consequences for human health and the environment.

A growing addiction to synthetic fibers and short-lived 'fast fashion' has fueled continuously burning piles of "waste" polyester clothing in the global south [10]. The nominal "recycling" of e-waste in Asian countries has poisoned children and pregnant women with lead, dioxins and other chemical pollutants when scrap electronics full of plastics are burned to recover precious metals [11]. Plastics, including highly-polluting polyvinyl chloride (PVC), make up a growing fraction of construction and demolition waste, which often ends up in unlined landfills or being openly burned [12].

Table 1-1. All uses of plastic generate waste

PLASTIC USE SECTORS	PRODUCTION SHARE, 2015	LIFESPAN AT PEAK WASTE (IN YEARS)
Packaging	**35%**	1
Consumer & Institutional	**11%**	3
Textiles	**16%**	5
Other Plastic Uses	**12%**	5
Electrical & Electronic	**4%**	8
Transportation	**5%**	13
Industrial Machinery	**<1%**	20
Building & Construction	**17%**	35

Adapted from Geyer et al. (2017) [6]

The shameful waste of plastics and its impacts does not tell the whole story. Even more harm occurs before plastic becomes trash.

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Plastic pollution reframed: Environmental health and climate justice threat

Consider these trends and growing impacts from the production, use, and disposal of petrochemical plastics:

- **The plastics industry emissions of greenhouse gas emissions**, currently equivalent to about 200 coal-fired power plants, will continue to grow until plastics account for at least 10% to 15% of the entire fossil carbon budget by 2050 [13];
- Of the more than 10,000 **chemicals used to make plastics**, about 24% pose known **hazards to human health or the environment**, while data gaps leave us in the dark about the safety of another 39% of plastics-related chemicals [14]; and
- **In a classic case of environmental injustice, petrochemical manufacturing plants** in the United States are often located in communities that are home to mostly people of color and/or lower income residents who are already heavily over-burdened by industrial pollution, according to a recent analysis [15] and prior studies [16,17] of fossil fuel racism.

It's time to reframe plastic pollution as a critical environmental health and climate justice threat, not simply as an unsightly mess of plastic waste. The fossil carbon industry has bet its future growth prospects on rising demand for petrochemical plastics [18], hoping to offset their losses in other markets to electric vehicles and renewable energy.

The stark implications of this petrochemical industry vision mean ever-increasing climate change, harm to human health, environmental injustice, and plastic waste. But acting together, we can build an alternate future in which the materials we need for our daily lives and prosperity are truly safe, just and sustainable.

Getting there will require a radical reduction in the extraction, production, use, and disposal of fossil-carbon plastics. This report suggests that the leverage needed to drive change can be enhanced by better connecting the lifecycle impacts of plastics to specific market uses. By holding major brand-owners and institutional consumers accountable, we can slash demand for petrochemical plastics and achieve a truly sustainable future.

Why take a deep dive into one plastic, PET resin and polyester fiber?

This report launches the first in a series of independent investigations that take a lifecycle approach to better understanding the full impact of plastics on human health, social justice, climate change, and resource sustainability. Since not all plastics are created equal – they vary widely by chemistry and lifecycle impacts – separate lines of inquiry are needed for different plastics.

This report begins that process by examining just one major type of plastic known as **polyethylene terephthalate**, often abbreviated as **PET or PETE**, and commonly referred to as **polyester** when it's spun into fibers.

You know PET as the most common plastic used in beverage bottles and polyester clothing. Its resin identification code is the number "one" that's often stamped inside of a triangle on the bottom of the bottle and other packaging. Polyester dominates the fiber market for clothing and other textiles. Almost all "polyester" is actually PET plastic.

This report profiles the toxic hazards, environmental injustice, and climate impacts associated with PET/polyester plastic across its lifecycle with an emphasis on its manufacturing and consumer impacts. The methods pioneered here will be applied to characterizing other plastics in future reports.

By exposing the lifecycle impacts of PET plastic, we hope to spur action to eliminate unnecessary uses, and substitute its remaining use with materials and functional strategies that are safer, more just, and more sustainable for people and the planet.

For many people, PET plastic enjoys an undeserved reputation as a minor commodity plastic, the transparent clarity of which implies a seemingly clean and benign material. The fact that PET is highly recyclable, and that more plastic bottles are recycled than any other plastic packaging, add to its appeal. The public disconnect between PET plastic resin and polyester fibers, which are chemically the same plastic, helps to fragment our understanding of its impacts.

This misperception of PET as a perfect plastic belies the breadth and depth of its hazards. Here are three reasons that justify an in-depth investigation of the PET plastic lifecycle;

1. PET plastic is actually the highest volume plastic, contrary to some reporting

Accounting for all uses, more PET plastic is produced and consumed than any other single type of plastic. Table 1-2 shows that by accounting for all plastic fibers in addition to plastic resins, PET tops the chart. More than 83 million metric tons of PET were produced in 2019, accounting for about 19% of all plastics production. Two-thirds of all PET is used in the form of polyester fiber for clothing and other textiles.

Table 1-2. Polyester (PET) Dominates the Production of Petrochemical Plastics

TYPE OF PLASTIC			PLASTIC PRODUCTION (2019) (IN MILLION METRIC TONS)			
ACRONYM	SOME COMMON OR BRAND NAMES	CHEMICAL NAME	RESIN	FIBER*	TOTAL	PERCENT TOTAL
PET	Polyester	Polyethylene terephthalate	21.5	61.9	83.4	**19%**
PP	Polypro, Typar®	Polypropylene	70.7	4.5	75.2	**17%**
LDPE **LLDPE**	Poly	Low-density polyethylene Linear low-density polyethylene	52.3	-	52.3	**12%**
PVC	Vinyl	Polyvinyl chloride	49.2	-	49.2	**11%**
HDPE **MDPE**	Poly, Tyvek®	High-density polyethylene Medium-density polyethylene	46.1	Some Tyvek	46.1	**10%**
PS **EPS** **HIPS**	Styrofoam™	Polystyrene Expanded polystyrene High impact polystyrene	21.5	-	21.5	**5%**
PUR	Polyurethane	Polyurethane resins Polycarbamates	18.4		18.4	**4%**
ABS **ASA** **SAN**		Acrylonitrile butadiene styrene Acrylonitrile styrene acrylate Styrene-acrylonitrile copolymer	11.0	-	11.0	**3%**
PA	Nylon	Polyamides	3.7	5.4	9.1	**2%**
PLA	Bioplastics	Polylactic acid & other bioplastics	3.0	1.2	4.2	**1%**
PC		Polycarbonate	3.7	-	3.7	**1%**
-		Other fossil-based thermoplastics	14.7	2.2	16.9	**4%**
Other plastics: thermosets (other than PUR), elastomers, rubbers, adhesives, sealants, paints, and coatings			56.1	-	56.1	**13%**
TOTAL Plastic Resin and Fiber Production			**366.5**	**75.2**	**441.7**	**100%**
Total Plastic Additives Production:					33.2	
TOTAL Plastics Production (million metric tons in 2019):					475	

* Excludes semi-synthetic cellulosic fibers, such as cellulose acetate and rayon

Sources: Englehardt (2020) [35], Geyer et al. (2017) [6], Nonwovens Industry (2016) [36], PlasticsEurope Market Research Group (2016) [37], PlasticsEurope (2020) [38], PlasticsEurope (2021) [39], Skoczinski et al. (2021) [40], Textile Exchange (2021) [41].

Yet most plastic waste reports undercount total production by including only plastic resins while ignoring the use of plastics to make fibers for clothing and other uses. For example, the annual PlasticsEurope market research report remains the go-to resource for reporting on the global production of plastics, yet it explicitly excludes plastic fibers. A full accounting of plastic and its impacts must examine all uses of plastics, including both resins and fibers.

Total production of PET exceeds that of each of the other major commodity plastics: polypropylene, low-density polyethylene (LDPE), polyvinyl chloride (PVC), and high-density polyethylene (HDPE).

2. PET, including polyester, is a major source of plastic waste

PET is the most commonly recycled plastic at the end of its short life as a consumer product. In North America, about 34% of all PET resin used for bottles, packaging, sheets, and strapping was recycled, more than any other plastic, in 2020 [19]. However, less than 1% of PET-based polyester fiber used for clothing and other textiles is currently recycled [20].

Therefore, the total PET recycling rate is only about 11%, when you take into account the fact that polyester fiber accounts for two-thirds of all PET production. As a raw material, recycled PET (rPET), almost entirely derived from plastic bottles, supplied nearly 14% of all PET fiber in 2020 [21]. The dominant use for rPET is polyester fiber, accounting for 41% of the entire rPET market [21].

That means that nearly 90% of all PET (including polyester) still ends up as plastic waste that’s landfilled, burned, or discarded onto land and water.

In fact, PET remains the most common plastic waste that litters our landscape, beaches, and oceans. PET was the second most frequently collected type of plastic waste in 55 countries in a brand audit coordinated by Break Free From Plastic, a global NGO network [22]. (The mixed category of “other” plastics was number one.) Nearly 82,000 pieces of identifiable PET plastic were collected, with about 60% consisting of plastic bottles. The same audit found that plastic bottles, which are mostly made of PET, was the third most common plastic waste product collected (following small flexible packages commonly referred to as sachets, and cigarette butts.)

The clothing industry, whose fiber of choice is polyester, is terribly polluting and wasteful, with 73% of fiber ending up in being landfilled or incinerated with another 14% lost during production and processing [23].

3. Some chemicals involved in producing PET plastic are highly hazardous

> *"In the 60 years since PET was first synthesized, it has become one of the world's most widely used, versatile and trusted materials." — PET Resin Association* [24]

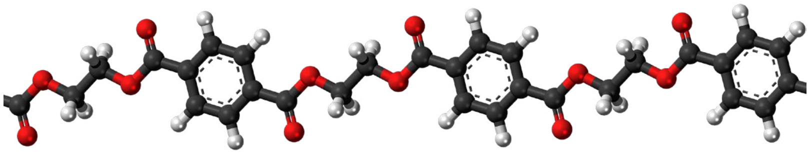
The chemical industry's confidence is unwarranted if one 'looks under the hood' of PET plastic. In fact, hundreds of hazardous chemicals are associated with the production, use, and disposal of PET plastics.

Consider a few selected facts, which are documented and discussed later in this report:

- Compounds of **antimony and cobalt, which are known to cause cancer** [25] **and organ toxicity** [25]**, are commonly used as processing aids or additives in PET and often escape from PET products** [26,27], resulting in human exposure from consuming plastic-bottled beverages [28] and when teething toddlers suck and chew on polyester cuddly toys, blankets, and clothing [28, 29];

- Among several other carcinogens, **ethylene oxide and 1,4-dioxane** [32]**, are routinely emitted into the air and discharged as waste from PET-related chemical manufacturing plants**, which often disproportionately impact nearby communities of color and lower-income residents [30];

- A building block chemical used to make PET plastic, **ethylene glycol, is a reproductive toxicant** [32] that can harm development of a fetus or baby if pregnant chemical workers or fenceline community residents are exposed [31].



Model of a section of the polyethylene terephthalate polymer, also known as PET.
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How this Report is Organized

This introduction (Chapter 1) summarizes the growing concern with plastic pollution and makes the case for a deeper examination of the lifecycle impacts of PET plastic resin and polyester fiber.

Chapter 2 provides a brief overview of the PET market, highlighting the major uses from a consumer perspective. The PET chemical supply chain in North America is mapped, while also highlighting some aspects of the global supply chain. The corporations that produce PET-related petrochemicals and PET plastic, both resin and fiber, are also identified.

Chapter 3 profiles what's known about the hazards of chemicals associated with PET plastic, with an emphasis on known human exposures and health risks from a consumer perspective. Many chemical substances are intentionally introduced into PET plastic to facilitate manufacturing, to add desirable properties, or to mitigate against undesirable properties. Here we take a close look at antimony, the dominant polymerization catalyst for PET, and cobalt. We reveal the results of our testing of PET plastic bottles and beverages for antimony and other additives.

Chapter 4 offers conclusions and recommendations based on our analysis. Some next steps are immediately actionable.

Future investigative reports will profile the toxic hazards and environmental injustice of the PET plastic manufacturing lifecycle and issues raised by over-reliance on PET recycling strategies. Other plastics will also be investigated.

A Note on Methodology

This report was prepared using the best data and other information readily available from reliable and authoritative sources.

Wherever practicable, we summarize and cite scientific research papers from peer-reviewed journals to back up the facts reported herein. We also relied on government technical reports and reference various public health goals or other health-protective measures adopted by authoritative government agencies. Some technical material and documentation are included in the Appendices.

For hazard characterization, we applied the GreenScreen® for Safer Chemicals [32], a comparative hazard assessment tool, and the Pharos chemical hazard database [33]. Both of these follow the Global Harmonized System of Classification and Labelling of Chemicals [34] and rely on authoritative lists of chemical hazards developed around the world.

Industry-reported data and other industry sources are also extensively referenced. Several governmental databases, often populated by industry-reported data, were also accessed, especially for mapping toxic hazards across the manufacturing lifecycle.

Portions of this report were reviewed by outside experts, and their comments incorporated. We strove for complete accuracy and take responsibility for any errors or critical omissions.

Endnotes

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CHAPTER 2

The PET Plastic Market – from Petrochemicals to Fast Fashion and Plastic

Key Findings:

Polyethylene terephthalate (PET) is the same polymer in both polyester fiber used to make clothing and textiles and in plastic resin used for bottles and other packaging

About 99% of PET is derived from non-renewable **fossil carbon** extracted by drilling for crude oil (the source of 80% of PET's carbon) and fracking for natural gas (20%)

Making PET plastic requires use of large amounts of toxic petrochemicals, including:
- About 90% of all ***para*-xylene**, which is toxic to the nervous system
- About 80% of all **monoethylene glycol**, which can cause breathing problems
- About 50% of all **ethylene oxide**, known to cause breast cancer & lymphomas

More than 30 chemical plants directly supply petrochemicals used to make PET plastic in North America, with most located in the Gulf Coast states of **Texas** and **Louisiana**

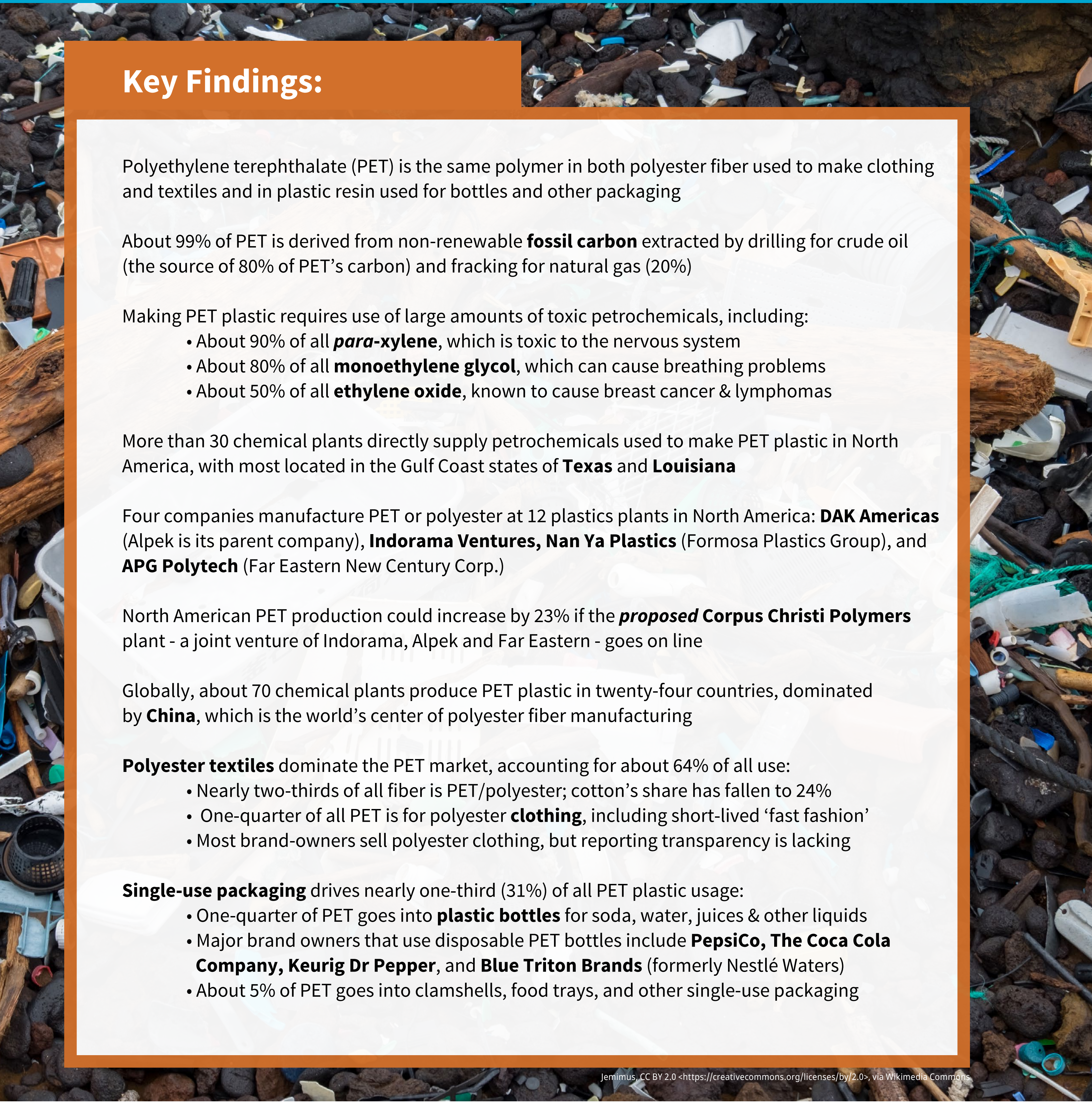
Four companies manufacture PET or polyester at 12 plastics plants in North America: **DAK Americas** (Alpek is its parent company), **Indorama Ventures, Nan Ya Plastics** (Formosa Plastics Group), and **APG Polytech** (Far Eastern New Century Corp.)

North American PET production could increase by 23% if the ***proposed* Corpus Christi Polymers** plant - a joint venture of Indorama, Alpek and Far Eastern - goes on line

Globally, about 70 chemical plants produce PET plastic in twenty-four countries, dominated by **China**, which is the world's center of polyester fiber manufacturing

Polyester textiles dominate the PET market, accounting for about 64% of all use:
- Nearly two-thirds of all fiber is PET/polyester; cotton's share has fallen to 24%
- One-quarter of all PET is for polyester **clothing**, including short-lived 'fast fashion'
- Most brand-owners sell polyester clothing, but reporting transparency is lacking

Single-use packaging drives nearly one-third (31%) of all PET plastic usage:
- One-quarter of PET goes into **plastic bottles** for soda, water, juices & other liquids
- Major brand owners that use disposable PET bottles include **PepsiCo, The Coca Cola Company, Keurig Dr Pepper**, and **Blue Triton Brands** (formerly Nestlé Waters)
- About 5% of PET goes into clamshells, food trays, and other single-use packaging



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What is PET plastic and how is it made?

Polyethylene terephthalate (PET) is a typically clear, strong, and lightweight plastic widely used as polyester fiber for clothing and other textiles, and as a plastic resin for bottles and other single-use packaging. More PET is produced, used, and disposed of than any other single type of plastic when both its resin and fiber forms are counted together [a].

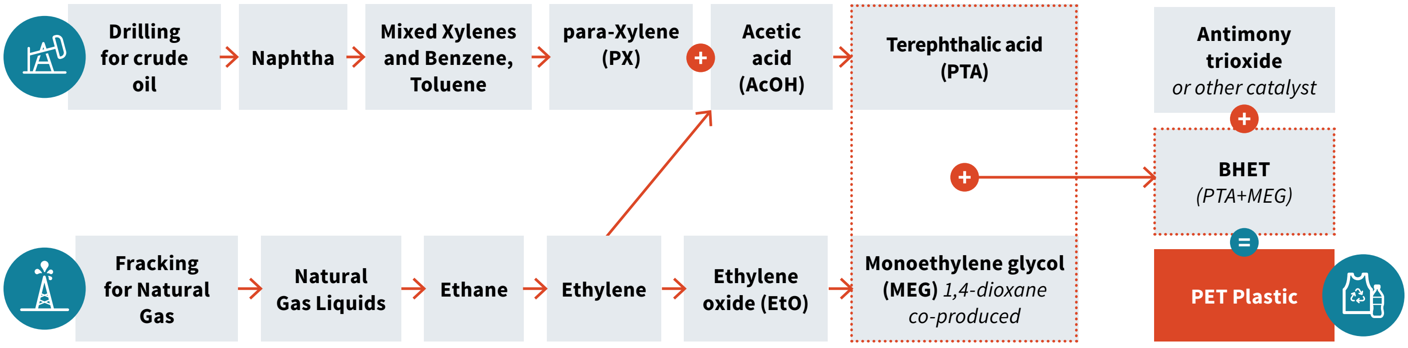
PET was first patented more than eighty years ago by British textile chemists. In 1951, the chemical company DuPont trademarked a polyester film known as Mylar. We're now approaching the 50th anniversary of the PET plastic bottle, which was invented by a DuPont engineer in 1973 [1].

As a polymer, PET is a linked chain of repeating chemical units known as monomers. The typical final building blocks of PET are the chemicals known as **monoethylene glycol** (MEG) and **purified terephthalic acid** (PTA), which are combined to form the monomer, **bis(2-hydroxyethyl) terephthalate** (BHET). With the addition of a catalyst, typically **antimony trioxide**, to speed up the reaction, the BHET monomer is polymerized, or linked together in a chain, to form PET plastic [2].

The chemical footprint of PET plastic, however, is much larger than just those substances. It also includes all the petrochemicals used to make those building block chemicals and the carbon sources they are derived from, typically crude oil and natural gas, as well as all the chemical additives and processing aids used to fine tune the properties of the final plastic products.

A simplified process flow diagram shows the steps used to make PET plastic (Figure 2-1). Multiple petrochemical plants located in many different communities are involved in PET plastic production. Some refine the crude oil or process the natural gas. Some use those fossil carbon extracts to manufacture the primary or intermediary chemicals. And some plants combine those final building block chemicals with additives to form PET resin or fibers.

Figure 2-1. Almost all PET Plastic is Made with Fossil Carbon from Oil and Gas



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[a] See Chapter 1. PET has the highest volume production of any plastic when the two major types of polyethylene, high-density and low-density, which have very different applications, are counted separately.

Today, more than 99% of all PET plastic is originally derived from fossil carbon extracted from the ground as crude oil and natural gas [3]. Eighty-percent of the carbon in PET comes from drilling for crude oil used to make the para-xylene that's converted to PTA. Fracking for natural gas contributes the other 20% of PET's fossil carbon, generating ethane which is converted to ethylene, then to ethylene oxide to make MEG.

Despite more than a decade of hype about the climate-friendly "plant bottle," only a fraction of 1% of all PET is currently biobased, which means the carbon is sourced from renewable plant material such as corn starch or sugar cane. Biobased MEG is commercially available and used to manufacture a small amount of PET for bottles, making each "plant bottle" about 30% biobased by weight of raw materials; the rest of the raw materials are still petroleum-based. Renewable chemical companies are also working to commercialize biobased para-xylene in order to produce 100% biobased PET [4].

It takes large amounts of petrochemicals to produce PET plastic. In fact, this plastic accounts for more than 80% of the production and use of two toxic petrochemicals, para-xylene and monoethylene glycol (Table 2-1). PET plastic also consumes more than half (53%) of all ethylene oxide produced, a cancer-causing substance that's also used as a sterilant [b]. Further, about 6% of all antimony trioxide (ATO) produced is used as the dominant catalyst to speed the final reaction that produces PET resin and fiber [c]. Antimony is a metal-like element that's mined from the Earth as an ore and processed to produce antimony trioxide.

Table 2-1. Production of PET Plastic Drives the Market for Hazardous Petrochemicals

CHEMICAL NAME		USED FOR PET	SOME HUMAN EXPOSURE HAZARDS	VULNERABLE GROUPS
para-Xylene	**(PX)**	**80% [5] to 97% [6]**	Neurological and respiratory effects [7]	Workers, Children of Workers, Fenceline Community
Monoethylene glycol	**(MEG)**	**80% [8] to 84% [9]**	Respiratory irritation, fetal toxicity [10]	
Ethylene oxide	**(EtO)**	**53 %** [d]	Cancer (breast, leukemia, lymphomas) [11]	
Antimony trioxide	**(ATO)**	**6 %** [12]	Cancer (lung and other organs) [13] Systemic organ toxicity (liver, heart) [14]	Workers, Consumers, Fenceline Community

Who makes PET plastic and where do they do it?

A long chemical manufacturing supply chain exists between fossil carbon extraction and final production of PET plastic resin and polyester fiber.

More than 30 chemical plants are known to supply the petrochemicals that are essential to the production of PET plastic in North America (Table 2-2) [e]. PET-related petrochemical production is concentrated in the Gulf Coast states of Texas and Louisiana and in the Province of Alberta, Canada. Of these 30 plants that produce PET precursor chemicals, six also produce PET: The five petrochemical plants operated by DAK Americas (and owned by Alpek), and the Indorama Ventures chemical plant in Decatur, Alabama.

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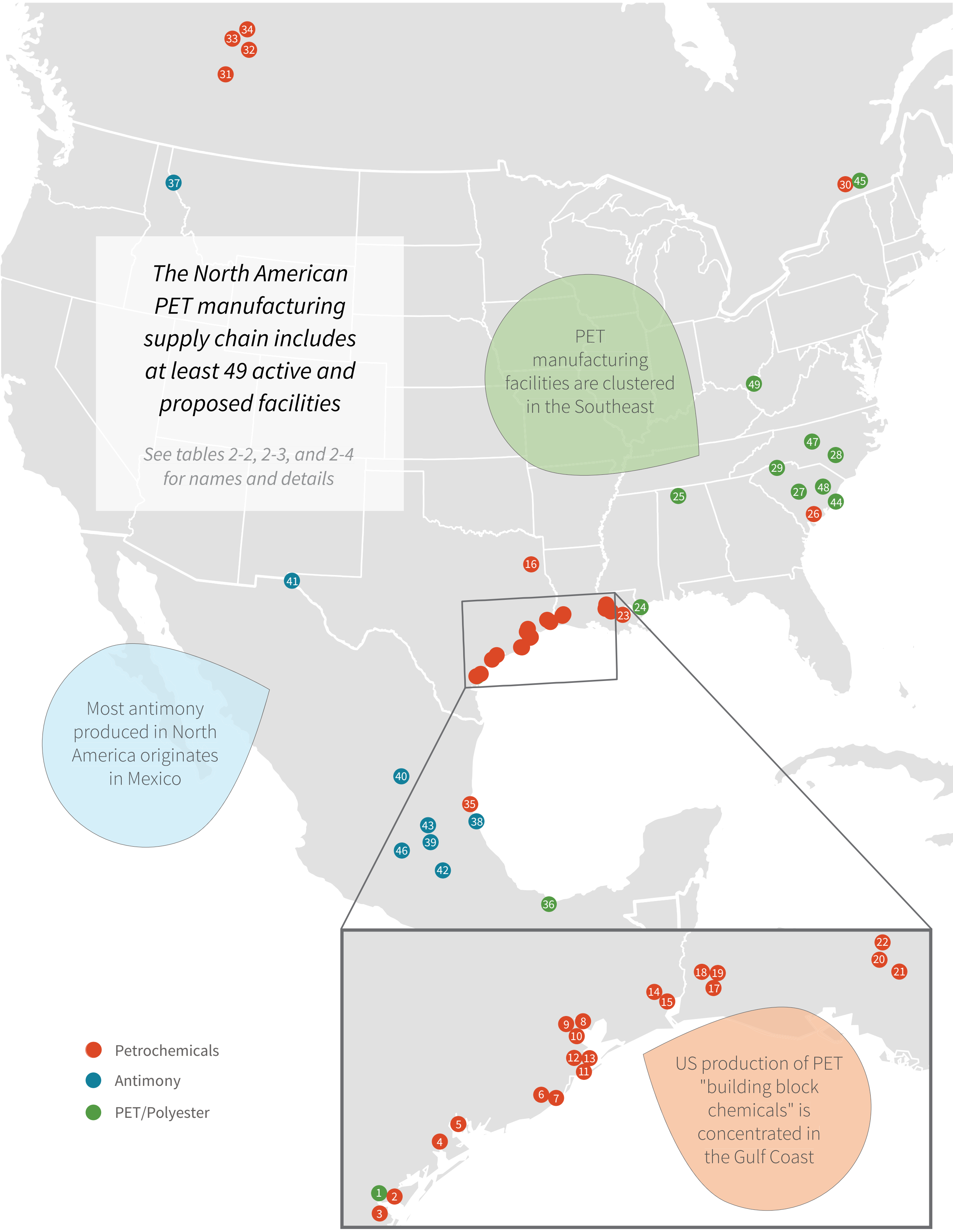
[b] Ethylene oxide is an intermediate chemical produced from ethylene and then converted to monoethylene glycol, an essential PET building block substance.

[c] About 60% of all uses of ATO are as a plastic additive, but mostly to boost the flame retardant properties of PVC plastic and other flame retardant chemicals added to many other plastics.

[d] See source at Endnote 9, which says that 72% of ETO is used to make ethylene glycol, 90% of which is MEG.

[e] This information was obtained from various government and industry sources in the public domain.

Fig 2-2. Locations of PET Plastic and Polyester manufacture and associated Petrochemical and Antimony Suppliers in North America


The North American PET manufacturing supply chain includes at least 49 active and proposed facilities

See tables 2-2, 2-3, and 2-4 for names and details

PET manufacturing facilities are clustered in the Southeast

Most antimony produced in North America originates in Mexico

US production of PET "building block chemicals" is concentrated in the Gulf Coast

Table 2-2. Petrochemical Plants Known to Supply PET Plastic Production in North America

CHEMICAL COMPANY (Joint Venture Partners or Parent Company) *NOTE: Proposed chemical plants are highlighted in italics*	CHEMICAL PLANT LOCATION (City, State/Province, Country)			CHEMICAL PRODUCED					
				Eth	**EtO**	**MEG**	**PX**	**AcOH**	**PTA**
COASTAL BEND OF SOUTH TEXAS									
1. Corpus Christi Polymers (Alpek, Indorama, FarEast NC)	Corpus Christi	*TX*	*US*						*X*
2. Exxon Mobil / SABIC	Corpus Christi	TX	US	X	X	X			
3. Flint Hills Resources (Koch Industries)	Corpus Christi	TX	US				X		
4. Dow Chemical	Seadrift	TX	US		X	X			
5. Formosa Plastics	Point Comfort	TX	US		X	X			
GALVESTON BAY AREA / HOUSTON SHIP CHANNEL									
6. Dow Chemical	Freeport	TX	US	X					
7. MEGlobal (Dow Chemical / Petrochemical Industries)	Freeport	TX	US			X			
8. ExxonMobil Chemical	Baytown	TX	US				X		
9. Indorama Ventures	Clear Lake	TX	US		X	X		X	
10. Celanese	Pasadena	TX	US			X		X	
11. Ineos Aromatics	Texas City	TX	US				X		
12. Eastman Chemical	Texas City	TX	US					X	
13. Marathon Oil	Texas City	TX	US				X		
GOLDEN TRIANGLE (SOUTHEAST TEXAS) AND EAST TEXAS									
14. ExxonMobil Chemical	Beaumont	TX	US				X		
15. Indorama Ventures	Port Neches	TX	US		X	X		X	X
16. Eastman Chemical	Longview	TX	US		X	X			
LAKE CHARLES AREA OF SOUTHWEST LOUISIANA									
17. Indorama Ventures	Westlake	LA	US	X					
18. LACC (Lotte Chemical / Westlake Chemical)	Westlake	LA	US	X	X	X			
19. Sasol	Westlake	LA	US		X	X			
CANCER ALLEY, LOUISIANA AND GULF COAST MISSISSIPPI									
20. Dow Chemical	Plaquemine	LA	US		X	X			
21. Shell Chemical	Geismar	LA	US		X	X			
22. Formosa Plastics	Welcome	*LA*	*US*		*X*	*X*			
23. Dow Chemical	Taft	LA	US		X	X			
24. DAK Americas (Alpek)	Bay St. Louis	MS	US						X
NORTHERN ALABAMA AND THE CAROLINAS									
25. Indorama Ventures	Decatur	AL	US				X		X
26. Ineos Aromatics	Cooper River	SC	US				?		X
27. DAK Americas (Alpek)	Gaston	SC	US						X
28. DAK Americas (Alpek)	Fayetteville	SC	US						X
CANADA									
30. Indorama Ventures	Montréal-Est	QC	Can						X
31. Dow Chemical	Fort Saskatchewan	AB	Can	X					
32. MEGlobal (Dow Chemical / Petrochemical Industries)	Fort Saskatchewan	AB	Can			X			
33. MEGlobal (Dow Chemical / Petrochemical Industries)	Red Deer	AB	Can			X			
34. Shell Chemical	Scotford	AB	Can			X			
MEXICO									
35. DAK Americas (Alpek)	Altamira	TA	Mex						X
36. DAK Americas (Alpek)	Cosoleacaque	VC	Mex						X

KEY: Eth = Ethylene; EtO = Ethylene oxide; MEG = Monoethylene glycol; PX = para-Xylene; AcOH = Acetic acid; PTA = Purified terephthalic acid

Numbers correspond to points on map (Fig 2-2)

In addition to the building block chemicals used to make the PET monomer, many other chemical substances are added to PET plastic as additives and processing aids. One major processing aid involved in the PET life cycle is antimony trioxide (ATO), which is the dominant PET polymerization catalyst. Most of the antimony trioxide produced in North America starts as antimony ore that's mined and processed in Mexico, which is then used to produce ATO in Montana by the United States Antimony Corporation in amounts of up to 15 million pounds per year (Table 2-3) [15]. (See Chapter 3 for more on PET plastic additives including antimony compounds.)

The final PET plastic resin or polyester fiber is produced by reacting MEG and PTA together with a catalyst such as ATO, along with other additives and processing aids.

Table 2-3. A Sole Antimony Producer in North America Supplies PET Plastic Catalyst

COMPANY	FACILITY	LOCATION		
37. United States Antimony	Smelter	Thompson Falls	MT	United States
38. United States Antimony	Smelter	Madero	CH	Mexico
39. United States Antimony	Leach Plant	Puerto Blanco	GJ	Mexico
40. United States Antimony	Mine, Mills	Wadley	SL	Mexico
41. United States Antimony	Mine	Los Juarez	QE	Mexico
42. United States Antimony	Mine	Sierra Guadalupe	ZA	Mexico
43. United States Antimony	Mine	Soyatal	QE	Mexico

Numbers correspond to points on map (Fig 2-2)

In North America, four multinational corporations (headquartered in Asia and Mexico) manufacture PET plastic at 12 different chemical plants (Table 2-4). Two-thirds (8) are located in the Southeast U.S., close to the textile industry that produces polyester fabric. Two are based in the Gulf Coast in Mississippi and Veracruz, Mexico. Together they have the capacity to produce more than 4.7 million tons of PET plastic resin and fiber every year.

Globally, PET production and polyester textile manufacture is dominated by the chemical industry in China. Outside of North America, about 70 chemical plants produce PET plastic in twenty-four countries, with the largest number (16) of manufacturers located in China.

Table 2-4. Four Chemical Companies Dominate PET Plastic Production in North America

COMPANY NAME	PARENT COMPANY, (OWNER), COUNTRY	# MFG. PLANTS	PLANT LOCATIONS (WITH MAP NUMBER) (rank-ordered by production capacity)	TOTAL CAPACITY (1,000 TONNES/YEAR)	MARKET POSITION
DAK Americas LLC	Alpek S.A. de C.V. (owned in turn by Alpha S.A.B. de C.V.), Mexico	6	**27. Gaston, South Carolina, USA** **24. Bay St. Louis, Mississippi, USA** **28. Fayetteville, North Carolina, USA** **44. Cooper River, South Carolina, USA** **45. Montréal-Est, Québec, Canada** **36. Cosoleacacque, Veracruz, Mexico**	2,177	Main producer of polyester staple fibers in Americas; Major global PET resin producer
Indorama Ventures Public Company Ltd.	(Thailand): Canopus International, Mauritius (offshore)	4	**46. Santiago de Querétaro, QR, Mexico** **25. Decatur, Alabama, USA** **29. Spartanburg, SC, USA** **47. Asheboro, North Carolina, USA**	1,760	World's largest PET producer with 20 plants in 14 countries
Nan Ya Plastics Corporation USA	Formosa Plastics Group, Taiwan	1	**48. Lake City, South Carolina, USA**	450	Nan Ya's largest chemical plant; Taiwan's largest plastics maker
APG Polytech USA Holdings	Far Eastern New Century Corporation (Far Eastern Group), Taiwan	1	**49. Apple Grove, West Virginia, USA** [16]	360	A major producer of synthetic fibers and textiles in Asia
TOTAL PET CAPACITY IN NORTH AMERICA:		**12**	**PET manufacturing plants**	**4,747**	
Corpus Christi Polymers LLC	A joint venture of Indorama, Alpek, and Far Eastern NC	*1 planned*	**1. Corpus Christi, Texas, USA** [17]	*1,100*	***Proposed** plant would increase PET capacity by 23% in North America*

Numbers correspond to points on map (Fig 2-2)

> *"In North America, four multinational corporations manufacture PET plastic at 12 different chemical plants. Together they have the capacity to produce more than 4.7 million tons of PET plastic resin and fiber every year."*

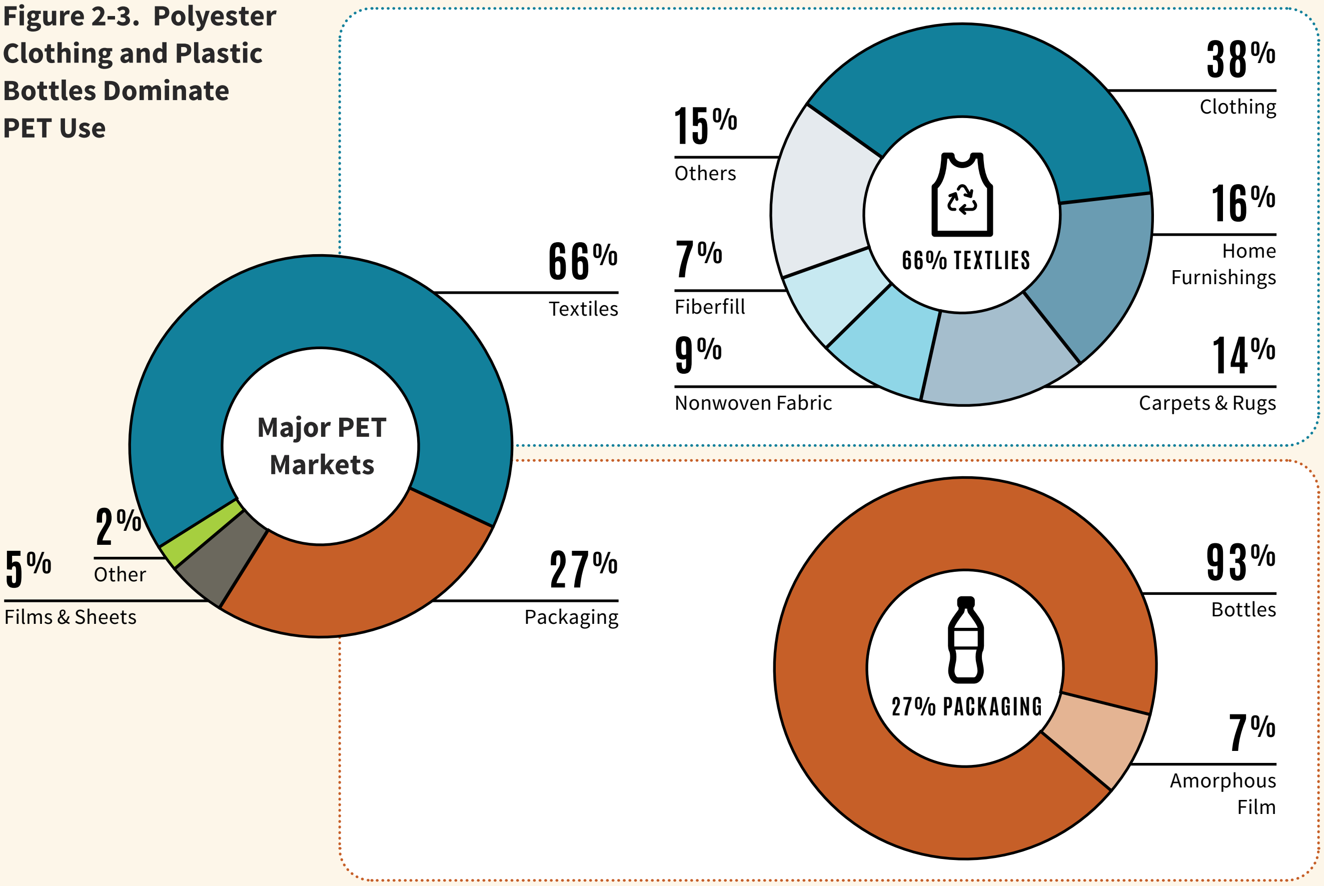
Petrochemical plastics production keeps expanding

Plastics production has grown exponentially in the last 70 years and doubled again in just the last 25 years [18]. Many industry analysts are bullish on an ever-increasing demand for petrochemical plastics, including PET. Polyester production is pegged to grow 8% annually through 2027 [19]. Others project a 4% to 6% annual growth rate for PET, including plastic bottles, through 2028 [20,21].

The petrochemical industry continues to bank on a radical expansion in the production and use of PET and other plastics. One of the largest PET manufacturing plants in the world has been proposed for Corpus Christi, Texas. A joint venture between the three PET market leaders, the Corpus Christi Polymers plant [22] would increase North American production capacity by 23% if construction is completed and the plant goes online.

The petrochemical industry expansion also fuels unnecessary growth in production of feedstock chemicals used to make PET plastic. For example, the Formosa Plastics chemical plant proposed for the community of Welcome in St. James Parish, Louisiana would produce ethylene oxide, as well as monoethylene glycol (at 1.6 million tons per year), an essential building block chemical for PET plastic production [23]. This chemical plant would become the third largest point source of emissions of ethylene oxide, a potent carcinogen. Its total chemical footprint would be enlarged by the production of several types of another plastic, polyethylene. The Formosa Plant is vigorously opposed by local residents and environmental health advocates [24].

Figure 2-3. Polyester Clothing and Plastic Bottles Dominate PET Use



Sources: Global Market Insights (2020) [19], Grand View Research (2019) [21]

What is PET plastic used for and who consumes it?

About two-thirds of all PET goes into polyester-based textiles and more than one-quarter is used for packaging (Figure 2-3). Within these major market segments, polyester clothing and plastic bottles (especially for water and soda) dominate the end uses for PET plastic, including polyester. These applications each account for about 25% of all PET use, or about half of all PET use combined.

These PET plastic markets also contribute to a disproportionate share of plastic waste. Most of the packaging is single-use for food and beverages, and polyester-based ‘fast fashion’ clothing is often used just a few times before discarding.

Polyester Fiber for Textiles

By major market segment, two-thirds of all PET in the form of polyester fiber is used in various textiles applications. Polyester is the dominant fiber among all synthetic fibers, which now account for nearly two-thirds of all fiber use. Polyester and other synthetic fibers have displaced natural fibers, with cotton’s market share dropping to less than 25% [25].

Nearly 40% of all polyester is used to manufacture clothing, primarily in Asia. Sustainability concerns with polyester are rising with the expansion of “fast fashion” in which manufacturers release new collections much more frequently and outfits are worn fewer times before being discarded [26].

A recent report on the growing climate and waste impact of “fossil fashion” surveyed 46 brands and found that only 26 provided even partial responses about their use of synthetic fibers including polyester by percentage and weight.

For some brands, 85% of the items sold contained synthetic fibers, mostly polyester. Only six companies expressed an intent to reduce their use of synthetic fibers, but none had made a clear commitment to do so. The most intensive use of synthetic fibers was reported in the sportwear market [27].

Other polyester textile applications for PET include home furnishings, such as fabric for upholstered furniture, and carpet and rugs. Nonwoven polyester fibers have diverse uses from personal care products and industrial filters to building and construction materials. Polyester-based fiberfill is used to stuff sleeping bags, pillows, toys, and more. Industrial applications of polyester include cording to reinforce tires and for conveyor belts.

PET Plastic Resin for Packaging

Most PET plastic resin is used to make plastic bottles, but also a variety of other single-use disposal packaging.

Globally, about 500 billion PET plastic bottles are sold every year. Nearly half of those contain bottled water. About 20% are used for carbonated soft drinks [28]. Other PET plastic bottles are used to pack food and non-food products in bottles and jars, fruit juices and juice drinks, beer, and other products, each with about 6% market share [29].

In the United States, about 100 billion plastic bottles are sold every year. U.S. bottle manufacturers made nearly $1 billion in profits on $12 billion in sales in 2021 [30].

Other PET plastic film used for packaging is converted to plastic jars, pails, trays, and clamshells. Prepared meals ready to heat up in a microwave or oven are often packaged in plastic trays that are made of crystalline PET.

Table 2-5. The Biggest Corporate Consumers of Plastic Bottles in the United States

MARKET SEGMENT	BRAND OWNER	MARKET SHARE, US	SOME MAJOR BRANDS
Bottled Water [31]	**PepsiCo**	**20%**	Aquafina, Propel, SoBe, H2oh!, LIFEWTR, Bubly
	Blue Triton Brands	**16%**	Poland Spring, Deer Park, Arrowhead, Ice Mountain
	Primo Water	**10%**	The Mountain Valley Spring Water, Primo Water
	Coca-Cola	**9%**	Dasani, smartwater, vitaminwater, Topo Chico
	Danone	**1%**	AQUA, Evian, Volvic, Levits
Carbonated Soft Drinks (Soda) [32]	**PepsiCo**	**40%**	Pepsi, Mountain Dew, Diet Pepsi, Sierra Mist, Mirinda
	Coca-Cola	**16%**	Coca-Cola, Diet Coke, Sprite, Fanta
	Keurig Dr Pepper	**13%**	US: Dr Pepper, 7 Up, IBC, A&W, RC, Hires, Sunkist
	Refresco (KKR)	**6%**	Large private-label contract manufacturer & bottler
Juice & Juice Drinks [33]	**PAI Partners**	**15%**	Tropicana, Naked, KeVita, Izze, Dole, Copella, Punica
	Keurig Dr Pepper	**14%**	Hawiian Punch, Nantucket Nectars, Mott’s, Clamato
	Coca-Cola	**7%**	Powerade, Minute Maid, Simply, innocent, Del Valle
	Campbell Soup	**7%**	V8 Vegetable Juice, V8 Fruit & Vegetable Blends

Conclusion

The rapidly growing market for PET plastic continues society’s over-reliance on fossil-based oil and gas while driving expanded production of hazardous petrochemicals and scarce minerals needed for its production. About half of all PET is used to make polyester clothing, including quickly-tossed ‘fast fashion,’ and plastic bottles, most of which are disposed of after a single use. Nothing about this PET plastic market can be described as sustainable.

Photo by Tom Fisk: https://www.pexels.com/photo/yellow-heavy-equipment-on-landfill-5424854/

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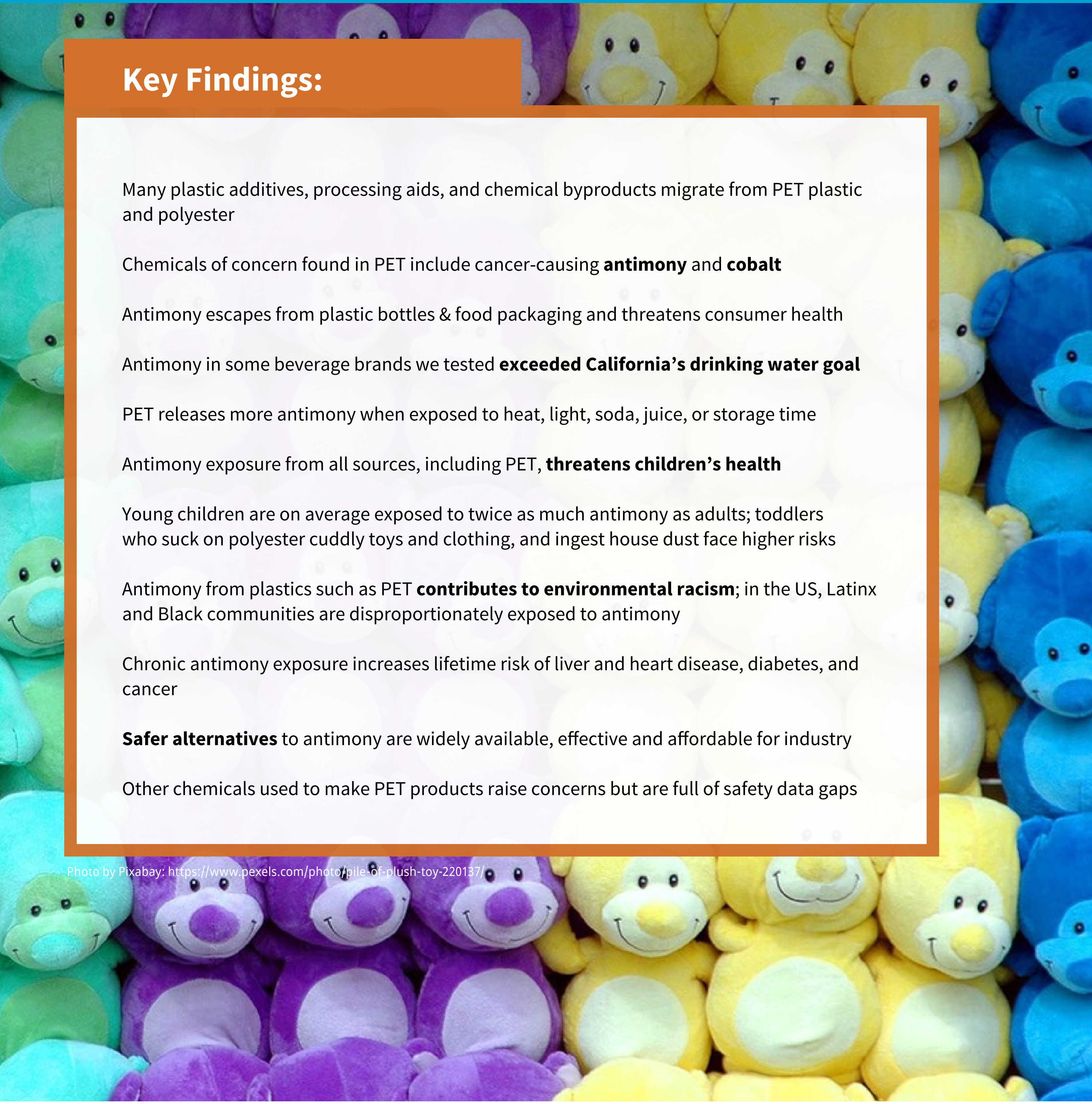
CHAPTER 3

Chemicals that Migrate from PET Plastic and Polyester May Threaten Your Health



Key Findings:

Many plastic additives, processing aids, and chemical byproducts migrate from PET plastic and polyester

Chemicals of concern found in PET include cancer-causing **antimony** and **cobalt**

Antimony escapes from plastic bottles & food packaging and threatens consumer health

Antimony in some beverage brands we tested **exceeded California’s drinking water goal**

PET releases more antimony when exposed to heat, light, soda, juice, or storage time

Antimony exposure from all sources, including PET, **threatens children’s health**

Young children are on average exposed to twice as much antimony as adults; toddlers who suck on polyester cuddly toys and clothing, and ingest house dust face higher risks

Antimony from plastics such as PET **contributes to environmental racism**; in the US, Latinx and Black communities are disproportionately exposed to antimony

Chronic antimony exposure increases lifetime risk of liver and heart disease, diabetes, and cancer

Safer alternatives to antimony are widely available, effective and affordable for industry

Other chemicals used to make PET products raise concerns but are full of safety data gaps

Photo by Pixabay: https://www.pexels.com/photo/pile-of-plush-toy-220137/

This chapter examines toxic chemicals found in PET plastic and polyester. In particular, we focus on the most common catalyst used to make PET, antimony trioxide, a potential carcinogen that's known to migrate from PET and polyester products to food, beverages and the environment. We present the results of our independent testing for antimony in PET plastic bottled beverages, and discuss necessary steps to ensure the health and safety of consumers who are exposed to antimony compounds through PET plastics.

1. Many Additives May Escape from PET Resin and Fiber During Use

All plastics used every day are polymers – linked chains of organic chemical compounds. But plastic products also have many other chemicals present in them. These can include intentionally added chemicals that impart desirable qualities to the plastic (like color or flexibility), processing aids (like catalysts and lubricants), and monomers (which are the building block of polymers). PET products can also contain chemicals that breakdown from intentionally added chemicals, side products of intentional chemical reactions, impurities in chemicals used or added, and environmental contaminants. These chemicals can migrate from plastic into human bodies and the environment. The health impacts of plastics cannot be fully understood without considering the role of these little-discussed chemicals in the plastic life cycle.

Thousands of chemical additives, processing aids, monomers, and other chemicals have been reported in plastics. A recent peer-reviewed study found that over 10,000 chemical substances have been recorded for use with plastics [1]; of these, 2,400 were found to be substances of concern, meaning that they met one or more of the conditions of persistence (long-lived in the environment), bioaccumulation (build up in living tissues and transfer through the food web), or toxicity (harmful to health). Of these 2,400 substances, 901 are still approved for use in food contact materials in some jurisdictions. Yet most consumers know little to nothing of such chemicals in everyday products, or what their presence might mean for their health. Table 3-1 provides a snapshot of just some of the chemicals that may migrate from PET plastics.

The health impacts of plastics cannot be fully understood without considering the role of these little-discussed chemicals in the plastic life cycle.

Photo by Magda Ehlers: https://www.pexels.com/photo/close-up-photo-of-plastic-bottles-2547565/

A recent study investigated the migration of chemicals in PET beverage bottles, and found that ***150 out of 193 tested chemicals have been known to migrate from the bottles into the beverages.*** *Of these, 18 exceeded EU limits, and 109 are not authorized substances in the EU. The authors note that many other chemicals that may be present in PET bottles have never been evaluated for migration. Recycling PET may further concentrate potentially hazardous chemicals.*

For more, see: Gerassimidou, S., Lanska, P., Hahladakis, J.N., Lovat, E., Vanzetto, S., Geueke, B. et al. (2022) Unpacking the complexity of the PET drink bottles value chain: A chemicals perspective. Journal of Hazardous Materials, 430. https://doi.org/10.1016/j.jhazmat.2022.128410

Table 3-1. Many Chemical Substances May Migrate from PET Plastic and Polyester

CHEMICAL NAME OR CHEMICAL CLASS	CASRN	FUNCTION OR SOURCE	KNOWN TO MIGRATE FROM PET OR POLYESTER	CHEMICAL HAZARD
Antimony trioxide	1309-64-4	Catalyst, reheat additive	Yes	High
Antimony triacetate	6923-52-0	Catalyst	No known studies	High
Germanium oxide	1310-53-8	Catalyst	No known studies	unknown
Diethyl 3,5-di-tert-butyl-4-hydroxybenzylphosphonate	976-56-7	Stabilizer	No known studies	unknown
Cobalt compounds		Bluing agent, catalyst	Yes	High
Terephthalic acid	100-21-0	Monomer	Yes	Moderate
Dimethyl terephthalate	120-61-6	Monomer	Yes	unknown
Monoethylene glycol (MEG)	107-21-1	Monomer	No known studies	High
Diethylene glycol (DEG)	111-46-6	Impurity in precursor	Yes	High
1,4-Dioxane	123-91-1	Reaction product	No	High
Bis(2-hydroxyethyl) terephthalate	959-26-2	Monomer	Yes	unknown
Isophthalic acid	121-91-5	Co-monomer	No known studies	unknown
1,4-Cyclohexanedimethanol	105-08-8	Co-monomer	Yes	unknown
Drometrizole	2440-22-4	UV light stabilizer	No known studies	unknown
Titanium nitride	25583-20-4	Reheat additive	No known studies	unknown
Anthranilamide (+ reaction products)	88-68-6	Acetaldehyde scavenger	No known studies	unknown
Acetaldehyde	75-07-0	Degradation product	Yes	High
Formaldehyde	50-00-0	Degradation product	Yes	High
Titanium alkoxide complex		Catalyst	No known studies	Not assessed
Organo-aluminum compounds		Catalyst	No known studies	Not assessed
PET cyclic trimer	7441-32-9	Reaction product	Yes	Not assessed

The FCCmigex database was used to identify chemical substances known to migrate from PET plastic into food or food simulants based on peer-reviewed studies. “Yes” indicates that at least one study found migration of the chemical to food or food simulants. “No” indicates that studies tested for migration to food or food simulants, but did not observe migration. “No known studies” indicates that there are currently no known studies of migration of this chemical substance into food or food simulants. For more, see the Food Packaging Forum Foundation (2022) [2] and Geueke et al (2022) [3].

The chemical hazard rating is reported in the Pharos database based on a GreenScreen assessment, authoritative lists, or very similar compounds. “HIGH” hazard means the chemical is a known, likely, or possible Benchmark-1 chemical substance. “MODERATE” indicates that the chemical is a known, likely, or possible Benchmark-2 chemical substance. “Unknown” means that the chemical substance was assessed using the GreenScreen List Translator, but there is currently insufficient information to classify it as a Benckmark-1 chemical substance. For more see the GreenScreen® for Safer Chemicals Hazard Assessment Guidance (2016) [4], GreenScreen (2022) [5], and Pharos (2022) [6].

CASRN stands for Chemical Abstract Services Registration Number, a unique identifier for individual chemical substances.

Other sources: Kishi et al. (2019) [7]; ILSI Europe (2017) [8]; Franz and Welle (2008) [9]; Kassouf (2013) [10].

(Continued...) **Table 3-1. Many Chemical Substances May Migrate from PET Plastic and Polyester**

CHEMICAL NAME OR CHEMICAL CLASS	CASRN	FUNCTION OR SOURCE	KNOWN TO MIGRATE FROM PET OR POLYESTER	CHEMICAL HAZARD
Other chemical substance types used in PET				
Color pigments		Colorant		
Lubricants		Reduce friction (bottles)		
Oxygen scavengers		For O_2 sensitive products		
Nucleating agents		Increase crystallization		
Antioxidants		Increase PET shelf-life		
Impact modifiers		For added strength		
Mold release agents		Processing aids		

BOX 1: Antimony – A Plastic Additive of High Concern in PET/Polyester

Antimony trioxide is a very common plastics additive. In PET plastic, it's the preferred catalyst for speeding the final chemical reaction that produces the resin. Small amounts of antimony continually escape from PET during use and disposal of plastic bottles, food packaging, and from polyester clothing, children's products, and other textiles.

By taking a lifecycle approach, antimony hazards can be apportioned to various uses including as a PET catalyst. Assessing all uses also allows a determination of whether total human exposure to antimony from all sources currently exceeds safety thresholds.

Antimony is a metalloid, having properties similar to both heavy metals and non-metals. About 153,000 metric tons of antimony ore were mined globally in 2020 [44], mostly in the form of stibnite (antimony trisulfide). It also exists as jamesonite, which contains lead, and as two forms of oxides. Smaller amounts of antimony are extracted from ores of lead, arsenic, copper, silver and gold, and from secondary smelting of lead-acid batteries and lead-antimony alloys [45].

Antimony is a scarce element that's unsustainably mined, with easily extractable reserves expected to be depleted by 2040 [40]. In 2020, more than 52% of global mine production of antimony occurred in China, which also holds most of the world's reserves. No antimony was mined in the U.S., where imports account for about 80% of consumption, the balance produced mainly from recycling of lead-acid batteries and lead-antimony alloys [45].

Table 3-B1. 60% of Antimony is Used as a Plastic Additive

USE CATEGORY	MAJOR PRODUCTS	SHARE (2010)	MAJOR MARKETS	MARKET SHARE
Plastic Additive	**Flame Retardants**	52%	PVC (vinyl) plastic Other plastics * Rubber Textile back-coating	42% 40% 10% 8%
	PET Catalyst	6%	Polyester clothes, textiles PET plastic bottles Other PET packaging Other PET use	66% 24% 5% 5%
	Heat Stabilizer	1%	PVC (vinyl) plastic	
	Colorant	1%	Yellow-orange pigments	
Other Additive	**Glass**	1%	Solar cell glass Cathode ray tubes	
	Ceramics	1%	Construction	
Metallurgical	**Batteries**	27%	Lead-acid batteries	
	Lead Alloys	11%	Construction Ammunition	

* Includes acrylonitrile butadiene (ABS), polypropylene (PP), polybutylene terephthalate (PBT), polyamides (nylon), high-impact polystyrene (HIPS), unsaturated polyester resins (UPR), high-density and low-density polyethylene (HDPE/LDPE), epoxies, adhesives, paints and coatings.

Sources: Henckens et al. (2016) [40], EU (2008) [24], See also Chapter 2 Endnotes for Global Market Insights (2020) [19], Grand View Research (2019) [21].

About 60% of antimony is used a plastic additive, primarily in the form of antimony trioxide. The largest use is as a synergist that enhances the flame retardant properties of PVC plastic and brominated flame retardants added to other plastics. About 6% of antimony is added to PET plastic as a catalyst. Metallurgical uses in lead-acid batteries and lead alloys account for more than one-third of antimony consumption. See Table 3-B1.

Antimony exists in its pure form and as about a dozen commercially relevant chemical compounds. The element occurs in four valence (or oxidation) states that dictate its power to combine and form chemical products. These include -3, O (the pure metalloid); and +3 (trivalent) and +5 (pentavalent), the most common forms in the environment. Humans are often exposed to negatively charged ions of antimony rather than to specific compounds.

Antimony and its compounds are inherently hazardous. Trivalent forms are thought to be more toxic. As a metalloid, antimony is very persistent in the environment. However, it does not bioaccumulate. The presence of antimony in the body reflects recent or daily exposure. Conversion between its trivalent and pentavalent forms commonly occurs in a somewhat unpredictable manner in the environment and human body [35].

2. Antimony that Escapes from Plastic Packaging Threatens Consumers' Health

Antimony (in the form of antimony trioxide) is the preferred catalyst for speeding the final chemical reaction that produces PET plastic. Small amounts of antimony can continually escape from PET during use and disposal of plastic bottles, food packaging, and from polyester clothing, children's products, and other textiles (Box 1). Antimony has been known to adversely affect health for decades based on health studies of exposed people and laboratory animals (see Appendix 1).

Our independent testing found antimony in all beverages sampled from PET plastic bottles.

Defend Our Health independently tested samples of 20 popular beverages, purchased between February 24-28, 2022 in the greater Los Angeles, California area and the Las Vegas, Nevada area. Beverage volumes ranged from 8-ounce to 28-ounce. We confirmed that all of the beverage bottles were made of PET plastic.

Beverages were tested at Vanguard Labs in Olympia, Washington using inductively coupled plasma mass spectrometry (ICP-MS) using EPA method 200.7 [11] for analysis of heavy metals and trace elements in drinking water, waste water, surface water, food, and cosmetics, on March 23, 2022. Of particular interest were metals known to be used (either in their elemental form or as compounds) in PET additives or processing aids. These include antimony, cobalt, titanium, germanium, aluminum, and tin. Full test results can be found in the technical lab report [12]. Antimony results summarized below, and Box 2 summarizes results for cobalt.

In addition, bottles were retained for 14 out of the 20 tested products, and were tested at the Ecology Center in Ann Arbor, MI, on April 26, 2022 using X-Ray Fluorescence (XRF) [13]. We primarily report results of the XRF method for evaluating antimony concentration in PET plastic here, due to a high degree of confidence in these results. Bottles were also tested at Vanguard Labs using ICP-MS to detect concentration of antimony and other heavy metals and trace elements [12]. The concentrations of antimony detected in the PET bottles using ICP-MS was highly correlated with antimony concentrations detected using XRF (R-squared = 0.72), but the absolute values differed due to suspected interference with silicate compounds. We discuss the relative ICP-MS results for titanium and aluminum in this and later sections, as concentrations of these metals in PET plastic [7] are typically below the detection limit for the XRF method used.

BOX 2: Cobalt in PET

Without the use of coloring agents, PET is a yellow plastic; cobalt may be added to neutralize yellowness or to impart a blue color to the plastic and provide UV stability. Cobalt (II) diacetate is the primary bluing agent used in PET, though cobalt oxide may also be used. Cobalt diacetate is also used as a catalyst in the upstream PET process: it is used to convert p-xylene to terephthalic acid, the monomer of PET.

While cobalt naturally occurs in Cyanocobalamin, an essential vitamin (B-12), cobalt compounds used in PET processing are potential carcinogens that can migrate into food, beverage, and food contact products. Cobalt acetate is listed as a carcinogen in New Zealand and Japan. Cobalt metal powder and several cobalt compounds are listed under Proposition 65 as known to cause cancer. Elevated levels of cobalt can be toxic to the nervous system, thyroid, and heart [46]. In California, cobalt is a "potential priority metal" for biomonitoring [47]. Workers exposed to cobalt are especially at risk [46]. In PET plastics, the presence of cobalt increases the decomposition of acetaldehyde, a toxic organic compound [7].

In our testing of PET bottled beverage samples, cobalt was detected in eight out of twenty samples. Concentrations ranged from 0.29 to 4.89 [12] parts per billion (ppb). While there are currently no drinking water standards for cobalt, cobalt levels are less than 1–2 ppb in most drinking water [46].

All beverages tested had detectable levels of antimony (see Table 3-2). The antimony concentration in eight out of 20 beverages (40%) exceeded California's Public Health Goal for drinking water of 1 ppb (part per billion). Eighteen out of 20 beverage samples (90%) exceeded the more health protective limit of 0.25 ppb antimony in drinking water, recommended by Defend Our Health to better account for antimony exposure from other sources.

The highest concentration was found in the **Campbell's V8** vegetable juice sample, which had 3.45 parts per billion (ppb) of antimony, more than three times California's public health goal for antimony in drinking water. The soda sample with the highest antimony concentration was **Coca Cola** (packaged in 100% recycled PET) at 2.2 ppb. **Nestle's Perrier** water had the highest concentration of antimony among the sampled bottled waters, at 1.58 ppb.

The plastic from 11 bottles had concentrations of antimony in the range of 216 to 321 parts per million (ppm). These concentrations fall within or slightly above the previously documented range of 172 to 261 ppm in PET bottles known to use an antimony catalyst [7].

Three bottles tested had undetectable concentrations of antimony. These PET samples were Simply Lemonade, Mountain Dew, and 7up bottles. Titanium concentrations for these PET samples were found to be six to seven times higher than in the other tested bottle samples using the ICP-MS method for evaluating metal concentration in plastic samples (the XRF method did not detect any titanium in these samples). Aluminum levels were also elevated in the plastic from two of these samples (Simply Lemonade and 7-up), suggesting that these bottles may have been produced using a titanium- and/or aluminum-based catalyst.

Antimony in PET bottled beverages is unlikely to be caused solely by antimony in source water. Peer reviewed studies support the conclusion that antimony levels detected in bottled beverages are likely due to some combination of antimony-based catalysts, antimony additives, and other food contact sources, rather than from antimony occurring in the source waters. Belzile et al. (2011) [14] synthesizes antimony exposure data from dozens of peer-reviewed and government sources, and reports that antimony concentrations in tap or well water are usually below the 1 ppb level. Similarly, an earlier study by Filella (2002) [15] finds that concentrations of dissolved antimony in unpolluted surface waters are "well below" 1 μg/L (ppb), and Shotyk et al. (2006) [16] report an average antimony concentration of 0.002 ppb in "pristine" ground water, compared to 0.2 ppb for bottled water. In a review of antimony migration studies with "good analytical design", Filella (2020) [17] finds that "PET is the origin of antimony presence in bottled waters."

In addition to the antimony catalyst used to make PET, metallic antimony may be also added to the PET resin as a reheat additive in concentrations around 0.5-10 ppm (parts per million) in order to accelerate the heat-assisted stretching and blow-molding of PET preforms into plastic bottles (US Patent 7479517B). This may contribute to total antimony in the PET product and/or beverage stored in it. Antimony may also be used in plumbing materials and fittings (particularly copper pipes with tin-antimony solder), that water or other ingredients used in beverages, or raw beverage itself, may be piped through at some point in their processing [18]. **While we don't always know the exact source of antimony in bottled water, these uncertainties are not an excuse for industry to engage in foot-dragging or inaction.**

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Table 3-2. Antimony was Detected in All Tested Samples of PET -Bottled Beverages

BRAND OWNER BEVERAGE BRAND	DRINK TYPE	ANTIMONY IN BEVERAGE (PPB)	ANTIMONY IN PLASTIC BOTTLE (PPM)
THE COCA-COLA COMPANY			
Coca Cola	Soda	**2.20**	Not tested
Diet Coke	Soda	**1.22**	238
Honest Tea (w/ lemonade)	Tea	**1.07**	255
Simply Lemonade	Juice	**0.96**	< 2.8
Powerade Fruit Punch	Energy	**0.88**	Not tested
Dasani	Water	0.17	265
PEPSICO, INC.			
Gatorade Blue Raspberry	Energy	**1.78**	Not tested
Mountain Dew	Soda	**1.38**	< 3.4
Diet Pepsi	Soda	**1.10**	310
Pepsi	Soda	**0.98**	Not tested
Tropicana Orange*	Juice	**0.56**	Not tested
Aquafina	Water	0.19	289
KEURIG DR PEPPER INC.			
Motts Apple Juice	Juice	**0.98**	264
Dr Pepper		**0.85**	300
7up	Soda	**0.82**	< 4.7
Diet Dr Pepper	Soda	**0.79**	296
Snapple Peach tea	Tea	**0.50**	216
NESTLÉ S.A.			
Perrier	Water	**1.58**	Not tested
OCEAN SPRAY CRANBERRIES, INC.			
Ocean Spray 100% Juice	Juice	**0.46**	309
CAMPBELL SOUP COMPANY			
V8	Juice	**3.45**	321

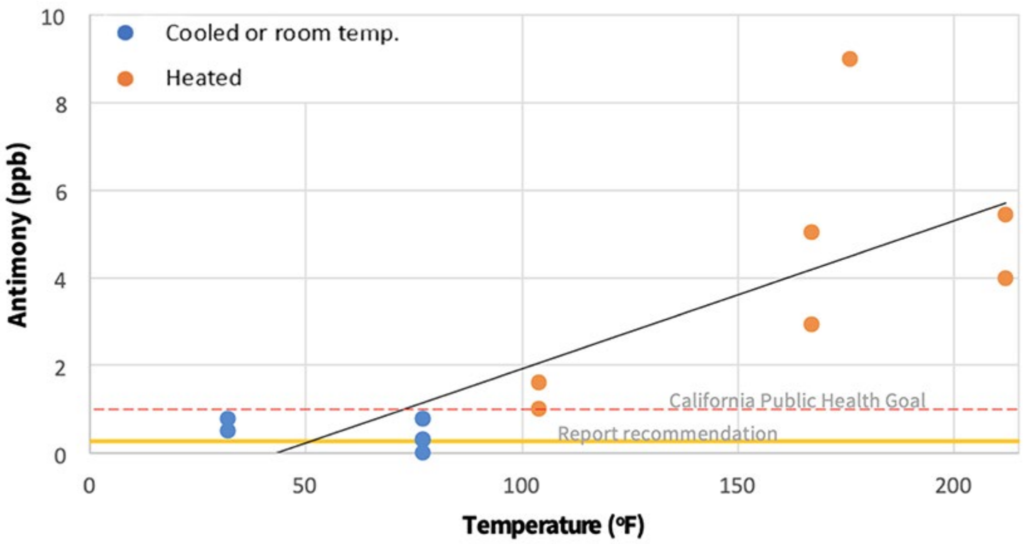
* Recently sold to PAI Partners

Values highlighted in **darker orange** text indicate antimony concentrations in beverages that exceed California's Public Health Goal of 1 part per billion (ppb) of antimony in drinking water. Values highlighted in **lighter orange** text indicate concentrations that exceed Defend Our Health's recommendation of no more than 0.25 ppb of antimony in drinking water. The antimony concentration in the plastic bottle is reported in parts per million (ppm). A value with a "less than" sign (<) indicates that antimony was not detected above the specified detection limit.

Antimony has been frequently reported in beverages and food packed in plastic

Peer-reviewed studies also document the migration of antimony from bottled beverages. Laboratory-based research on commercially available beverages and food and experiments using food and beverage simulants demonstrate that **antimony migrates into many common products under conditions of typical use**, at amounts that exceed recommended levels. In these studies, PET bottled beverages showed antimony levels that frequently exceeded Defend our Health's recommendation for safer drinking water, and also exceeded California's Public Health Goal for antimony in drinking water (see Appendix 2). Studies also show a strong correlation between antimony migration and temperature (Fig. 3-1), a moderate correlation between antimony migration and acidity, and greater migration in bottled water exposed to UV radiation and sunlight [19-21]. Research also demonstrates a positive correlation between increasing antimony concentration in bottled beverages with longer storage time [22].

Figure 3-1. Antimony Migration Increases with Temperature in Bottled Beverages



Data sources: Westerhoff et al. 2008 [19]; Cheng et al. 2010 [20] Chapa-Martinez et al. 2016 [21]. Each point represents one sample tested.

PET is also used as ready-to-eat meal packaging and oven bags. PET packaging is often labeled as "microwave save" or "oven safe", and microwave meals in PET trays are popular for their convenience. However, past studies [14,17] have found that even before heating, most PET-packaged food products contained high levels of antimony, possibly because containers were filled with hot prepared food during production, which may promote leaching from the plastic to food [20,23]. Antimony concentrations in foods increase further when these products are microwaved or cooked in the oven inside their PET packaging according to packaging directions [20,23].

Detailed summaries of peer reviewed findings of antimony migration from beverage and food can be found in Appendix 2.

1. Antimony Exposure from all Sources Threatens Children's Health

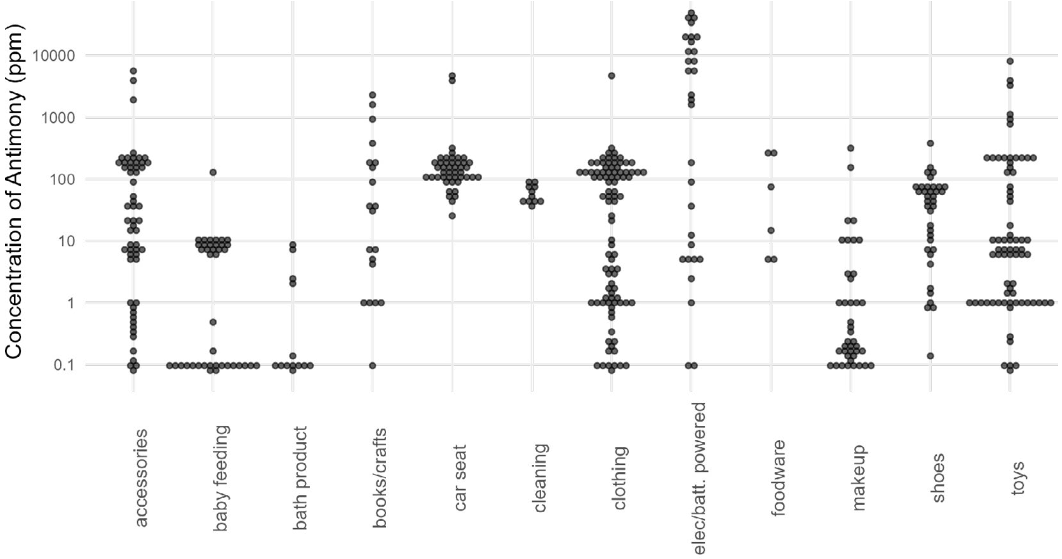
Children are exposed to multiple sources of antimony from its use as a plastic additive, including its common use with flame retardant chemicals, including in PET and polyester. In addition to exposure from food and beverages, antimony may be ingested from house dust and from the mouthing of polyester-based toys and clothing. This aggregate exposure to antimony by children appears to exceed the maximum daily dose established by the State of California to protect against chronic organ toxicity.

Antimony is present in many children's products that have components made of PET plastic and polyester fiber

Water bottles are not the only plastic products from which antimony migrates. Antimony is also found in many children's PET and polyester clothes and toys. Just as with bottles, antimony can escape other products made of PET resin or polyester fiber, and antimony can then be directly ingested when infants and toddlers mouth, suck, or chew these products [24]. Polyester textiles are commonly found in children's clothing. Polyester is also commonly used in the outer fabric and soft fills in cuddly toys. PET and other plastic components of hard plastic toys, electronic toys' casings, and costumes and accessories may contain antimony associated with fire retardants. Antimony and PET microplastics containing antimony also accumulate in household dust [25,26], which young children can then ingest from regular hand-to-mouth activity [27].

Results of testing by Washington's Department of Ecology, and independent car seat testing by the Ecology Center, show that antimony is present in nearly all tested children's products with PET or other plastic components (Figure 3-2).

Fig 3-2 - Antimony is present in most children's products with PET or other plastic components



All results of children's products component testing (except car seats) from Washington's Department of Ecology [28], downloaded May 12th, 2022. Data on car seats from Ecology Center (2022) [29].

Out of 476 product components tested, all but 15 (all car seat components) had detectable levels of antimony. Electronics and battery powered products had the highest levels (median = 2050 ppm, maximum = 45200 ppm), likely from use of antimony with flame retardants in casings. Products that might be mouthed by babies (soft toys, baby bottle components and pacifiers) had lower but detectable antimony levels. Antimony in children's products contribute to antimony exposure in children.

BOX 3: Endocrine disruptors are found in PET products

Endocrine disrupting chemicals (EDCs) are a major concern with all plastics [48]. In particular, chemicals called “xenoestrogens” mimic estrogens produced in the body and can interfere with processes moderated by this hormone. All humans are exposed to some xenoestrogens through normal dietary intake (e.g. in dairy, soy) but high levels of xenoestrogens can also be introduced through contaminants in plastics. Adverse effects include negative impacts on the development of reproductive and nervous systems in utero, and breast cancer in adults. Pregnant people, fetuses, and infants are especially vulnerable.

PET has long been considered a “safe” plastic - bisphenols (such as BPA) or phthalates, which are known classes of EDCs, are not typically intentionally added to PET. Yet there are two problems with the common perception that PET is a plastic free of endocrine disrupting chemicals. First, evaluations of PET have found both phthalates and bisphenols in PET plastics [49,50]. Second, some studies suggest that antimony can also contribute to estrogenic activity [51]. Finally, most studies of EDCs in plastics focus on evaluating the presence of just a small handful of known EDCs but do not evaluate other synthetic compounds that may mimic the activity of hormones [52]. As Wagner and Oehlman [53] note: “understanding the complexity of human exposure to manmade chemicals, including endocrine disruptors, is compromised by the overwhelming number of compounds in use and the technical limitations in their detection”.

To overcome this shortcoming of compound-specific studies, some researchers have evaluated the total estrogenic activity of PET products and their contents. Multiple studies have found estrogenic activity in PET containers. Using bioassays (which evaluate effects of substances on living cells or tissue), Wagner and Oehlman [53] found estrogenic activity in seven out of nine brands of water bottled in PET. To confirm that the estrogenic activity was due to substances migrating from the bottle and not already present in the water, they also assessed estrogenic activity of the bottle themselves, and found that PET bottles caused significantly higher activity than glass bottles. A similar study by Pinto and Reali [54] also found detectable levels of estrogenic activity in all of nine PET samples tested, although Bittner et al. [55] did not find estrogenic activity in any of their stressed or unstressed PET bottled water samples. Yang et al.[48] found detectable estrogenic activity in 75% of the 57 PET bottles tested. All bottles were advertised as BPA free. Researchers also tested estrogenic activity after subjecting plastics to common stressors associated with typical use (UV, temperature, and microwaving), and found that a PETG baby bottle that did not show endocrine activity initially showed detectable levels after exposure to UV [56].

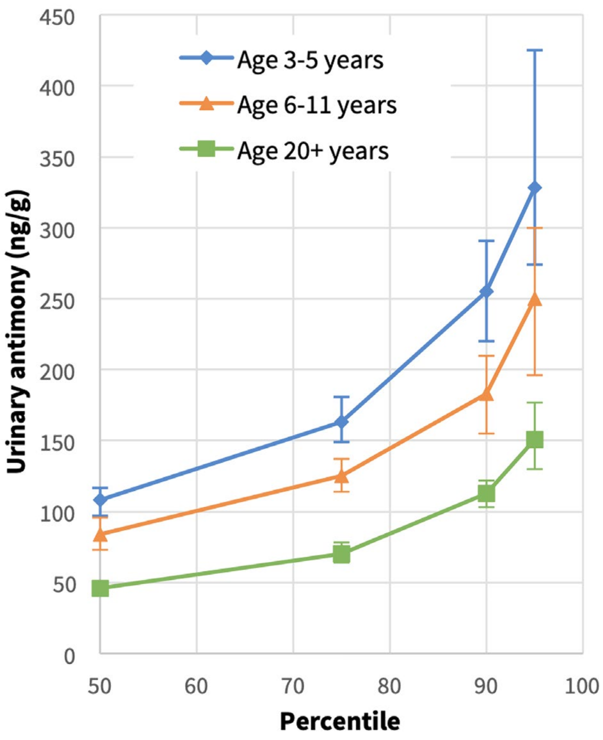
Humans may be exposed to significant levels of estrogenic compounds through PET bottled beverages. Adults meeting all of their hydration needs through bottled water (about 3 liters/day) would on average add an equivalent of 54 ng of estrogen to their total daily intake [52]. If they consumed water from a brand found to have the highest documented estrogenic activity, they could add the equivalent of 226 ng of estrogen to their total intake, effectively tripling their estrogen from external sources [52], far exceeding the level at which adverse estrogenic effects have been observed in animal subjects [57]. As bottled water consumption grows, even low-dose, long-term exposures to estrogen-mimicking compounds may adversely affect large segments of the global population, particularly infants, pregnant people, and people with breast cancer [52].

Young children are more exposed to antimony from all sources than adults

Large scale studies of human health indicate the disproportionate burden of antimony exposure on young children. The National Report on Human Exposure to Environmental Chemicals (2022) [30] summarizes data on antimony in the US population based on National Health and Nutrition Examination Survey (NHANES) responses and health examinations. This data includes tests for antimony in urine, which is an indicator of how much participants are exposed to antimony through different pathways. Higher levels indicate higher exposure, and can help reveal disparities in exposure for different demographic groups (Figure 3-3).

This National Biomonitoring Program report finds that, compared to teens and adults, children aged 3-5 years and 6-11 years show significantly higher levels of urinary antimony.

Figure 3-3. Children are More Exposed to Antimony than Adults



Creatinine-corrected urinary antimony concentration, from the National Report on Human Exposure to Environmental Chemicals (2022) [30]

Children's daily exposure to antimony from all sources far exceeds acceptable health limits. (See Table 3-3).

Based on the sources listed in Table 3-3, we estimate that the average child is exposed to upwards of 207 nanograms of antimony per kilogram of body weight per day. Compared to the estimated exposure for adults, an average child is exposed to over 2.5 times more antimony per kilogram of body weight per day than an average adult.

Based on our analysis, children's total exposure to antimony exceeds the daily dose adopted by state and federal environmental health agencies to protect against adverse health effects. Children in the highest exposure group are exposed to at least six times the Acceptable Daily Dose for antimony established by California's Office of Environmental Health Hazard Assessment. Even compared with the less protective reference dose used by the US EPA, a highly exposed child is exposed to 1.75 times the federal daily limit for antimony. This is without accounting for inhalation of antimony through indoor air, absorption through skin during dermal contact with surfaces treated with antimony-enhanced flame retardants, and inhalation of tobacco smoke, all of which contribute to total antimony intake and likely make children's exposure even higher.

Table 3-3. Total Daily Exposure of Children to Antimony Exceeds Safety Limits

Exposures reported below for plastic bottles, drinking water, food, and upholstered furniture are estimates for adult exposures from authoritative sources. Note that on a per unit body weight basis, children drink more fluids, eat more food, breathe more air, and have a greater skin surface area than adults [31]. Therefore, the values reported below are likely to be underestimates for children's exposure.

EXPOSURE PATHWAY	EXPOSURE SOURCE	DAILY EXPOSURE (IN NG/KG/D)		NOTES
		TYPICAL	HIGH	
INGESTION	PET Plastic Bottles	12	29	Based on migration into bottled water before and after six months of storage [16]. Greater migration likely from plastic-bottled soda and juices due to lower pH (higher acidity).
	Drinking Water	?	24	May be higher from antimony leaching from plumbing materials and fittings, including tin solder [18].
	Food	62	80	Based on a well-balanced diet. May be higher from migration from heated PET plastic food trays [23].
	Polyester Cuddly Toys	?	208	Children who suck or chew on cuddly toys, blankets, and other polyester or PET plastic items, extract antimony in their saliva, and/or ingest polyester particles or fibers.
	House Dust	133	500	About 100 milligrams per day of dust are ingested by children's frequent hand-to-mouth activity [33]. Sources include antimony used with flame retardants in plastics.
Estimated child exposure from ingestion only		**> 207**	**841**	
DERMAL	Polyester Fabric	?	?	Antimony can escape from polyester clothing during skin contact with perspiration [34]. Sleeping with cuddly toys may also cause antimony exposure from skin contact.
	Upholstered Furniture	?	1,500	Skin contact with textiles with antimony trioxide added to enhance effect of flame retardant chemicals.
INHALATION	House Dust	5	21	Assumes that a child aged 1 to <2 years old inhales eight meters cubed of air per day of air [33].
	Outdoor Air	?	21	
Estimated child exposure from all sources		**> 212**	**2,383**	
Daily Exposure Limit	California EPA, OEHHA:	140		Acceptable Daily Dose (ADD) of antimony for its Public Health Goal for Antimony in Drinking Water (2016) [35]
	Unites States EPA, IRIS:	430		Reference dose (RfD) for antimony adopted by U.S. Environmental Protection Agency, IRIS (1987) [36]

Source: Unless otherwise noted, all values are based on the European Union Risk Assessment Report: Diantimony Trioxide (2008) [24], an aggregate risk assessment developed for Europe by the Swedish Chemical Inspectorate. See pp. 362-384. Daily exposure values are expressed as nanograms of antimony per kilogram of bodyweight per day. About half the population is exposed at the "Typical" exposure level. "High" exposure represents a reasonable worst-case scenario for each source. Additional exposure not included above occurs during breastfeeding.

2. Unjust Exposure to Antimony from Plastics Contributes to Environmental Racism

Workers often face much higher levels of chemical exposure than the general population. And worker health studies are often the first to reveal the adverse effects of chemical substances in human populations (See Appendix 4). Disproportionate exposure to chemicals on the job is one type of environmental injustice, which is exacerbated for workers of color [37].

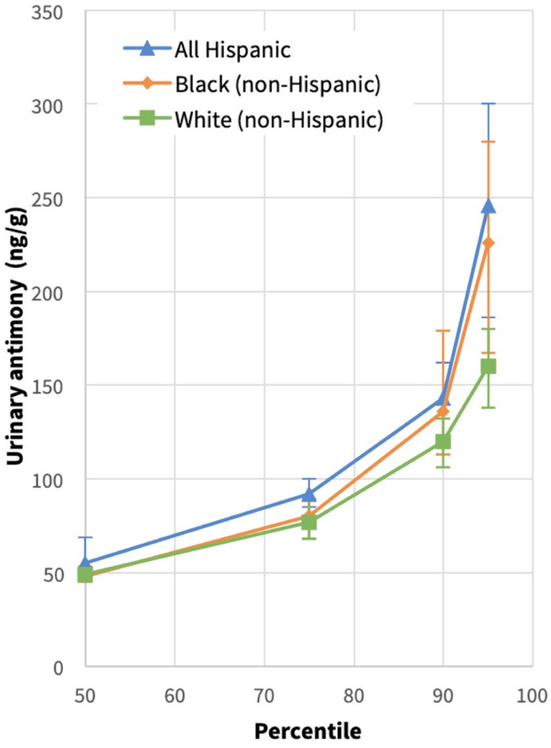
Latinx workers made up more than 90% of a large workforce at a large antimony smelter in Laredo, TX, where raw ore was transformed into antimony trioxide and other compounds. A well-conducted occupational health study [38] found a nearly 40% higher death rate from lung cancer among these workers compared to the general Latinx population. The study also found that the lung cancer death rate increased with years of employment.

Racial disparities in antimony exposure also affect the general American population. Antimony exposure is disproportionately higher in Hispanic and Black communities than among the white population. Nationally, Hispanic participants in the national biomonitoring program have higher urinary antimony levels compared to white or Asian participants (Fig 3-4). Hispanic community members with the highest exposure (at the 95th percentile level) had statistically significantly higher levels of antimony in urine – over 1.5 times more urinary antimony than white participants.

Biomonitoring data integrate exposure from all sources without revealing the relative contribution of each source or the cause of any resulting racial disparities. However, the existence of racial disparities in exposure points toward systemic racism [37]. Further investigation is needed to determine the factors that contribute to the greatest racial disparities in antimony exposure. Hypotheses to test include greater contact with flame-retarded plastics, polyester fabric, or plastic packaged food and beverages, among people of color.

Figure 3-4. Among the Most Highly Exposed Americans, Antimony Hazards Fall Heaviest on Hispanic and Black People

Creatinine-corrected urinary antimony concentration, from the National Report on Human Exposure to Environmental Chemicals (2022) [30]



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*Note that the NHANES survey includes questions on self-identified race ethnicity categories. When discussing NHANES data, we follow NHANES conventions for race and ethnicity categories. Survey definitions can be found at https://wwwn.cdc.gov/Nchs/Nnyfs/Y_DEMO.htm

3. Potentially Safer Alternatives to Antimony Catalysts are Widely Available, Effective, and Affordable

Eliminating unnecessary uses of plastics and substituting with safer materials is the best way to prevent environmental release and exposure to all plastic-related chemicals. For continuing uses of PET plastic resin and polyester fiber, an alternatives assessment can reveal whether existing processing aids such as antimony can be replaced with safer substitutes.

Antimony trioxide remains the dominant polymerization catalyst used to manufacture polyethylene terephthalate (PET) plastic for beverage bottles, other packaging, and polyester fiber for clothing and other textile applications [39]. However, given the growing concerns about the hazards and scarcity of antimony [40], the market has begun to shift to alternative catalysts.

We conducted an alternatives assessment for PET catalysts based on readily available information (see Appendix 5). The results are summarized in Table 3-4, which shows that potentially safer alternatives to antimony are functionally equivalent, commercially available, and comparably affordable.

Table 3-4. Comparison of Alternative PET Catalysts to Antimony Compounds

CATALYST COMPOUNDS	SAFER	EFFECTIVE	AVAILABLE	COST
Organo-aluminum salt	MAYBE	YES	YES	LOWER
Germanium oxide	YES	YES	YES	HIGHER
Titanium alkoxide complex	YES	YES	YES	~ SAME
Dibutyltin oxide	NO	?	YES	HIGHER
Enzyme (biobased)	YES	YES?	?	HIGHER?

Question marks indicate insufficient data to make a definitive conclusion.
For a detailed comparison of known PET catalysts, see Appendix 5.

This conclusion is supported by other evidence. Sustainability researchers have determined that the use of antimony as a PET polymerization catalyst is 100% substitutable [40]. Germanium oxide is already widely as used a catalyst to produce PET for plastic bottles in Japan [7]. Suntory sells plastic-bottled beverages made from PET plastic catalyzed with an aluminum-based catalyst developed by Toyobo [41]. A substantial portion of polyester production in Asia has switched to antimony alternatives [42]. Prominent textile manufacturers, including Herman Miller now advertise that their products are made of antimony-free polyester [43].

Our testing results provide preliminary evidence to suggest that some PET plastic manufacturers may have already begun transitioning to non-antimony catalysts for use in plastic bottles sold in the US. In our laboratory analysis, antimony was not detected in three out of sixteen plastic bottle samples tested using XRF (with a detection limit of 3 to 5 parts per million). XRF did not detect titanium or aluminum in these samples, but results of the more sensitive ICP-MS suggest that three of those antimony-free plastic bottles may have the three highest titanium concentrations in the plastic (Mountain Dew, Simply Lemonade, and 7-up), and two of them may have the highest results for aluminum (Simply Lemonade and 7-up) [12]. Both titanium- and aluminum-based PET polymerization catalyst systems are now commercially available and may have been used in the production of PET used in these bottles.

4. Conclusion

PET and polyester manufacturers, and the companies that use their products, can act immediately to reduce harm from PET catalyzed by antimony. The health impacts of antimony are clearly established, and these negative effects are disproportionately borne by small children and people of color. Immediate action is necessary and possible, by transitioning to safe catalysts.

Replacing antimony catalysts in PET manufacture is a crucial step to reduce the harms posed by PET plastics. But it's just the beginning. Hundreds of additives, processing aids, and chemical byproducts in plastics remain understudied, and their continued use poses health hazards that we've barely begun to understand.

Detoxifying the chemicals used to make plastic products is a small but immediately actionable step. The ultimate solution to preventing all harm from PET plastic and polyester require that its use be phased down and out in favor of truly safer, just, and sustainable materials as determined across their entire lifecycles.

Photo by La Miko: https://www.pexels.com/photo/plastic-wrap-3615710/

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CHAPTER 4

Conclusions and Recommendations

The negative impacts of polyethylene terephthalate (PET), used to make plastic bottles and packaging, and polyester fiber for clothing and textiles, justify action to reduce its harm.

Based on this report's analysis, we conclude that PET plastic resin and polyester fiber is:

Unsafe – because of its many toxic additives and the hazardous chemicals used in the manufacturing process, and the resulting aggregate and cumulative impacts from human exposure and environmental releases during production, consumer use, and disposal;

Unjust – due to elevated population-wide exposure of children and people of color to antimony – a common PET plastic additive, higher hazards faced by chemical workers, and the location of many chemical plants that supply PET production near communities of color and low-income residents who are already heavily over-burdened by industrial pollution;

Unsustainable – because PET plastic manufacturing relies on non-renewable fossil resources (oil and gas) and on extremely scarce minerals such as antimony; production and disposal of PET and polyester emits greenhouse gases that are fueling the climate crisis.

The continued expansion of the petrochemical plastics industry will worsen its impacts.

To reverse these trends, plastic pollution should be reduced at the source by eliminating unnecessary uses of plastics and substituting others with safer materials and more sustainable solutions. Rather than working backwards to reduce plastic waste by recycling more, as many in industry wish, the most preventative solutions should be pursued aggressively first. Due to all its inherent limits, recycling should be the option of last resort.

The Preferred Hierarchy for Safe, Just, and Sustainable Solutions to Plastic Pollution

1. **Eliminate unnecessary uses, such as through reusable and refillable packaging**
2. **Substitute with safer more sustainable materials, such as with natural fibers**
3. **Convert durable and semi-durable uses to renewable carbon, preferably derived from sustainably harvested biomass such as agricultural waste and forestry residues**
4. **Increase recycling of plastic bottles and polyester clothing, and avoid down-cycling**
5. **Prevent open burning and the discard of plastic waste to our land and waters**
6. **Halt incineration and avoid landfilling of plastic waste – zero waste remains the goal**

The problems created by PET (and other petrochemical plastics) cannot be solved overnight. A comprehensive road map is needed on how to make the transition to safer, more just and sustainable materials to meet society's needs for goods and services.

Although such a detailed plan is beyond the scope of this report, a broad outline of the necessary actions and timeline to reduce the harm has already emerged. And many of the following actions have been endorsed by leading scientists and corporate market leaders.

RECOMMENDATIONS:

The solutions to the problems of PET plastic and polyester are intertwined. Parallel actions should be pursued that phase down the use of fossil carbon and toxic chemicals, while simultaneously increasing recycled content and the use of renewable carbon. Radical transparency in information must be made available in all supply chains and will help drive down demand for petrochemical plastics. The goal is that all solutions should be non-toxic, climate-friendly, and environmentally just.

1. By 2040, the use of virgin fossil PET plastic and polyester should be largely phased out [1].

Except for truly essential uses for which there's no reasonable alternative, petrochemical plastics such as PET should be eliminated or safely substituted. Any residual use of PET plastic should be based on 100% recycled content or 100% renewable carbon sources.

2. By 2030, replace 50% of PET bottles and packaging with reusable and refillable systems [2].

The emerging reuse economy should be robust, universally accessible, and rely on sustainable materials that are free from toxic hazards and injustice.

3. By 2030, substitute 50% of virgin polyester with recycled clothing or natural fibers [3].

Downcycling of plastic bottles into lower quality polyester cannot be sustained. For circularity, clothing must be recycled into clothing. Recycling alone cannot reduce the fashion industry's carbon footprint enough to meet climate goals. Production of synthetic fibers must be reduced.

4. By 2030, replace 50% of PET with 100% non-toxic biobased PET [4] or bioplastics such as PEF [5].

Starting with renewable raw materials, rather than oil or gas, dramatically reduces the carbon footprint of plastics. Preference must be given to second-generation feedstocks, such as agricultural waste and forestry residues, which have greater climate benefits.

5. By 2025, meet the industry's Recycled Polyester Challenge to increase the recycled content of polyester to 45% (on the path toward achieving a 90% share by 2030) [6].

Recycling must be considered an interim step on the path to true sustainability, rather than a means of perpetuating continued reliance on fossil carbon and toxic additives. Down-cycling to inferior-quality, one-time uses – the current dominant practice – should end.

6. By 2025, meet the industry pledge to eliminate unnecessary and problematic plastic materials (e.g. opaque or pigmented PET plastic bottles, and PETG in rigid packaging [7]).

Both items impede the quality and efficacy of recycling, according to the U.S. Plastics Pact. Darkly-colored PET bottles reduce the clarity and value of the recycled plastic. PETG, which is glycol-modified PET, acts differently than pure PET, impairing effective recycling.

7. By 2025, assess the hazards of all chemical substances used or produced to make PET [8,9].

Conduct hazard assessments using the GreenScreen® for Safer Chemicals (or its equivalent) to score all chemicals used and/or produced across the manufacturing lifecycle of all PET. Act to fill any data gaps that prevent a hazard ranking from being determined by this time.

8. By 2024, eliminate chemicals of high concern [10] as PET plastic additives & processing aids.

Any substances scored as Benchmark 1 by GreenScreen® (or an equivalent hazard assessment method), or that appears on authoritative lists based on similar hazards, should be avoided. Brand-owners and PET manufacturers should know and choose safer chemistry when it comes to the many additives and processing aids available for PET.

9. By 2023, end all use of antimony and cobalt compounds in PET plastic and polyester.

These chemicals of high concern are not needed to make PET plastic. Safer alternatives to antimony [11] and cobalt compounds are available, effective and affordable. Antimony-free polymerization catalysts for PET are based on titanium, germanium or aluminum. Alternative blue toners or other strategies can achieve clear plastic without cobalt additives.

All those with agency to act should implement the above recommendations, including:

- **Brand owners with market pull, such as major beverage and clothing companies**
- **Market leaders whose sustainability innovation drives a competitive race to the top**
- **Local and state policy makers whose leadership often drives national policy actions**
- **The United Nations, poised to develop a global treaty to prevent plastic pollution**
- **The United States federal government, following the lead of the all pace-setters**
- **Organized consumer demand to drive corporate change and government policy**

It’s past time to rethink PET and polyester, and take the business-as-usual scenario off the table. We can stop plastic pollution, one plastic at a time, beginning with PET and polyester.

Together, we can achieve a new materials economy that is virtually fossil-free and toxic-free, and steeped in the principles of environmental justice and sustainability.

Photo by Scott Webb: https://www.pexels.com/photo/green-grass-field-under-white-clouds-1048039/

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APPENDICES

Appendix 1. Antimony Toxicology

Exposure to antimony and its compounds can increase your risk of chronic disease

Authoritative government agencies have concluded that daily exposure to small amounts of antimony and some antimony compounds can pose serious health risks over one's lifetime. California's Office of Environmental Health Hazard Assessment lists antimony trioxide as a carcinogen [1]. The Department of Health and Human Services (HHS) lists antimony trioxide as "reasonably anticipated to be a human carcinogen" [2]. Similarly, the International Agency for Research on Cancer (IARC) has concluded that antimony trioxide is "probably carcinogenic to humans" [3].

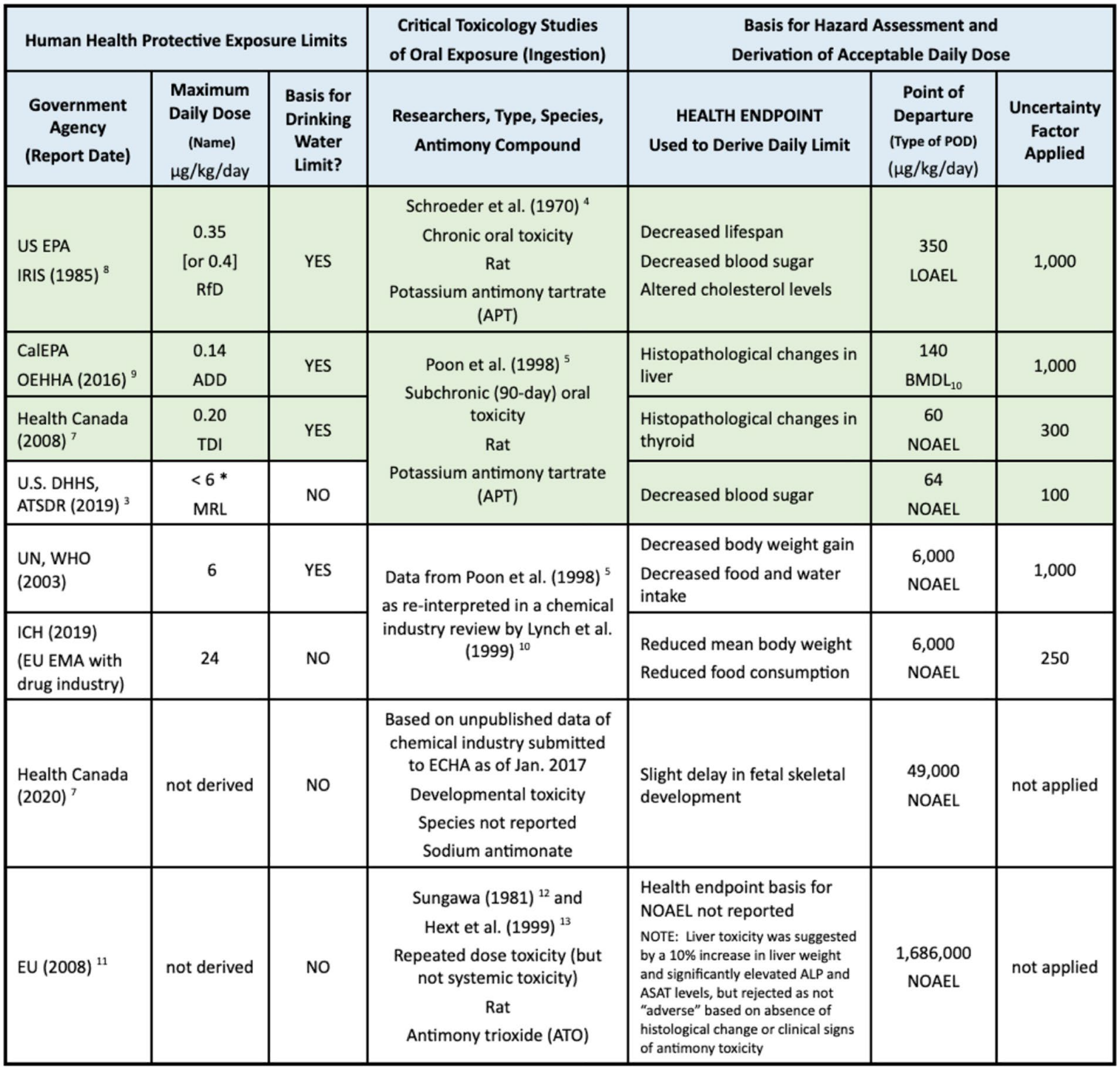
Antimony has been known to adversely affect health for decades based on laboratory studies. Schroeder et al. (1970) [4] found evidence that antimony exposure led to early death, increases in blood sugar levels (a risk factor for diabetes), and changes in cholesterol levels (a risk factor for heart disease). Poon et al. (1998) [5] found evidence of changes in liver tissue that could lead to liver disease. The study also found histopathological changes to the thyroid, and elevated levels of antimony in the spleen even after a recovery period.

Antimony has also been shown to slow fetal and infant growth in test animals. A study by Miranda et al. (2006) [6] reported interference in fetal development and growth, reduced fetal weight gain, and variations in skeletal and soft tissue development in rats due to antimony exposure. Unpublished data from the chemical industry, submitted to Health Canada (2020) [7] found that antimony (in the form of sodium antimonate) can cause delays in fetal skeletal development.

Presumed safety thresholds for maximum daily exposure to antimony (from all sources) have been derived from toxicity studies assessed by the State of California, the United States, and other governmental jurisdictions. While these thresholds are intended to protect public health, they may fall short of their goals [See Appendix 3: U.S. drinking water standards].

Table A1-1. Daily Ingestion of Low Levels of Antimony May Threaten Human Health

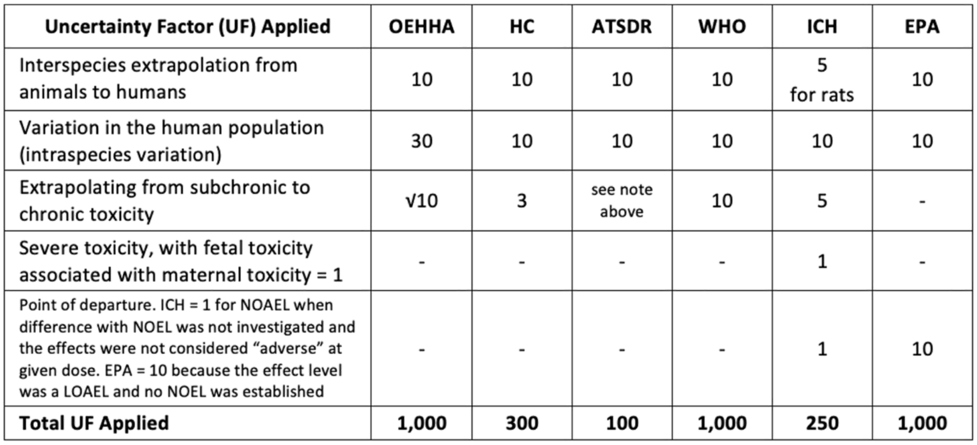
The most authoritative maximum daily doses, with their agencies and studies, are highlighted in green below.



Human Health Protective Exposure Limits			Critical Toxicology Studies of Oral Exposure (Ingestion)	Basis for Hazard Assessment and Derivation of Acceptable Daily Dose		
Government Agency (Report Date)	**Maximum Daily Dose (Name) µg/kg/day**	**Basis for Drinking Water Limit?**	**Researchers, Type, Species, Antimony Compound**	**HEALTH ENDPOINT Used to Derive Daily Limit**	**Point of Departure (Type of POD) (µg/kg/day)**	**Uncertainty Factor Applied**
US EPA IRIS (1985) [8]	0.35 [or 0.4] RfD	YES	Schroeder et al. (1970) [4] Chronic oral toxicity Rat Potassium antimony tartrate (APT)	Decreased lifespan Decreased blood sugar Altered cholesterol levels	350 LOAEL	1,000
CalEPA OEHHA (2016) [9]	0.14 ADD	YES	Poon et al. (1998) [5] Subchronic (90-day) oral toxicity Rat Potassium antimony tartrate (APT)	Histopathological changes in liver	140 $BMDL_{10}$	1,000
Health Canada (2008) [7]	0.20 TDI	YES		Histopathological changes in thyroid	60 NOAEL	300
U.S. DHHS, ATSDR (2019) [3]	< 6 * MRL	NO		Decreased blood sugar	64 NOAEL	100
UN, WHO (2003)	6	YES	Data from Poon et al. (1998) [5] as re-interpreted in a chemical industry review by Lynch et al. (1999) [10]	Decreased body weight gain Decreased food and water intake	6,000 NOAEL	1,000
ICH (2019) (EU EMA with drug industry)	24	NO		Reduced mean body weight Reduced food consumption	6,000 NOAEL	250
Health Canada (2020) [7]	not derived	NO	Based on unpublished data of chemical industry submitted to ECHA as of Jan. 2017 Developmental toxicity Species not reported Sodium antimonate	Slight delay in fetal skeletal development	49,000 NOAEL	not applied
EU (2008) [11]	not derived	NO	Sungawa (1981) [12] and Hext et al. (1999) [13] Repeated dose toxicity (but not systemic toxicity) Rat Antimony trioxide (ATO)	Health endpoint basis for NOAEL not reported NOTE: Liver toxicity was suggested by a 10% increase in liver weight and significantly elevated ALP and ASAT levels, but rejected as not "adverse" based on absence of histological change or clinical signs of antimony toxicity	1,686,000 NOAEL	not applied

* This Minimal Risk Level of 6 µg/kg/day was established for an "Intermediate" frequency of oral exposure only. ATSDR said there's insufficient data to establish a Minimal Risk Level for "Chronic" (daily, long-term) oral exposure, which would be a lower value than the Intermediate MRL.

RfD	Reference Dose, an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to human populations (including sensitive subgroups) that is likely to be without deleterious (non-carcinogenic) effects during a lifetime
ADD	Acceptable Daily Dose, an estimate of the maximum daily dose of a chemical from all sources (aggregate exposure) that can be consumed by humans for an entire lifetime without adverse health effects
TDI	Tolerable Daily Intake is the total intake by ingestion, to which it is believed that a person can be exposed daily over a lifetime without deleterious effect, based on non-carcinogenic effects
MRL	Minimal Risk Level, an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure
LOAEL	Lowest Observed Adverse Effect Level is the lowest exposure at which there are biologically significant increases in frequency or severity of adverse effects between the exposed population and its control
$BMDL_{10}$	The benchmark dose (BMD) is defined as the dose that corresponds to a specific change in an adverse response compared to the response in unexposed subjects. The benchmark dose level (BMDL) is the lower 95% confidence limit. The BMDL10 is that level associated with a 10% extra risk of adverse effect in the exposed test animals, as compared to the background levels of risk.
NOAEL	No Observed Adverse Effect Level is the highest exposure at which there are no biologically significant increases in frequency or severity of adverse effects between the exposed population and its control
POD	Point of Departure is the point on a toxicological experimental dose-response curve of low or no effect
UF	Uncertainty Factors are applied to the POD to account for extrapolating across species and from subchronic to lifetime exposure, and for variations among humans in how chemicals are metabolized



Uncertainty Factor (UF) Applied	OEHHA	HC	ATSDR	WHO	ICH	EPA
Interspecies extrapolation from animals to humans	10	10	10	10	5 for rats	10
Variation in the human population (intraspecies variation)	30	10	10	10	10	10
Extrapolating from subchronic to chronic toxicity	√10	3	see note above	10	5	-
Severe toxicity, with fetal toxicity associated with maternal toxicity = 1	-	-	-	-	1	-
Point of departure. ICH = 1 for NOAEL when difference with NOEL was not investigated and the effects were not considered "adverse" at given dose. EPA = 10 because the effect level was a LOAEL and no NOEL was established	-	-	-	-	1	10
Total UF Applied	**1,000**	**300**	**100**	**1,000**	**250**	**1,000**

Note: OEHHA applied a UF of 30 for variation in the human population based on multiplying these two factors together:

- 10 for pharmacokinetics is applied due to concerns regarding variability in the human population related to absorption, distribution, tissue accumulation, excretion, and conversion of Sb(V) to Sb(III)
- √10 for pharmacodynamics (√10, the square root of 10 = 3.16)

OEHHA's application of an uncertainty factor of √10 for subchronic to lifetime exposure is based on the study's duration of 8 to 12% of estimated lifetime. See guidelines (OEHHA 2008) [15].

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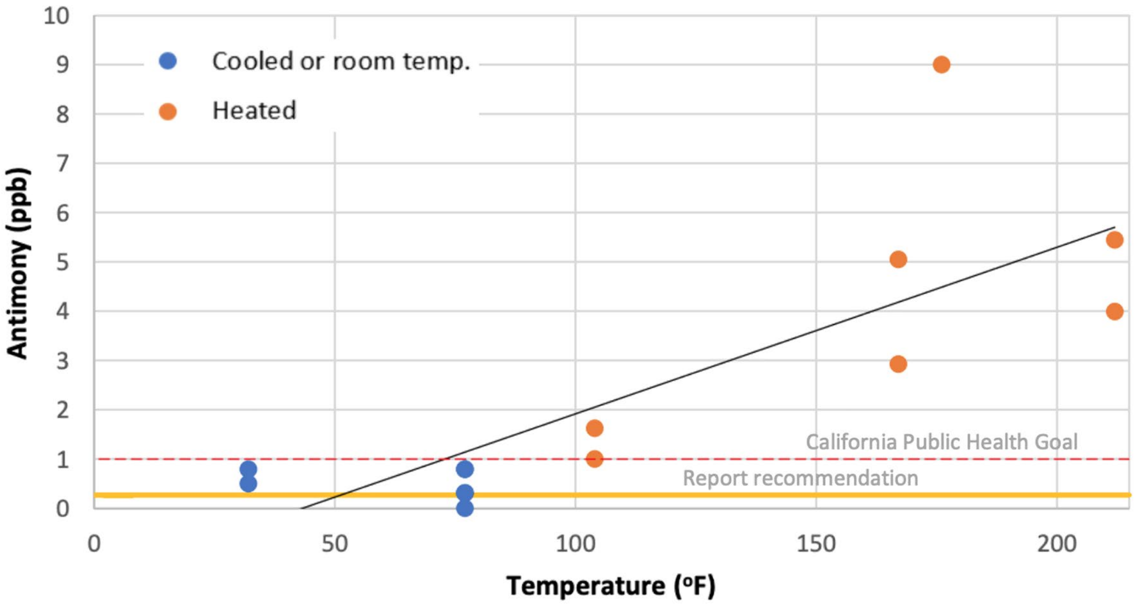
Appendix 2. Migration of Antimony from PET Plastic Bottles and Other Products

Antimony in beverages

According to an industry survey conducted by the International Bottled Water Association, 37% of adults in the US get their water mostly or entirely from bottled water – 21% say they mostly drink bottled water, and 16% say they drink only bottled water) [1]. That is, over a third of Americans are relying on beverages bottled in plastic, most of which are made of PET, to meet their water intake needs. These bottles are frequently stored improperly (such as at high temperatures or exposed to sunlight), often for long periods, resulting in increased concentrations of antimony in the beverage.

Temperature: Temperature increases migration of antimony in PET bottled waters. For bottles stored at 104 degrees Fahrenheit for a minimum of one day, migration exceeds California's Public Health goal of 1 ppb. Using data aggregated from three peer-reviewed studies, we find that for every 10° F increase in temperature, migration of antimony increases by 0.34 ppb [Figure A2-1].

Why this matters: Temperatures of 104 degrees F and above are common for cities in the US southwest; for example the average high temperature in Las Vegas in July is 107° F, and is 104° F in August. Water bottles left out under these conditions will on average have a concentration of 2.09 ppb, over double the California Public Health Goal of 1 ppb. Temperatures inside a car on a hot day can exceed 200° F; at these temperatures, antimony concentration is expected to average 5.3 ppb, over 5 times the CA public health goal. For the many in the US who rely mostly or entirely on bottled beverages to meet their hydration needs, particularly in the Southwest, regularly drinking PET bottled water left in these conditions is typical [4] and may result in chronic exposure to elevated concentrations of antimony.

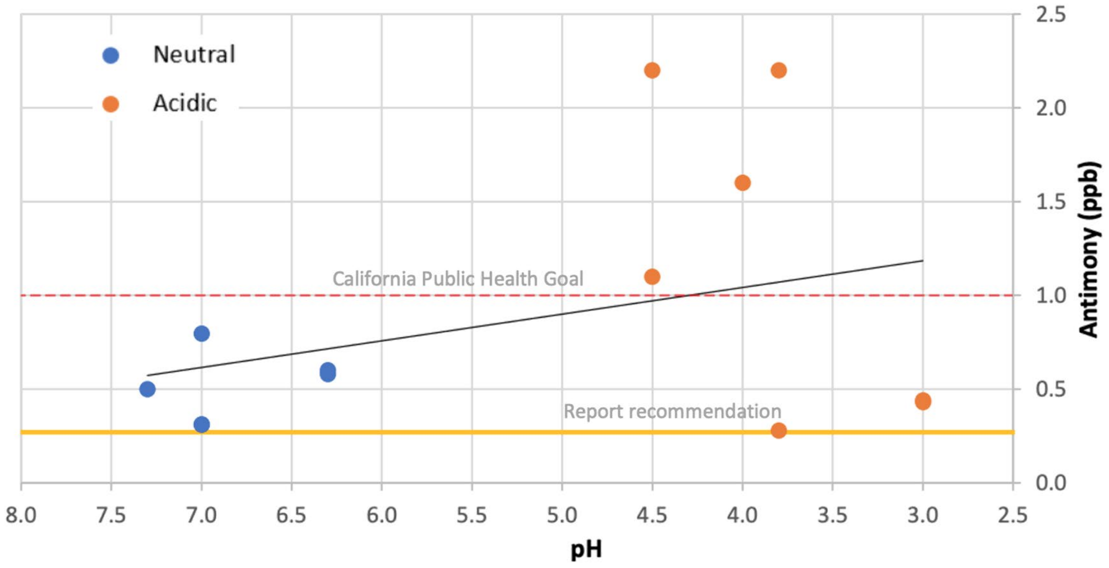


Data sources: Westerhoff et al. 2008 [2]; Cheng et al. 2010 [3]; Chapa-Martinez et al. 2016 [4]. Each point represents one PET bottled water sample. See sources for testing methods used in each study.

pH: At room temperature, acidic beverages including carbonated sodas (typically pH 4.5), citrus juices (pH 3.3-4.2), and other juices show elevated concentrations of antimony compared to water in similar containers. The storage time of acidic beverages in PET also affects migration: juice in expired bottles contained more Sb than juice in unexpired ones [5]. Heating and pH also have a compounding effect: acidic beverages heated in PET showed greater migration of total Sb4,5, and the total increase is mainly driven by inorganic Sb(III), known to be the more toxic of the two inorganic antimony species [5]. [Fig A2-2]

Why this matters: Carbonated beverages and juices bottled in PET are expected to have higher levels of antimony than bottled water kept under similar conditions.

Fig A2-2. Antimony migration increases in more acidic beverages

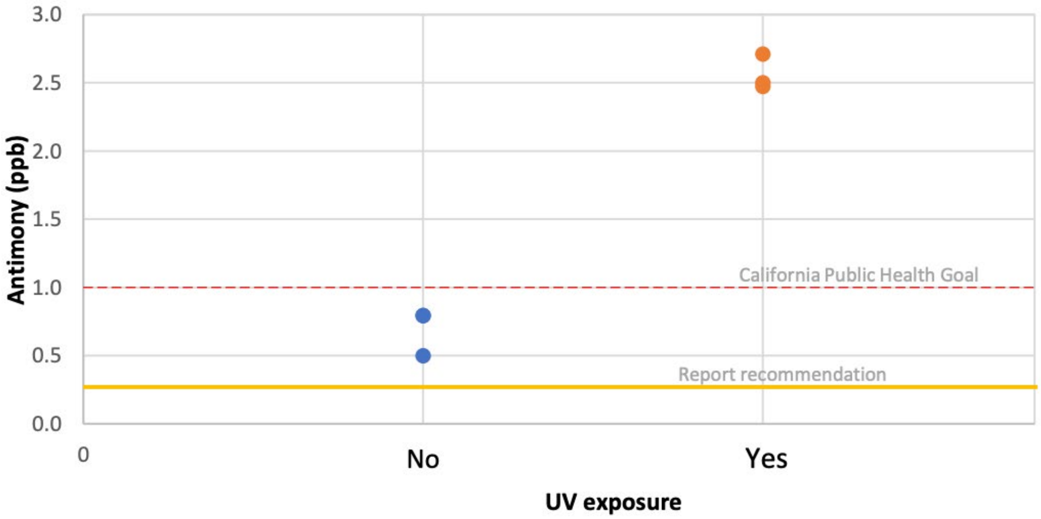


Data sources: Westerhoff et al. 2008 [2]; Cheng et al. 2010 [3]; Chapa-Martinez et al. 2016 [4]. Each point represents one PET bottled water sample. See sources for testing methods used in each study.

UV exposure: Bottled water is likely to be exposed to ultraviolet (UV) light during regular. One study (Cheng et al. 2010) found that antimony migration may triple or quadruple when exposed to UV irradiation for seven days. [Fig A2-3]

Why this matters: Bottled water and sports beverages are popular for athletes and others who engage in outdoor activities. Bottled water is also frequently stored in areas where it may be exposed to frequent UV radiation, including in sunlit homes and outdoor storage areas.

Fig A2-3: Antimony migration increases with exposure to UV radiation in bottled beverages



Data sources: Westerhoff et al. 2008 [2]; Cheng et al. 2010 [3]. Each point represents one PET bottled water sample. See sources for testing methods used in each study.

Storage time: Antimony migration also increased with storage time. In a study evaluating migration based on time from expiration date, Hansen and Pergantis (2006) found that every 10-day increase in storage increased antimony concentration in beverages by 0.02 ppb, on average.

Why this matters: Stores routinely sell products nearing their expiration dates at discounted rates, making consumers trying to find more affordable products particularly vulnerable. Consumers often store bottled water for weeks or months after purchase.

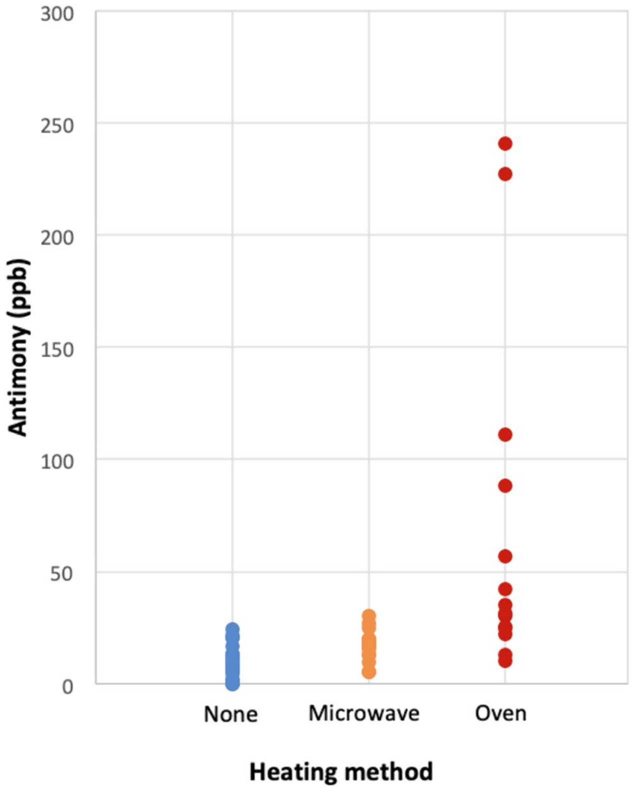
Heating food in “microwave/oven safe” PET containers may expose consumers to elevated concentrations of antimony

Haldiman et al. (2007) evaluated food products intended to be heated in PET containers, including trays, oven bags, and wrappers. In this study, all of the food items were packaged in PET and also intended to be reheated in the packaging. All products were tested straight out of the package, and replicates were reheated according to package instructions (either in the oven or microwave at the specified power/temperature for the specified time) after which antimony concentrations were evaluated. Results found that, even before heating, most food products contained high levels of antimony, possibly because containers were filled with hot prepared food during production. Antimony concentration in foods increase further when microwaved or cooked in the oven. In particular, baking in PET resulted in antimony concentrations as high as 241 ppb. [Fig A2-4]

Why it matters: Many PET products are labeled as “microwave save” or “oven safe” [6], and are a popular choice for convenient meals.

Antimony can migrate out of some polyester textiles, including clothes, cuddly toys (e.g. stuffed animals), other childcare articles, and polyester (fleece) clothing, especially when exposed to bodily fluids such as sweat [7]. For more on antimony in children’s products including toys and clothing, see Section 4 on children’s products in Chapter 3 of this report.

Fig A2-4. Heating food and beverages in PET containers, according to packaging instructions, can expose consumers to elevated concentrations of antimony.



Sources: Haldiman et al. 2007 [6]; Cheng et al. 2010 [3]. Each point represents one PET packaging sample. See sources for testing methods used in each study.

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Appendix 3. Drinking Water Standards for Antimony

Our analysis suggests that current drinking water limits may not be sufficiently protective of public health due to potentially faulty assumptions. Based on our analysis, a health protective standard for antimony in drinking water should be 0.25 parts per billion (ppb).

US agencies, including the US EPA, and California's OEHHA, determine acceptable concentrations of antimony (or any contaminant) in drinking water as:

Concentration = (ADD * RSC) / DWI

Where:

ADD = **Acceptable Daily Dose** [a] (Note that some agencies use **Reference Dose** (RfD) [b] instead of ADD)
RSC = **Relative source contribution**. This is the percentage of antimony that is assumed to come from water.
DWI = **Daily water intake**. This is the rate at which water is assumed to be consumed by an individual.

Table A3-1 [Antimony drinking water] shows drinking water limits calculated for different jurisdictions. Values range from 18 ppb (WHO) to 1 ppb (OEHHA); differing assumptions about antimony toxicity, how much water contributes to total antimony consumption, and daily water intake, results in vastly different recommended concentrations which may not be sufficiently protective of human health.

EPA's ADD value may be too high

Drawing primarily on the most recent and complete lab-based analysis of health impacts of antimony in drinking water, California Environmental Protection Agency adopted an Acceptable Daily Dose (ADD) of 0.14 micrograms (140 nanograms) of antimony per kilogram of body weight per day. However, US EPA uses an earlier study [c] to derive a value of 0.4 micrograms per kilogram of body weight per day as the RfD. This contributes to EPA's less health-protective maximum limit for antimony in drinking water.

RSC values overestimate drinking water contribution to total antimony

Both EPA and OEHHA assumed that 40% of one's exposure to antimony comes from drinking water. That percent is known as a "relative source contribution (RSC)". If other sources of antimony exposure are added up and account for more than the remaining 60% of total exposure, then the RSC for drinking water is pegged too high. The World Health Organization (WHO), for example, assumes that only 10% of antimony exposure comes from drinking water.

Applying a more protective RSC of 10%, the California and U.S. drinking water limits should be one-fourth their current value, or 0.25 ppb and 1.5 ppb, respectively. Our review supports this more protective approach on drinking water, given other significant sources of antimony ingestion from food, beverages, house dust and products, especially for young children.

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[a] An Acceptable Daily Dose is defined as "an estimate of the maximum daily dose that can be consumed by humans for an entire lifetime without adverse health effects" (OEHHA 2016).

[b] A Reference Dose is defined as "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system.

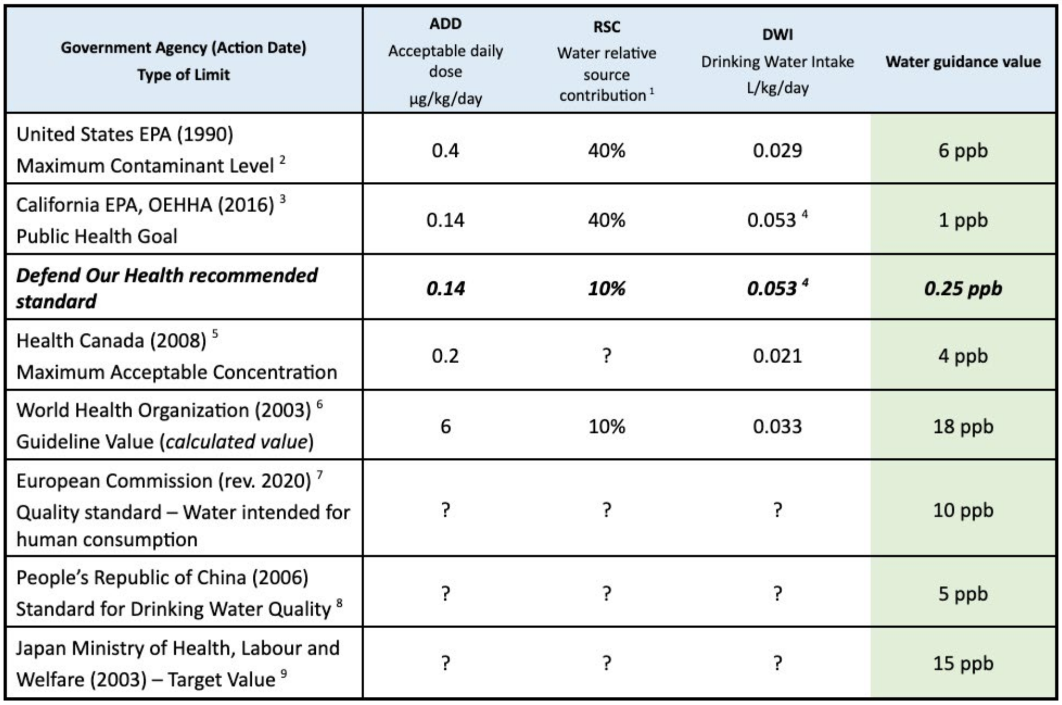
[c] Schroeder, H.A., Mitchener, M. and Nason, A.P. (1970) Zirconium, niobium, antimony, vanadium and lead in rats: life term studies. The Journal of Nutrition, 100, 59–68. https://doi.org/10.1093/jn/100.1.59

Underestimated DWI values may be producing less-protective antimony standards

In setting its drinking water goal for antimony, OEHHA assumes that people drink almost twice as much water as USEPA does, based on a robust data set on water consumption rates for different age groups [4]. USEPA simplistically assumed that a 60-kilogram (132-pound) adult consumes 2 liters (slightly more than a half-gallon) of water per day. If the OEHHA consumption rates were applied to federal standard-setting, the national MCL for antimony would be reduced to about 3 ppb. Applying more realistic assumptions for both RSC and DWI would reduce the federal standard to 0.8 ppb, less than the current California Public Health Goal.

Defend Our Health's recommended standard

Based on OEHHA's ADD and DWI values, and WHO's RSC value, Defend Our Health recommends that antimony in drinking water should not exceed 0.25 ppb.



Government Agency (Action Date) **Type of Limit**	**ADD** Acceptable daily dose µg/kg/day	**RSC** Water relative source contribution [1]	**DWI** Drinking Water Intake L/kg/day	**Water guidance value**
United States EPA (1990) Maximum Contaminant Level [2]	0.4	40%	0.029	6 ppb
California EPA, OEHHA (2016) [3] Public Health Goal	0.14	40%	0.053 [4]	1 ppb
Defend Our Health recommended standard	***0.14***	***10%***	***0.053 [4]***	***0.25 ppb***
Health Canada (2008) [5] Maximum Acceptable Concentration	0.2	?	0.021	4 ppb
World Health Organization (2003) [6] Guideline Value (*calculated value*)	6	10%	0.033	18 ppb
European Commission (rev. 2020) [7] Quality standard – Water intended for human consumption	?	?	?	10 ppb
People's Republic of China (2006) Standard for Drinking Water Quality [8]	?	?	?	5 ppb
Japan Ministry of Health, Labour and Welfare (2003) – Target Value [9]	?	?	?	15 ppb

ppb	Parts per billion, a concentration equal to micrograms of chemical per liter of water (µg/L)
L/kg-d	Liters of water consumed per kilogram of body weight per day
µg/kg/d	Chemical exposure metric expressed as micrograms of chemical per kilogram of bodyweight per day

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[4] U.S. Department of Agriculture's Continuing Survey of Food Intake of Individuals 1994-1996, 1998 dataset, cited by OEHHA 2016.

Endnotes

1. The Relative Source Contribution (RSC) is the percent of the maximum daily dose assumed to be contributed by drinking water. A lower RSC results in a lower, more protective drinking water standard since less of the total exposure may be contributed by that one source.
2. A Maximum Contaminant Level (MCL) is an enforceable drinking water standard based on technological and economic feasibility. From: U.S. Environmental Protection Agency (EPA). (1990) Drinking Water Criteria Document for Antimony.
3. A Public Health Goal (PHG) is a limit on a chemical in drinking water that's based solely on scientific and public health considerations without regard to economic cost considerations. California's enforceable maximum contaminant level for antimony remains at 6 ppb. From: Office of Environmental Health Hazard Assessment (OEHHA) California Environmental Protection Agency (CalEPA). (2016) Public Health Goal for Antimony in Drinking Water. https://oehha.ca.gov/media/downloads/water/chemicals/phg/antimonyphg092316.pdf.
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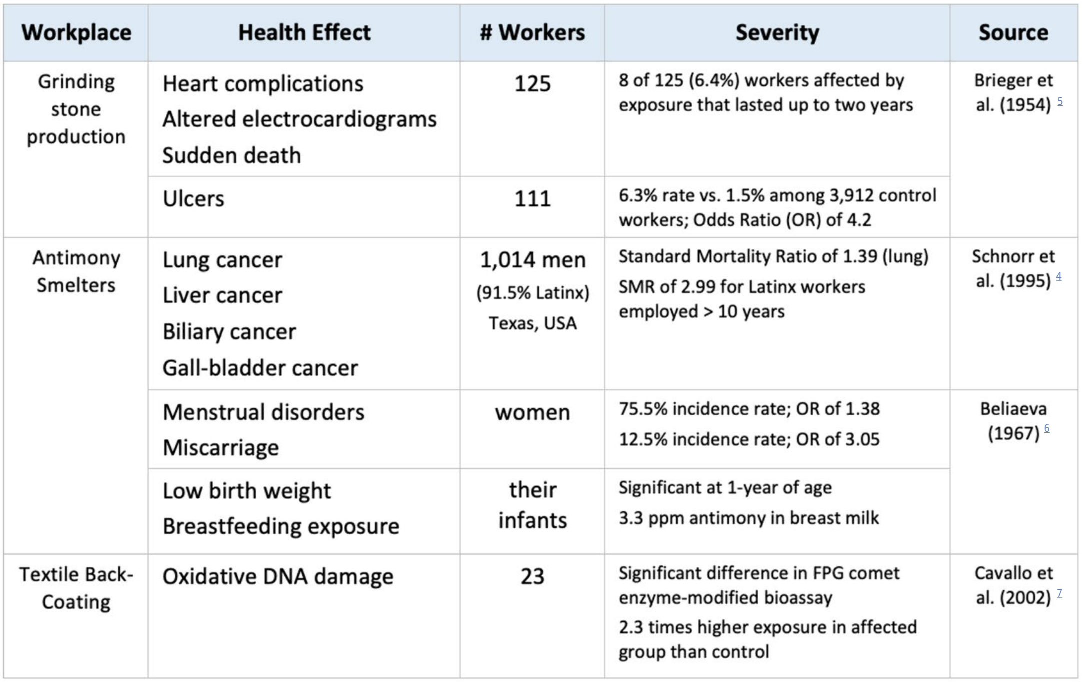
Appendix 4. Antimony Hazards to Workers

Some workers face significant health risks from antimony exposure

Workers all along the antimony supply chain face health risks from lung damage and lung cancer due to inhalation of dust . This includes workers at antimony smelters, and those handling antimony-based powder for use as a catalyst for PET production, as a flame retardant to produce plastics, rubber and treated textiles; and from formulating pigments, paints, coatings and ceramics; and from the production and secondary smelting of lead-acid batteries and lead alloys [1].

Today, most antimony smelting and refining occurs in China. United States Antimony Corporation (USAC) operates the only two antimony smelters in North America. One is located 15 miles west of Thompson Falls, Montana in the U.S., and the other in Estación Madero in Coahuila, Mexico . USAC also extracts antimony ores at several mine sites in Mexico [2]. Studies have shown that workers exposed to antimony can experience occupational disease that kills or harms them and threatens their children's health (Table A4-1). At a former antimony smelter in Laredo, Texas [3], once the largest in the world, the mostly Latinx workforce died of lung cancer at a 40% higher rate than the general Spanish-surnamed population, and at three times the rate among workers employed longer than ten years [4].

Table A4-1. Antimony Exposure Can Seriously Harm the Health of Workers and Their Children



Workplace	Health Effect	# Workers	Severity	Source
Grinding stone production	Heart complications Altered electrocardiograms Sudden death	125	8 of 125 (6.4%) workers affected by exposure that lasted up to two years	Brieger et al. (1954) [5]
	Ulcers	111	6.3% rate vs. 1.5% among 3,912 control workers; Odds Ratio (OR) of 4.2	
Antimony Smelters	Lung cancer Liver cancer Biliary cancer Gall-bladder cancer	1,014 men (91.5% Latinx) Texas, USA	Standard Mortality Ratio of 1.39 (lung) SMR of 2.99 for Latinx workers employed > 10 years	Schnorr et al. (1995) [4]
	Menstrual disorders Miscarriage	women	75.5% incidence rate; OR of 1.38 12.5% incidence rate; OR of 3.05	Beliaeva (1967) [6]
	Low birth weight Breastfeeding exposure	their infants	Significant at 1-year of age 3.3 ppm antimony in breast milk	
Textile Back-Coating	Oxidative DNA damage	23	Significant difference in FPG comet enzyme-modified bioassay 2.3 times higher exposure in affected group than control	Cavallo et al. (2002) [7]

"Standardized Mortality Ratio (SMR) is a ratio between the observed number of deaths in a study population and the number of deaths that would be expected, based on the age- and sex-specific rates in a standard population and the population size of the study population by the same age/sex groups. If the ratio of observed:expected deaths is greater than 1.0, there is said to be "excess deaths" in the study population." Source: New Mexico's Health Indicator Data & Statistics. Accessed June 7, 2022. https://ibis.health.state.nm.us/resource/SMR_ISR.html

"An odds ratio (OR) is a measure of association between an exposure and an outcome. The OR represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure. … The odds ratio can also be used to determine whether a particular exposure is a risk factor for a particular outcome, and to compare the magnitude of various risk factors for that outcome. OR=1 Exposure does not affect odds of outcome; OR>1 Exposure associated with higher odds of outcome; OR<1 Exposure associated with lower odds of outcome." From Szumilas, M. (2010) Explaining odds ratios. Journal of the Canadian Academy of Child and Adolescent Psychiatry, 19, 227–9.

Endnotes

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Appendix 5. Alternatives to Antimony as a PET Polymerization Catalyst

Antimony trioxide is the dominant catalyst used to speed the final chemical reaction that produces polyethylene terephthalate (PET) plastic for beverage bottles and other packaging, and polyester fiber for clothing and other textile applications. (Other antimony compounds have also been used for this purpose, including antimony acetate and antimony glycolate.) Due to growing concerns about antimony, the market is beginning to shift to non-antimony catalyst systems for PET and polyester.

Henckens et al. (2016) [1] concluded that 100% of antimony use as a catalyst can be readily substituted. They argue that case on sustainability grounds, citing the extreme scarcity of recoverable antimony ore relative to its high demand, mostly as a plastics additive for use with flame retardant chemicals. They conclude that only about 25 years of extractable antimony ore is readily available at projected consumption rates, compared to their sustainability benchmark for the extraction rate of minerals, defined as providing at least 1,000 years of supply [2].

Based on a literature review using six comparative metrics, we conclude that safer alternatives to antimony as a PET catalyst are commercially available, effective (i.e. functionally equivalent), and affordable. Although there are some tradeoffs, these choices of catalysts for PET plastic and polyester production are preferable over antimony trioxide or other antimony compounds:

- **Germanium oxide**, has low toxicity, but the cost is higher and the element somewhat scarce;
- **Biobased enzymes** or other organic (non-metal) biocatalysts may be the safest and most sustainable solution but don't appear to be commercially available yet for PET polymerization;
- **Titanium alkoxide complex**, which appears more effective than antimony, is safer for consumers but may pose worker and fenceline community hazards during mining and refining;
- **Organo-aluminum salt**, the cheapest solution, creates hazards during mining and refining and may pose consumer hazards from migration from PET plastic; and

The table below (Table A5-1) summarizes the comparative benefits of the major PET catalyst systems that are in commercial use now, or are desirable (in the case of enzymes).

Here's a brief description of the six metrics compared under five categories in the table header for each catalyst alternative:

Safety – This measure is based on the inherent hazard properties of the element or compound reported in two related ways:

- **Consumer Health** profiles the catalyst hazard based on possible daily exposure and chronic human toxicity. This includes a consumer exposure scenario from migration of the catalyst or related metal compounds or ions from PET plastic or polyester items during use; and

- **Lifecycle Health** considers the hazards posed to workers during mining and refining of the metal ores. By extension similar concerns may be experienced as fenceline impacts on people who live or work next to mining, refining and related chemical manufacturing operation.

Table A5-1. Comparison of Alternative PET Polymerization Catalysts

Catalyst compounds	SAFER (HAZARDS) [a]		SUSTAINABLE	AVAILABLE	EFFECTIVE [b]	AFFORDABLE [c]
	Consumer Health	Lifecycle Health	Supply Scarcity [d]	Commercially Available	Amount Needed	2021 Price per Pound (raw)
Antimony trioxide	HIGH [e]	HIGH [f]	Extreme	YES	~ 250 ppm	$5.20
Organo-aluminum salt [g]	MAYBE [h]	HIGH [i]	Abundant	YES	Not Sure	$1.40
Germanium oxide	SAFER [j]	SAFER [k]	Moderate	YES	~ 25 ppm	$349 - $544
Titanium alkoxide complex [l]	SAFER [m]	HIGH [n]	Abundant	YES	~ 10 ppm	$5.31
Dibutyltin oxide	HIGH [o]	HIGH [p]	Moderate	YES	Not Sure	$15 - $16
Enzyme (biocatalyst) [q]	SAFER	SAFER	Unknown	NO?	Not Sure	High?

Color coding: RED = More problematic; GREEN = More preferable; YELLOW = Moderate concern or unknown status. Question marks indicate relatively high degree of uncertainty. "ppm" = parts per million in PET plastic. Sources are cited in the footnotes.

[a] This hazard assessment is informed by the GreenScreenTM [4] score for each element and/or its compounds, obtained from the Pharos [5] database, and further from information obtained from U.S. EPA's CompTox Chemicals Dashboard [6].

[b] Reviews of the relative effectiveness of PET polymerization catalysts include: antimony trioxide and germanium dioxide (Thiele 2001 [7]), organo-aluminum salt (Nakajima et al. 2006 [8], Toyobo 2017 [9]), titanium alkoxide complex (Schoennagel & Cooper 2016 [10], Catalytic Technologies Ltd. [11]) and dibutyltin oxide (Davies 2010 [12]).

[c] USGS Mineral Commodity Summaries (2022) [3]. Prices reported for various forms of the metals in various markets provide a relative gauge of the cost of the raw material rather than the actual cost of the specific compound or catalyst product.

[d] The European Chemical Society (2021) [13] and Henckens et al. (2014) [2] are in general agreement on the relative scarcity of these elements except for germanium. EuChemS says that the supply of germanium faces a "serious threat in the next 100 years," while Henckens says that its availability is "not scarce," and its supply will last more than 1,000 years.

[e] The acceptable daily dose for chronic human exposure to antimony ranges from 0.14 µg/kg/day (OEHHA 2016) [14] to 0.35 µg/kg/day (USEPA 1990) [15]. Antimony trioxide is a GS Benchmark [1] chemical and is reasonably anticipated to cause cancer in humans via inhalation (NTP 2021) [16].

[f] Workers face serious cancer risks from mining and refining of antimony, which is reasonably anticipated to be a human carcinogen from inhalation, according to NTP (2021) [16], Saerens et al. (2019) [17] and Schnorr et al. (1995) [18]. Occupational exposure to antimony is also associated with chronic organ toxicity of the liver, heart and lungs, per OEHHA (2016) 14, ATSDR (2019) [19], and Cavallo et al. (2002) [20]. Environmental impacts from antimony mining are documented by Bolan et al. (2022) [21].

[g] A patent has been assigned to Toyobo Co., Ltd. for the invention of an organo-aluminum salt of an organo-phosphonate compound for use as a PET catalyst (Nakajima et al. 2006) [8]. Toyobo has licensed a proprietary aluminum-based catalyst to Indorama Ventures Public Company Ltd., the world's largest PET producer (Toyobo 2017) [9].

[h] The acceptable daily dose for chronic human exposure to elemental aluminum ranges from 18 µg/kg/day (OEHHA 2001) [22] to 1 mg/kg/week (comparably expressed as 140 µg/kg/day) (EFSA 2008) [23] to 1,000 µg/kg/day (ATSDR 2008) [24]. Elemental aluminum is a GS Benchmark 1 chemical.

[i] Occupational asthma and other respiratory effects have been well documented in aluminum smelter workers in reviews by Wesdock and Arnold (2014) [25] and OEHHA (2001) [22].

[j] No limit has been established on chronic human exposure to elemental germanium or germanium dioxide. There is some evidence that germanium does not cause cancer (Gerber & Leonard 1997) [26]. The European Chemicals Agency lists one key study that established a No Observed Adverse Effect Level (NOAEL) of 30,000 µg/kg/day for developmental and reproductive toxicity of germanium dioxide based on subacute oral exposure to rats [27]. However, high-dose repeated exposure to germanium compounds in drugs and dietary supplements has been linked to kidney failure, liver toxicity, and death (Keith & Maples-Reynolds 2022) [28].

[k] There is limited evidence of mild kidney effects in workers exposed to airborne germanium dioxide but no significant effect on liver, blood, or respiratory function were identified (Swennen 2000) [29].

[l] Catalytic Technologies, Ltd. has patented a method for producing an organo-titanium-based catalyst that's complexed with an alpha-hydroxy carboxylic acid, such as citric acid, for the manufacture of polyester. This substance is highly purified and contains less then 0.1% titanium dioxide, a chemical of concern. In this complex, the acid chelates the titanium preventing the formation of titanium dioxide (Schoennagel & Cooper 2019) [10].

[m] No limit has been established on chronic human exposure to elemental titanium, titanium dioxide or other titanium compounds. However, titanium dioxide, which is commonly added to many food products as a white colorant, is no longer considered safe for use as a direct food additive based on concern about the effects of human ingestion of nanoparticles, which make up to 50% of the titanium dioxide (EFSA 2021) [30].

[n] For titanium tetrachloride, the primary chemical substance produced from titanium-bearing ore, the human exposure limit (inhalation, chronic toxicity) is 1 µg/m3/day for respiratory effects (ATSDR 1997, 2014). Titanium tetrachloride is a building block (intermediate chemical) for the production of titanium metal, titanium dioxide, and most titanium compounds. Titanium dioxide is a possible human carcinogen via inhalation (IARC 2010).

[o] No acceptable daily dose for chronic exposure to dibutyltin oxide has been established. However, many organo-tin compounds are known or possible GS Benchmark 1 chemicals, including dibutyltin oxide. For an intermediate frequency of exposure (less than chronic), ATSDR (2005) [31] set a Minimum Risk Level of 300 µg/kg/day for inorganic tin, 5 µg/kg/day for dibutyltin dichloride, and 0.3 µg/kg/day for tributyltin oxide.

[p] Tin miners die from lung cancer and suffer from silicosis at higher rates than comparable populations due to concurrent exposure to radioactive radon and its decay products, arsenic and silica dust, and other pollutants (Fox et al. 1981 [32], Xiang-Zhen et al. 1993 [33], Chen et al. 1994 [34]). Occupational exposure to organotin compounds may harm the liver, kidneys, lungs and central nervous system at low concentrations (NIOSH 1976) [35].

[q] Enzymes are currently used as biocatalysts to commercially produce some pharmaceuticals, fine chemicals, and bulk chemicals (Abdelraheem et al. 2019) [36]. Enzymes are being actively researched and developed for potential use in depolymerizing PET plastic [37], a controversial chemical recycling strategy for managing plastic waste.

Sustainability – This considers the relative scarcity of supply of the mined element or metal ores relative to projected global consumption. Henckens et al. (2014) proposed that mineral mining rates be considered "sustainable" if the readily extractable resource will last at least 1,000 years based on projected average global consumption rates 2. Reliance on scarce minerals contributes to conflict, economic injustice, and preventable environmental impacts from mining.

Availability – This refers to the commercial availability of the catalyst system. If we identified one or more major commercial vendors the sold the catalyst for PET polymerization, we concluded that the alternative was available.

Effectiveness – This is a qualitative measure how effective and efficient the catalyst is in polymerizing PET plastic and polyester. Systems that require lesser amounts of added catalyst for a functionally equivalent effect score higher.

Affordability – For the metals, we reported the price per pound of metal reported by the USGS (2021) 3 in its annual mineral survey. Although the reported form of the metal may be different than the final chemical formulation of the catalyst system, it provides a good basis for comparing the underlying costs.

Note that affordability is in the eyes of the beholder. Catalyst systems amount to a small fraction of the total cost of PET plastic or polyester, which in turn is a small fraction of the cost of a final product made from or packaged with PET or polyester. Any cost increase to a final consumer is likely to be miniscule. But in industrial manufacturing, where cost reduction pressures are high and fractions of a penny deemed important, the relative costs may have a bearing on catalyst choice.

Note also that more efficient use of catalysts, reported under effectiveness, will tend to lower total costs since less catalyst material is needed to produce the same amount of PET or polyester.

Conclusion

Safer alternatives to the use of antimony compounds as a PET (and polyester) polymerization catalyst are effective, available, and affordable. The use of antimony compounds should be immediately phased out due to their human health hazards across their lifecycle and for sustainability reasons related to the relatively extreme scarcity of this metalloid element.

Endnotes

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